An ASR Primer

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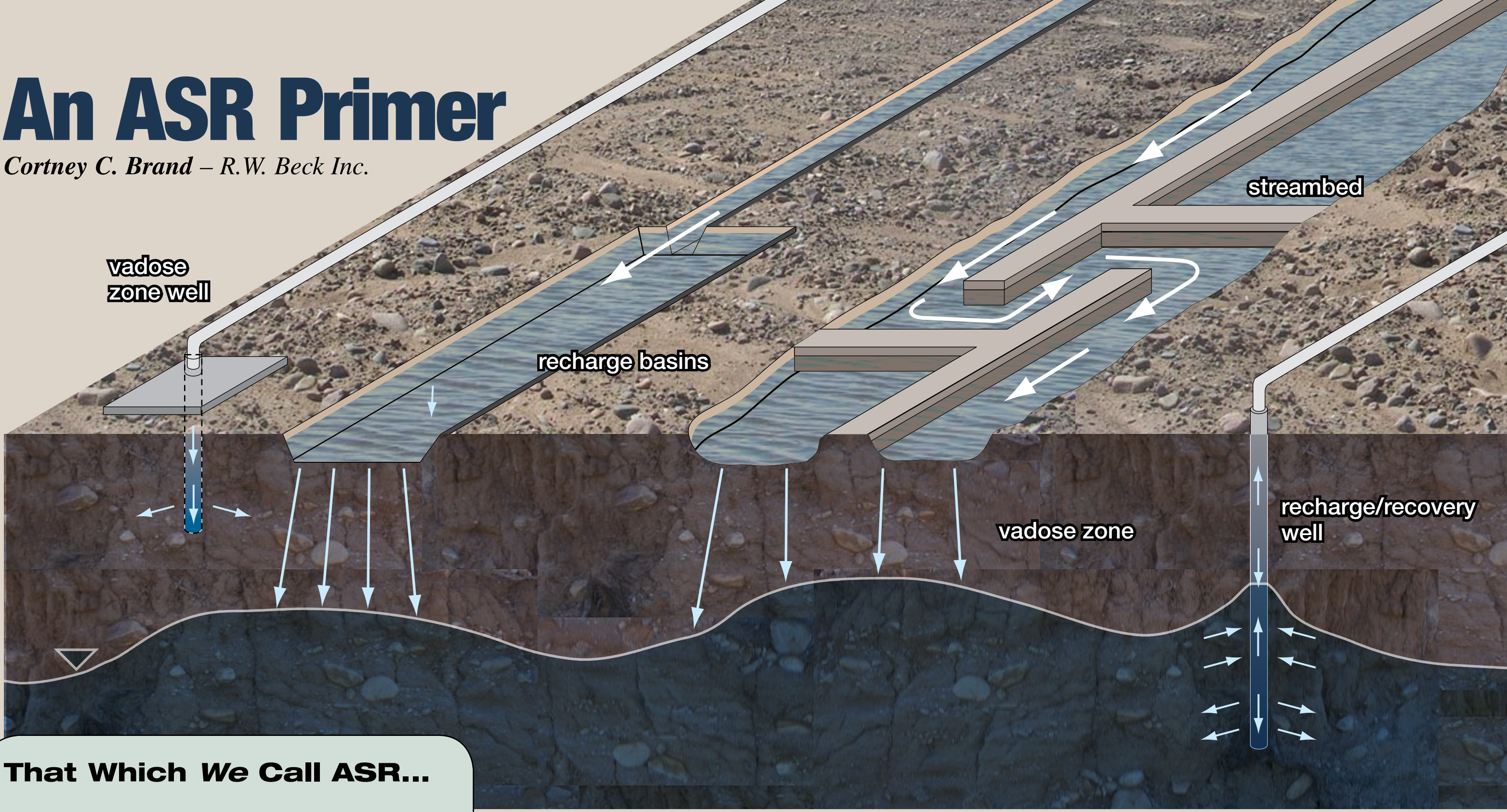

That Which *We* Call ASR…

…others may not. In preparing this issue, *Southwest Hydrology* polled numerous experts for the best term to describe the process of recharging aquifers (by a variety of means using a variety of source waters), storing water (for short to long periods), and then recovering water (from the same or other wells). We received many opinions and no clear consensus. The top candidates, none of which include "recharge," "storage," *and* "recovery," are:

Aquifer Storage and Recovery (ASR): To some, this means strictly recharge and recovery from the same well. Others believe it is the most widely recognized term—at least in the Southwest—to refer broadly to all forms of aquifer recharge, storage, and recovery.

Managed Aquifer Recharge (MAR): Has the greatest international use; less common in this country. The original definition referred to intentional banking and treatment of water in aquifers.

Managed Underground Storage of Recoverable Water (MUS): Introduced in 2008 by NRC's Committee on Sustainable Underground Storage of Recoverable Water to define "purposeful recharge of water into an aquifer system for intended recovery and use as an element of long-term water resource management."

Southwest Hydrology is using the broad definition of ASR.

Most water resources professionals have heard of ASR, or aquifer storage and recovery, but it can mean different things to different people. ASR can mean artificial recharge, groundwater recharge, managed aquifer recharge, underground water storage, conjunctive use, or a combination thereof. For purposes of this and accompanying articles, ASR is a water management technique that encompasses the *purposeful recharge and temporary storage of water in an aquifer with the intent to recover all or a portion of the water from the same aquifer in the future*. Without the intent to, or act of, recovering recharged water it is simply groundwater recharge.

ASR is thought to have originated several hundred years ago in the Kara Kum Plain of Turkmenistan and in Western India (Pyne, 1995), but is now conducted in some form on every continent except Antarctica. The motivators and potential benefits of ASR vary based on geography, hydrology, water chemistry, and water policies/laws. A majority of the Southwest is arid or semi-arid, susceptible to drought, and characterized by declining groundwater levels, unreliable surface water supplies, and overappropriated rivers. As a result, the capture and storage of water when it is available is critical to sustainable water management. The traditional approach has been to store water aboveground by constructing dams and reservoirs. The benefits of aboveground storage include rapid fill and release, large storage capacities, straightforward measurement and management, and opportunities for recreation. However, escalating costs and environmental permitting requirements associated with surface reservoirs, as well as declining availability of land and suitable sites, have driven water professionals to explore ASR as an alternative.

Implementing ASR

Where feasible, storing water underground can save money, increase yields, mitigate the impacts of drought, firm up surface water supplies, improve water quality, and avoid evaporative losses. The necessary ingredients are 1) an aquifer of suitable character, 2) source water of suitable quality, 3) the means to transmit the source water into the aquifer, and 4) the means to recover it. ASR can be accomplished in bedrock, alluvial, or limestone aquifers as long as the formation can receive, store, and transmit water without adversely impacting native groundwater or source water quality.

There are myriad configurations and methods of implementing ASR, and the inherent variability of natural systems necessitates site-specific solutions. Suitable source waters can include surface water diverted from streams, stormwater runoff, remediated groundwater, reclaimed water, and industrial-process water. Water can be transmitted into an aquifer using nonstructural means such as natural drainages or structural means such as impoundments, basins, trenches, injection wells, vadose zone wells, or combinations thereof. Some ASR systems, because of the nature of the water source, require aboveground storage to capture and hold water before it can be transmitted underground. Water recovery is typically accomplished through wells; however, some ASR systems utilize natural discharge of groundwater to a stream as a virtual means of recovery.

ASR is practiced by governmental entities and water utilities throughout the Southwest. Some familiar examples include Scottsdale, Tucson, Orange County, Las Vegas, El Paso, Salt River Project, Central Arizona Project, and Metropolitan Water District of Southern California (MWD). Most of these entities utilize the vast storage capacity available in alluvial-fill basins. In contrast, entities situated along Colorado's Front Range, including Highlands Ranch and Colorado Springs, utilize deep bedrock aquifers of the Denver Basin. The City of San Antonio utilizes the Edwards Aquifer, a cavernous limestone formation. Other examples of ASR include water conservation districts in the San Luis Valley and the lower South Platte River in Colorado, the Wintergarden region of south Texas, and the Jordan Valley Water Conservancy District in central Utah. As illustrated in the table below, these projects vary in their objectives, water sources, aquifer characteristics, and means of recharging and recovering water.

Challenges to Overcome

Although the potential benefits of ASR are numerous, ASR also poses significant challenges. These primarily revolve around issues of water quality; water recovery; the management, monitoring, and accounting of recharged water; water rights; and source water availability. These challenges are geographically dependent due to interstate and intrastate variations in water administration, local hydrology, and aquifer characteristics.

ASR is typically accomplished using water derived from a source other than the receiving aquifer. Waters from different sources can have different chemistries, pH, temperatures, and redox conditions. Mixing dissimilar waters underground and exposing aquifer materials to non-native water can drive geochemical reactions that alter water chemistry. Some potential impacts include dissolution of arsenic compounds and precipitation of clays. Water quality changes can also occur as water percolates through the vadose zone and encounters evaporite deposits or leaching zones underlying agricultural areas. Recharged water can acquire salts and nitrogen compounds as it percolates to groundwater, degrading source water and groundwater quality.

The increased use of reclaimed water for ASR has created an emerging water quality issue posed by pharmaceuticals and endocrine disrupting compounds. These contaminants occur in wastewater at very low concentrations and are not effectively

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Entity / Project	Objective	Water Source	Aquifer Type	Recharge Method	Recovery Method
Arizona					
City of Scottsdale	store excess surface water and stormwater runoff	treated CAP water, reclaimed water	alluvial basin	direct injection wells, vadose zone wells	production and dual-use wells
Salt River Project	store excess surface water	CAP water, surface water (Salt and Verde rivers), reclaimed water	Salt River alluvium	basins	to be determined
Central Arizona Project (CAP)	store excess surface water	CAP water	alluvial basin	basins	to be determined
Tucson Water	treat and store surface water and reclaimed water	CAP water, reclaimed water	alluvial basin	basins	production wells
Vidler Recharge Facility	store surface water	CAP water	alluvial basin	basins, vadose zone wells	to be determined
California					
Orange County Water District	long-term storage, groundwater replenishment	surface water (from MWD), stormwater runoff, reclaimed water	alluvial basin	direct injection wells, in-lieu, basins	production wells
Coachella Valley	long-term storage, groundwater replenishment	surface water (from MWD), All-American Canal	alluvial basin	in-lieu, basins	production wells, water transfer
Texas					
City of El Paso	recharge aquifer and store water	reclaimed water	alluvial basin	direct injection wells, basins	production wells
City of San Antonio	store seasonally available Edwards Aquifer water	groundwater	alluvial basin	direct injection wells	production wells
Wintergarden Groundwater Conservation District	enhance recharge to the Carrizo aquifer	stormwater runoff	sandstone	impoundments, passive wells	production wells
Colorado					
Centennial Water & Sanitation District	store excess surface water	surface water (S. Platte River)	sandstone	direct injection wells	production and dual-use wells
Colorado Springs Utilities	store excess surface water	surface water (Colorado River)	sandstone	direct injection wells	dual-use wells
Lower South Platte Water Conservancy District	streamflow augmentation, wildlife recovery	surface water (S. Platte River) and alluvial wells	S. Platte River alluvium	basins and ditches	accretion to river
Nevada					
Las Vegas Valley Water District	store excess surface water	surface water (Colorado River)	alluvial basin	direct injection wells	production and dual-use wells

Examples of ASR projects in the Southwest. Note: CAP water is untreated Colorado River.

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- a reduction in total dissolved solids (TDS) concentrations in the aquifer from an average of 457 milligrams per liter (mg/l) to 59 mg/l at the beginning of the storage phase, measured at the Diamond Creek Well. The TDS of the water being injected ranged between 47 and 62 mg/l.

The charts on the previous page show the changes in DBP concentrations during each period of the demonstration test. By comparing DBP to conservative constituents such as chloride and fluoride, it appears that haloacetic acids were naturally attenuated in the aquifer during the storage phase of testing: they were not detected after five months of storage. Trihalomethane (THM) concentrations (as represented by chloroform) were reduced during the storage period, but not completely eliminated. The mechanism of THM reduction is not fully understood, but appears to be caused by dilution, again based on correlation with chloride concentrations over the same time period.

Long-Term Plans

Roseville expects to complete the demonstrate test by May 2008 and to have extracted 300 percent of the injected volume in an effort to remove DBPs below basin objectives (chiefly chloroform below 1.1 µg/l). Clearly 100 percent injection followed by 300 percent extraction is not sustainable for long-term operation, but was necessary to comply with the waiver for the testing phase of implementation. Roseville and CVRWQCB now have a better understanding of the water quality implications of a long-term ASR operation.

What's next? Roseville has begun discussions with CVRWQCB management and staff regarding long-term operation of ASR in Roseville and expansion of the program to eventually include up to 12 operating ASR wells over the next three to five years. In striking a balance between the water supply benefit of ASR and the need to protect groundwater quality, it is anticipated that a long-term operational permit will:

- allow a designated portion of the aquifer to be impacted above basin objectives during the operational life of the ASR program;
- establish institutional controls to prevent other beneficial users from accessing the portion of aquifer designated for ASR;
- allow a point of compliance within the aquifer downgradient of the project;
- require a reasonable monitoring program, agreed upon by Roseville and CVRWQCB; and
- likely require that water quality objectives be restored to either pre-project conditions or reasonably achievable conditions at the end of the project.

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removed by traditional wastewater treatment processes. Much research is being conducted on the potential health risks associated with introducing reclaimed water to potable aquifers. Lastly, pathogen removal by chlorination can cause formation of disinfection byproducts, such as trihalomethanes, that can persist in some ASR systems (NRC, 2008).

Getting It Back

Recovery is a critical component of any ASR system because the objective is to recover the recharged water, or a nearly equivalent amount, in the future. However, full capture and recovery is not always feasible due to aquifer characteristics and the practical placement of wells. As a result, the potential exists for losing a portion of recharged water. However, water recovery issues can also be political or legal in origin, as when a governing entity intervenes and imposes limitations on the rate or volume of water that can be recovered.

The management, monitoring, and accounting of recharged water are inherently obscure as groundwater is not visible. Therefore, computer models, monitoring wells, and sophisticated accounting systems are employed to accomplish these tasks. Even with these tools it can be challenging to adequately demonstrate control and capture of recharged water. Many western states utilize some form of prior appropriation to allocate scarce water resources. Some states such as Colorado administer groundwater and surface water conjunctively, and others administer these resources discretely. The protection of senior water rights can represent a significant barrier to ASR projects, particularly with respect to accounting and recovery. It must be demonstrated that ASR operations will not cause an out-of-priority diversion of stream flows or native groundwater that is not otherwise replaced.

Source water availability can be the limiting factor for some entities, even when a suitable aquifer and recovery system are available. However, these situations can engender creative solutions such as "borrowing" source water from a surface water provider in exchange for delivering groundwater to the same provider during periods of drought.

ASR is expanding in scope and complexity as more projects are initiated, long-term data become available, monitoring and analytical technologies advance, and the demand for water increases with respect to supply. Not every situation or set of conditions is favorable for implementing ASR, and ASR will not displace the need for surface storage. However, it is a viable alternative and a beneficial water management technique where and when the necessary ingredients exist.

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