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Lessons learned from an aquifer storage and recovery program

UTILITIES CAN APPLY THE LESSONS LEARNED FROM THREE SEASONS OF AN AQUIFER STORAGE AND RECOVERY PROGRAM AT ANTELOPE VALLEY, ONE OF FIVE LOS ANGELES COUNTY WATERWORKS DISTRICTS, IN DEVELOPING, REGULATING, OR IMPROVING THEIR OWN PROGRAMS.

Los Angeles (Calif.) County Waterworks District No. 40, Antelope Valley (LACWD-AV), is the water retailer to a population of roughly 150,000 people in the Antelope Valley of Southern California, the southernmost area of the Mojave Desert. LACWD-AV provides customers a blend of groundwater drawn from the local groundwater basin and surface water imported to the region from the Sacramento/San Joaquin Delta through the California State Water Project. Although LACWD-AV is able to use a consistent volume of groundwater supplies each year, there is tremendous variation in the availability of its surface water supplies, which are dependent on hydrologic, environmental, and political conditions throughout California. Groundwater supplies are insufficient to meet the district's annual demands, and the groundwater basin underlying its service area is the subject of a complex lawsuit that is expected to result in the adjudication of water rights in the basin. The California Department of Water Resources and the US Geologic Survey (USGS) have both determined that the basin has been overdrafted. As a result of this overdraft, several areas throughout the basin have experienced significant land subsidence, and the groundwater table has significantly declined.

Because of the overpumping in the groundwater basin, there is a considerable dewatered volume in the aquifer for surplus surface water supplies to be stored in during particularly wet years for subsequent extraction in periods of drought or high demand. LACWD-AV's primary method for managing its available water supplies is to use surface water in lieu of groundwater as its primary water source. When available surface water supplies exceed demand

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in the district's service area, LACWD-AV effectively stores its groundwater supplies by leaving them in the ground.

The second method the district can use to store excess surface water supplies is to spread them on the land surface and allow them to infiltrate and replenish the groundwater. However, the geologic makeup of the aquifers in the Antelope Valley, which has been covered in detail in several reports published by the USGS (Planert & Williams, 1995; Templin et al, 1995), limits the use of this practice in and around LACWD-AV's service area. Multiple clay lenses in the aquifer under the service area limit the capacity of the groundwater basin's ability to accept recharge by surface percolation. In addition, the areas of the groundwater basin that show the greatest decline in groundwater levels are beneath and immediately adjacent to the district's densely populated service area.

DEMONSTRATION PROJECT TESTS FEASIBILITY OF USING ACTIVE WELLS TO STORE TREATED WATER

In 1994, LACWD-AV, in partnership with the USGS, initiated a demonstration project to evaluate the feasibility of using active groundwater wells to inject and store treated surface water that meets all drinking water standards directly into the water-bearing strata of the groundwater basin. This injected water was subsequently extracted during high-demand periods. Multiple reports published by the USGS have documented this demonstration project in detail (Howle et al, 2003). In summary, the demonstration project showed that a full-scale project was feasible but that the residual disinfectant in the injected potable water would need to be completely removed before injection to reduce the potential formation of trihalomethanes (THMs) in the groundwater after injection. During the final injection cycles of the demonstration project, LACWD-AV determined that a steady stream of sodium metabisulfite introduced into the injected water effectively removed the chlorine residual; no evidence of further THM formation was observed when the injected water was subsequently extracted.

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Following the completion of the demonstration project, the district prepared and circulated an environmental impact report (EIR) for the project in compliance with the California Environmental Quality Act. The EIR described the project, the potential environmental impacts of the project, and the measures proposed to mitigate those impacts. The public comments LACWD-AV received in response to the EIR centered around three primary concerns.

- Although the USGS had performed extensive modeling to predict the movement of the injected water through the groundwater aquifer, many neighboring groundwater pumpers were concerned over

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LACWD-AV's ability to control the lateral movement of the water into the aquifer.

• The district's neighbors were also concerned about the unknown effects of storing a large volume of nonnative water in the groundwater basin.

• In addition, because LACWD-AV would be injecting treated, potable water that was disinfected with chlorine, several neighboring water agencies were concerned that THMs would continue to form in the groundwater because any residual disinfectant in the injected water continued to react with organics, potentially compromising their ability to use groundwater as a potable supply.

WAIVER "GREEN LIGHTS" INJECTION

As a mitigation measure to address the potential impacts, LACWD-AV proposed to secure a discharge permit from the California Regional Water Quality Control Board for the aquifer storage and recovery project. The regional board's mission is to develop and enforce water quality objectives and implementation plans that will effectively protect the state's waters. This is done by establishing beneficial uses of and requiring permits for all discharges to the state's waters. The regional board determined that a discharge permit was not necessary for the project and instead issued a conditional waiver of waste discharge requirements for the project in 2004. This first waiver established the boundary for the project, the water quality requirements for the injected water, and the contingency plan if there was evidence that the injected water was migrating out of the boundary or if the water quality limitations were being exceeded. The project operated under the initial waiver until 2009, when staff from the district renegotiated the requirements in the waiver with the staff of the regional board and built a strong, scientific case for easing the monitoring requirements and restrictions on the project. After reviewing this information, the regional board staff members were amenable to revising the requirements in the waiver and defending the changes to their board. That board, in turn, gained a better understanding of the project when presented with sound but not overcomplicated science and readily agreed to the modifications of the waiver.

The initial 2004 waiver established the 2,150-foot groundwater elevation contour as the boundary within which the district could inject water. The EIR for the project included a map of the groundwater contours in mean feet above sea level in the region, which at the time indicated there was a groundwater depression or "bowl" with its rim defined by the 2,150 foot contour. The waiver identified five sites within this bowl that the district intended to use for injecting water. This broad boundary for the project proved to be a benefit when, during the second-season injection, the LACWD-AV petitioned the regional board to add additional injection sites. The regional board staff members determined that because sites were located within the established 2,150-foot contour boundary, the district's request was consistent with the intent of waiver and allowed the additional sites to be used without revising the waiver even though the specific new sites were not identified within it. However, creating a monitoring plan that characterized the anticipated effects of the project throughout the project area proved to be difficult.

The 2004 waiver assumed that any water injected within the 2,150-foot groundwater contour would be clearly observed flowing toward the center of the bowl. However, the surface area of the top of the bowl is about 7 square miles, and the static water level at the bottom of the bowl had been measured at 2,100 feet. Therefore, the volume of soil in the bowl when the project was initiated was around 1 million acre-feet. USGS estimates that the specific yield in the project area is 0.12 and the porosity

An injector check valve was used on the sodium metabisulfite line as a backflow prevention device.

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of the dense sandy soils in the Antelope Valley is approximately 0.3, so there was between 120,000 and 300,000 acre-feet of dewatered void space in the bowl to fill. The waiver limited injection to 6,843 acre-feet per year, and in reality, the district was only able to inject around 1,500 acre-feet per year during the initial years the project was implemented. Thus, the monitoring program established by the initial waiver provided an impractical amount of data because the anticipated impacts it was designed to characterize were not realistic.

Operationally, the amount of extra time required to collect static water levels from all the wells was also unwarranted given the value added. Under the initial waiver, the district staff collected static water level readings from nearly all of the district wells within the bowl on a weekly basis. Today, under the revised waiver, the district reports the normal static water level readings collected monthly by staff members from each of the injection wells and a subset of the district's wells. In effect, the district is reporting the results of its normal operational monitoring program. The calculated radius of influence is also reported from each of the injection wells rather than estimating the basinwide impacts to the static water table using complicated modeling software. The radius of influence from each well is calculated using equations from Driscoll (1986) for unconfined aquifers:

$$Q_r = \frac{K\,(h_w^2 - h_0^2)}{1{,}055 \log\left(\frac{r_0}{r_w}\right)} \tag{1}$$

$$K = \left(\frac{1{,}500}{b}\right)\left(\frac{Q}{s}\right) \tag{2}$$

in which Q_r = injection flow rate (gpm), h_w = head above bottom of aquifer while recharging (feet), h_0 = head above bottom of aquifer when no pumping is taking place (feet), r_0 = radius of influence (feet), r_w = radius of injection well (feet), K = hydraulic conductivity (gpd/sq ft), b = wetted aquifer thickness (feet), Q = injection flow rate (gpm), and s = change from static water level (feet).

In order to renegotiate the water quality monitoring requirements in the waiver in 2010, the district focused on helping regional board staff members understand how the rationale for the monitoring requirements typically established for discharge projects did not fit the aquifer storage and recovery project. Several working meetings were held to demonstrate that the project did not dispose of waste but temporarily stored a high-quality asset. The regional board staff debated about how to set water quality limits for the injected water that satisfied the state's antidegradation policy and protected the beneficial use of the groundwater basin. When it came time to establish the "discharge limits" for the injected water in the waiver, the regional board staff members focused more on protecting the beneficial uses of the groundwater basin and relaxed the previous requirements in the waiver that were based primarily on the antidegradation policy. This decision was a clear indication that the regional board staff understood that the project did not fit the mold of a typical discharge project. The requirements for the constituents of concern in both waivers are shown in Table 1.

When the waiver was revised and reissued in 2010, staff from the district also worked with the regional board to focus the monitoring efforts on the immediate vicinity of the injection wells. When the waiver was revised, the district requested that the number of monitoring wells and frequency of sampling events be reduced because very minimal changes in water quality had been observed throughout the bowl during the

During the final injection cycles of the demonstration project, an insulated feed line was used to introduce sodium metabisulfite into the injected water to remove chlorine residual and eliminate trihalomethane formation potential.

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TABLE 1 Requirements for the constituents of concern in both waivers

Constituent	MCL	Typical Level in Native Groundwater	Typical Concentration in Injected Water	Initial Waiver Requirements		Revised Waiver Requirements	
				Maximum	Monthly Average	Maximum	Monthly Average
TTHMs—*μg/L*	80	ND	30–70	72	40	72	62
HAA5—*μg/L*	60	ND	5–10	N/A	25	54	39
Chlorite—*mg/L*	1	ND	< 0.01	1	N/A	0.9	N/A
Bromate—*μg/L*	10	ND	5–10	10	N/A	9	N/A
TOC—*mg/L*	N/A	ND	2–15	N/A	4	N/A	6.2
TDS—*mg/L*	N/A	150–500	250–300	350	350	350	350

HAA5—the sum of five haloacetic acids, MCL—maximum contaminant level, TDS—total dissolved solids, TOC—total organic carbon, TTHMs—total trihalomethanes

entire period of injecting water. Rather than trying to characterize the changes in water quality throughout the bowl on a weekly basis (as was done under the first waiver), the district now analyzes weekly samples of the injected water for THMs only. Samples are collected monthly to monitor for the remaining constituents of concern, which are listed in Table 1. Monthly samples are also collected to monitor for these same constituents from one other existing well located on the same property as an injection well (if one exists), and semiannual samples are collected from four additional monitoring wells in the district's service area.

INFRASTRUCTURE REQUIREMENTS WERE SIMPLE

The district's imported surface water is supplied by the Antelope Valley-East Kern Water Agency after it undergoes conventional treatment at the Quartz Hill Treatment Plant. This water flows by gravity into the district's distribution system through multiple 8- to 16-inch interconnections within the agency's transmission system. The infrastructure needed to inject the water into the ground using existing wells was fairly simple. Initially, water from the distribution system was injected into existing extraction wells through 4-inch pipes installed next to the column pipe in each well or through the wells' sounding tubes that attach to each well approximately 250 feet below the ground surface. A flow-control valve was used at the ground surface to restrict the amount of water injected into each well. The water level in the well was maintained no lower than 100 feet above the static water table and no less than 100 feet below the ground surface.

After two seasons of injecting water, one of the wells used for injection developed a sizable hole in the well screen immediately adjacent to the end of the 4-inch injection pipe and the aquifer material collapsed into the well. This complete failure of the well prevented the district staff from removing the pump or column pipe from the well to attempt a repair. To prevent any similar failures in the future, fluid-activated downhole valves[1] were installed on the column pipe in each well in order to use the same line for

Because one of the wells used for injection developed a sizable hole in the well screen immediately adjacent to the end of the injection pipe and aquifer material collapsed into it, flow control valves were installed on the column pipe to allow use of the same line for injection and extraction and reduce cavitation during injection.

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injection and extraction and reduce cavitation during injection.

IMPORTANT OPERATIONAL LESSONS WERE LEARNED

To date, the district has stored more than 3,000 acre-feet of water through its ASR program in the Antelope Valley Groundwater Basin. This volume has been limited by operational and financial restrictions at the district and water supply availability throughout California. Nonetheless, the district learned important operational lessons while implementing the program.

- Make sure all staff members understand the value of the program. Taking perfectly good potable drinking water and dumping it down a hole in the ground was not the most responsible use of the resource in the minds of many of our field staff. The more time our office staff spent in the field with the water service workers and electromechanics who were making the project work, the better the field staff members understood the concept and value of the project.
- Communicate expectations early, and check that they are feasible. Success for management meant getting a lot of water in the ground—the more water stored, the more successful the program. The initial goals for the volume of water to be stored had much more to do with the amount of surplus water that was available than the capacity of the district's wells to accept the water. Looking back on the initial injection seasons, the district could have potentially stored more water if field staff had better understood the volume targeted by management. Field staff had expected a longer-term ramp-up of the program while the impacts of injecting were studied. To its credit, the district avoided additional infrastructure failure because conservative amounts of water were injected into the wells and the number of wells used in the project was limited.
- Check for anomalies in water quality at the start of an injection cycle in order to avoid needing high-quality water days to bring overall averages down. On a couple of occasions, if injection had been delayed just for a couple of days, a slug of poorer-quality source water, which drove season averages up but disappeared in a matter of days, could have been avoided.
- Do not let a well sit idle for an extended period immediately before or after an injection season; this will avoid biofouling on the well screens and gravel pack.
- Conduct video inspections down the well hole following sustained injection periods and/or subsequent dormant periods of injection wells to check for biofouling or structural damage to the well casing.
- Practice periodic backflow of water through the well screen, gravel pack, and aquifer media to mitigate potential biofouling.
- By introducing a controlled stream of sodium metabisulfite solution before injecting the water, the district effectively removes the chlorine residual in the injected water and eliminates the THM formation potential in the injected water while it is stored in the groundwater basin.
- Cavitation starts in the injection pipe at a 30-psi drop when the outlet pressure is 0 psi. Maintain sufficient back pressure downstream of the flow control valve, either by undersizing the injection pipe or by installing a restrictor plate after the flow-control valve. Once a fluid-activated regulating valve is used, this is no longer an issue.
- Controls on fluid-activated valves and the supply of nitrogen need to be closely monitored. If a leak develops in the nitrogen lines, the valve closes and injection stops.
- Install freeze protection on the flow-control valve ancillary piping and site glass during the winter when injection typically occurs.

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FOOTNOTE

[1]In-Flex flow control valves, Baski Inc., Denver, Colo.

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