Attenuation of Disinfection Byproducts During ASR Storage

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Aquifer storage recovery (ASR) is increasingly being utilized by water managers as a cost-effective, viable technology for storing large volumes of water to meet long-term needs. In the Southwest, surface recharge by infiltration through large, shallow basins is the prevalent method, particularly where suitable land is available at relatively low cost. Where basin recharge is technically infeasible or economically not viable, aquifer recharge can be achieved through wells, and indeed, that is the prevailing method nationwide.

Seventy-two ASR wellfields are currently operating in 17 states with more than 300 ASR wells storing fresh water in a wide range of hydrologic and geologic settings, at depths ranging from 30 to 2,700 feet. Recovery capacities range from about 0.5 to 8.0 million gallons per day from individual wells. The largest ASR wellfield is for Las Vegas Valley Water District, with 46 ASR wells. Common to all ASR systems is that they store water in a suitable aquifer through wells when water is available and of suitable quality, and recover water from the same wells when needed.

Because disinfected water is frequently used for ASR, the subsurface fate of disinfection byproducts (DBPs) is of interest. Research (Pyne et al., 1996; Pyne 2005; Dillon et al., 2005; Clinton et al., in press; Fram, 2003) has shown that DBPs attenuate during ASR storage under hydrogeologic conditions common in most of the country, although exceptions occur, particularly in the Southwest.

The ASR Well Environment

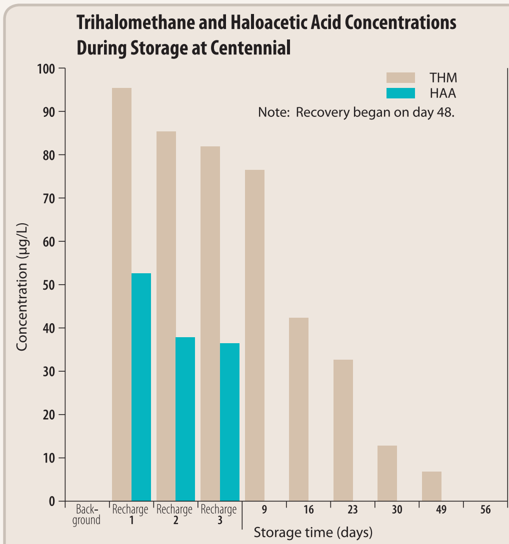
Most ASR wells store water in deep, anoxic, confined or semi-confined aquifers. Organic carbon and nutrients in the recharge water stimulate microbial activity adjacent to the well, typically within a few tens of feet. As water flows through the pore spaces of the aquifer, the number of pore volume flushes diminishes exponentially with increasing distance from the well; geochemical and microbial gradients likewise decline with distance.

Microbes exist naturally in the aquifer, and depending on the type of water being recharged, they may also be introduced. Some microbes can exist in either anaerobic or aerobic conditions, but prefer aerobic conditions such as those introduced by the oxygenated recharge water. Although the recharge water likely contains chlorine that could kill existing microbes, chlorine reacts relatively quickly with aquifer material and its concentration dissipates a short distance from the well, typically within a few days.

THMs and HAAs in the Subsurface

The subsurface fate of five haloacetic acids (HAAs) and four trihalomethanes (THMs), the DBPs currently regulated by the U.S. Environmental Protection Agency, has been most studied. HAAs attenuate very rapidly, typically within a few days, due to aerobic microbial activity that develops near the well. THMs may initially increase for a day or two until the chlorine has fully reacted in the aquifer, but then concentrations attenuate, typically within several weeks, due to anaerobic microbial activity. Brominated THM species attenuate first, followed by chloroform. Both THM and HAA attenuation occur simultaneously where a range of redox conditions occurs in the pore spaces around an ASR well. The time required for HAA or THM attenuation is usually much shorter than the storage period prior to ASR recovery.

The chart below shows THM and HAA concentrations at the ASR well during the first operating cycle for Centennial Water and Sanitation District, Highlands Ranch, Colorado (Pyne et al., 1996). The storage zone is a deep, confined, anoxic artesian aquifer containing fresh water. The recharge water is treated drinking water from the South Platte River, with a dissolved oxygen (DO) content of about 7 milligrams per liter (mg/L) and total organic carbon (TOC) of about 2.5 mg/L. HAAs were eliminated within nine days and THMs were eliminated within nine weeks. These results are reasonably representative of most ASR wells in the United States for which DBP data are available.



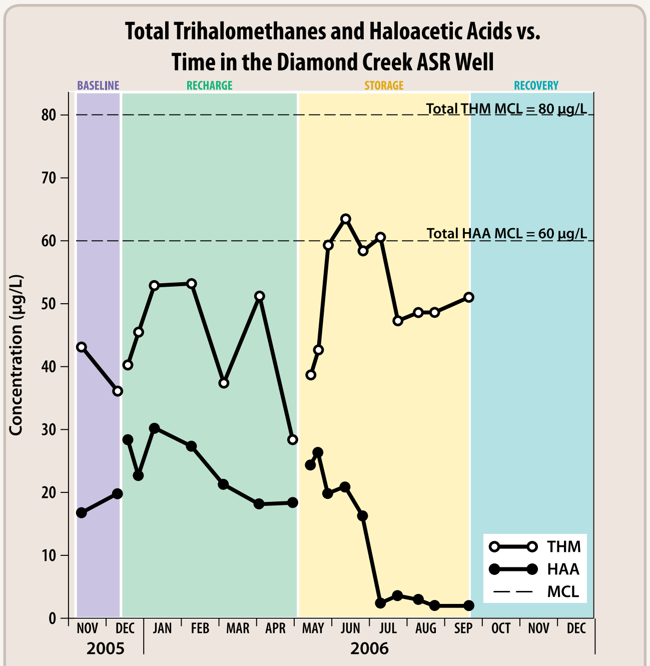
Data from the Centennial Water and Sanitation District ASR well show a rapid reduction in HAA concentration, followed more slowly by reduction of THM. Source: Pyne et al., 1996.

Southwest Aquifer Conditions

Many of the aquifers in the Southwest are unconfined or semiconfined, or water is recharged into the deep vadose zone, thus ASR storage zones typically contain oxygen. These conditions favor HAA reduction. THM reduction also can occur, however, if the recharge water contains significant concentrations of dissolved organic carbon, nitrogen, and phosphorus to stimulate subsurface microbial activity close to the well, depleting the oxygen and causing anaerobic conditions to develop. Recharge water treated to drinking water quality could contain sufficient nutrients in the form of ammonia (a chloramine disinfectant) and phosphorus (an orthophosphate corrosion inhibitor), but some wastewaters have much higher concentrations of these constituents, plus organic carbon. Under these circumstances, THM attenuation could occur, but more slowly than in the anaerobic aquifers, after sufficient time elapses for the chlorine residual to dissipate and a microbial biomass to accumulate around the well.

Without a significant concentration of dissolved organic carbon in either the recharge water or the aquifer, or where TOC concentrations are reduced to below 1 mg/L prior to injection, such as occurs in southern California, little microbial activity would be expected. Under such conditions, any chlorine residual would tend to persist and THM concentration would tend to behave as a semi-conservative tracer.

The figure above right shows THM and HAA data for the first operating cycle at a new ASR well in Roseville, California (MWH Americas, 2006). The storage zone is a deep, confined, oxic aquifer, and recharge water is treated drinking water from Folsom Reservoir. THM and HAA reduction occurred slowly during storage, after an initial delay. The 0.46 mg/L chlorine residual in the recharge water persisted underground for several weeks, suggesting the virtual absence of organic matter or microbiota in either the recharge water or the storage zone. Baseline DO in the aquifer was 11 mg/L, and the dissolved organic content of the recharge water averaged 2 mg/L, compared to 1.4 mg/L background concentration in the aquifer. Baseline oxidation-reduction potential in the aquifer was 335 millivolts (mv); it declined steadily during storage, but did not reach a negative value (-78.5 mv) indicative of reducing conditions until after 12 weeks of storage.



In Roseville, California, DBP reduction occurred slowly due to continued chlorine residual and negligible amounts of organic matter in either the aquifer or recharge water. Source: MWH Americas, 2006.

Some THM reduction occurred after eight weeks of storage, but more recently, concentrations have leveled off due to the continued presence of chlorine residual and lack of organics. In contrast, HAA reduction began after just two weeks, and was essentially complete after two months.

Chloride concentration is an excellent conservative tracer at this site: the recharge water has a concentration of 4 mg/L compared to ambient groundwater's concentration of 162 mg/L. After 10 weeks of storage, the recovered water sample had a chloride of 19 mg/L, representing a mix of 90 percent recharged water and 10 percent ambient groundwater.

In ASR sites recharging reclaimed water, elevated concentrations of organic carbon and nutrients in the recharge water stimulate subsurface microbial activity very close to the well, thereby reducing THM concentrations.

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Recent data from an ASR well that stores reclaimed water in a confined aquifer at Chandler, Arizona, showed THM concentrations declining from 170 µg/L to 19 µg/L during two months of storage, while HAA concentrations declined from 96 µg/L to less than 2 µg/L (Clinton, in press). TOC during this period fell from 7.36 mg/L to 2.94 mg/L. Nutrient and pH changes indicated microbial activity. Chloride and total dissolved solids concentrations during recharge and recovery indicated no significant mixing between recharge water and ambient groundwater.

Research Areas

As we become increasingly dependent upon aquifer recharge to sustain our water supply, we will need to focus research on enhancing water quality through natural and sustainable subsurface physical, microbial, and geochemical processes, whether they occur close to the well during ASR operations or beneath a recharge basin during surface recharge. The current understanding of subsurface microbial and geochemical processes occurring during ASR storage is limited. Much can be learned from the hazardous waste field, where "push-pull" technology, very similar to ASR, is used to clean up contaminated aquifers. Genetic research is beginning to identify the microbes contributing to observed water quality changes so that their activity may eventually be enhanced or controlled. Geochemical research is needed, with monitor wells located very close to ASR wells so that water quality changes close to the well may be studied and better understood. ASR cycle testing, particularly with sampling every few minutes during the first few hours of recovery, can illuminate water quality changes close to the well. Further research is needed to confirm the breakdown products of DBP attenuation. Through these continuing efforts, we can improve our understanding of water quality changes during ASR storage.

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