Water Quality Changes During Subsurface Storage

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While underground storage of water offers many benefits, transformations in water quality resulting from the recharge of one type of water into an aquifer of different composition warrant attention. The primary constituents of concern that may be introduced into or form in storage systems include organics and pathogens; nutrients and inorganics can also cause problems. These constituents may be broken down, mitigated, or otherwise changed through chemical, biological, adsorption, dilution, or filtration processes that take place in the storage zone. The extent to which these processes occur depends on the compositions of the two water types and the subsurface conditions.

Time, Surface Area Are Factors

Some water quality transformations occur rapidly, such as those that result from changes in oxidation-reduction (redox) conditions or chemical interactions between the injected water and the aquifer. These reactions may not only change the water quality but also impact the hydraulic capacity of injection wells.

Other transformations, such as the biodegradation of trace organic compounds, often occur slowly; sufficient time is required to achieve the full benefits of aquifer storage. For example, with enough time, natural attenuation processes can improve the quality of stored water to that approaching native groundwater.

Alluvial aquifers, comprised mostly of sand and gravel, contain abundant surface area, which permits plenty of contact with the water traveling through it. This surface area mediates many biogeochemical reactions that can improve water quality. Such water quality transformations are less likely in fractured and karst aquifers where preferential flow through cracks and fissures limits contact between the water and aquifer material.

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Flowpaths also affect transformations during subsurface storage. Flowpaths surrounding dual-purpose wells—used for both injection and recovery—have highly variable travel times and the most unpredictable effects on water quality. Subsurface storage systems with different recharge and recovery points can have defined flowpaths and associated travel times. Such systems have more consistent and predictable water quality transformations.

Oxygen Matters Also

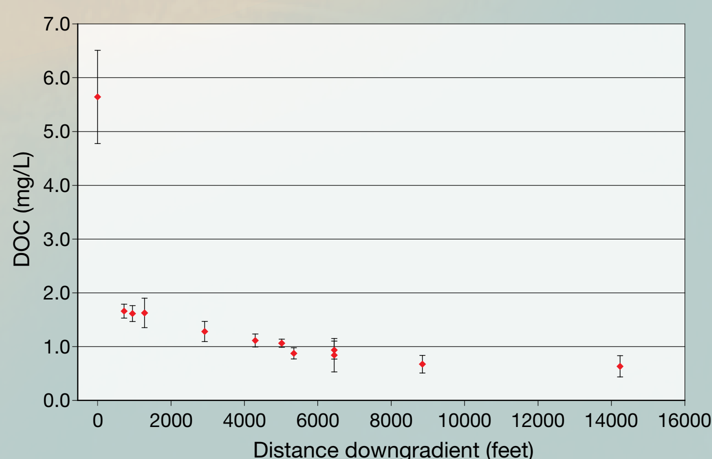
Many organics, nutrients, and pathogens of concern can be removed in the subsurface through biological mechanisms. Key factors that affect biological removal during subsurface storage include the biodegradable organic carbon content of the recharge water and redox conditions of the aquifer. Therefore reverse-osmosis-treated water, lacking organic carbon, does not support significant biological removal. In fact, trace constituents such as N-nitrosodimethylamine (NDMA) have been shown not to attenuate during the injection of reverse-osmosis-treated water, unlike in other recharge systems.

Most biological transformations will occur whether or not oxygen is present, however, some organic compounds require a specific electron acceptor to degrade. Many chlorinated organic compounds, such as trihalomethanes, degrade faster under conditions where oxygen is low or absent. Finally, recharging waters high in oxygen demand will create anoxic conditions and increase the potential for the dissolution of mineral iron and manganese.

The Organic Players

Three types of residual organic materials undergo transformation: natural organic matter (NOM), which is present in most water supplies; soluble microbial products (SMPs) formed during the wastewater treatment process from the decomposition of organic compounds, and synthetic organic compounds (SOCs) added by consumers and also generated as disinfection byproducts (DBPs) during water and wastewater treatment (Barker and Stuckey, 1999).

Most waters contain NOM; reclaimed waters contain a mixture of NOM and SMPs. NOM and SMPs measured together as dissolved organic carbon have concentrations typically measured in the milligrams per liter range. The primary concern over NOM and SMPs is their potential to form DBPs and stimulate biological growth in distribution systems. Concerns over both human and aquatic health effects are generally associated with SOCs and DBPs, which are measured individually at concentrations of micrograms or nanograms per liter.



Dissolved organic carbon (DOC) concentration is shown as a function of distance for the Mesa (Arizona) Northwest Water Reclamation Plant groundwater recharge basins. Each 1,000 feet of travel equals around six months of travel time. After several years of travel, DOC concentrations are less than 1 milligram per liter, approaching background conditions of the aquifer.

Subsurface Removal of Organics

Organic compounds are removed during subsurface storage by a combination of biodegradation, filtration, sorption, and oxidation/reduction. Biodegradation is the most sustainable removal mechanism for organic compounds during subsurface transport. Concentrations of NOM and SMPs are reduced during subsurface transport as high molecular weight compounds are hydrolyzed into lower molecular weight compounds, which serve as substrate for microorganisms. As NOM and SMP concentrations decrease, their potential for forming DBPs also decreases. Given sufficient surface area and contact time, the stored water may approach the quality of native groundwater with respect to organic carbon content (see figure, below left).

However, a select group of SOCs has been found to persist in the subsurface, and the list is growing as new analytical techniques are developed. In the Netherlands where Rhine River water has been recharged for over a century, recharged groundwater can be dated by the presence of persistent pharmaceutical compounds during the last five decades. The persistence of carbamezapine (an anticonvulsant and mood-stabilizing drug) is so widespread that researchers have suggested its use as a universal indicator of anthropogenic contamination. These compounds are all polar and resist biodegradation, making them both mobile in the aquifer and persistent. In contrast, the steroid hormones and alkylphenols suspected of causing estrogenicity are nonpolar and biodegradable, and have been observed far less frequently in aquifers.

The Fate of Pathogens

Alluvial recharge systems effectively filter bacteria and protozoa, leaving viruses as the major concern for pathogen transport during subsurface flow. In fact, the survival of viruses has been used as travel-time criteria for systems designed for potable water production. In California, the minimum travel time requirement is six months, while 50 and 70 days are required in Germany and the Netherlands, respectively. Higher levels of microbial activity in an aquifer decrease the survival of pathogenic viruses since the viruses are subject to predation. This is one reason for the discrepancy between criteria in different parts of the world.

Nutrients

Recharge systems have limited potential for the removal of nutrients. Biological processes may sustain the removal of nitrogen species under specific conditions. The addition of ammonia in secondary effluent to surface recharge basins can result in significant nitrogen removal since cyclic aerobic/anoxic conditions will result from the use of wetting/drying cycles. The adsorption of ammonia is dependent on the cation exchange capacity of the soils. Some adsorbed ammonia is converted to nitrate under aerobic conditions and the nitrate can be reduced to nitrogen gas under anoxic conditions. Adsorbed ammonia may also serve as the electron donor to reduce nitrate by anaerobic ammonia oxidation. Removal rates of 70 percent have been observed at the Tucson Sweetwater Underground Storage and Recovery system. Direct injection systems may remove some nitrate if the aquifer is anoxic and the potential for ammonia oxidation is low since there is insufficient oxidation. Phosphorous can be removed by precipitation on calcerous soils for time periods that have been estimated to be centuries, but the removal is not sustainable.

Inorganics

Similar to phosphorous, inorganics may be removed by precipitation or as a consequence of changes in their redox state. Most waters, including reclaimed waters, that are used for recharge do not contain inorganics at concentrations that cause concern. As long as the waters applied do not contain elevated concentrations, they should equilibrate with the local geochemical conditions and not pose a problem. However, rapidly changing redox conditions that can occur in dual-purpose wells can create both dissolution and precipitation of naturally occurring iron, manganese, and arsenic. Such conditions can result in well plugging and contamination of recovered water. It is necessary to inject a sufficient quantity of water to create a storage zone that eliminates the recovery of water that is subject to varying redox conditions.

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Reference

Barker, D.J., and D.C. Stuckey, 1999. A review of soluble microbial products (SMP) in wastewater treatment systems, Water Resour. Res, 33: 3063-3082.