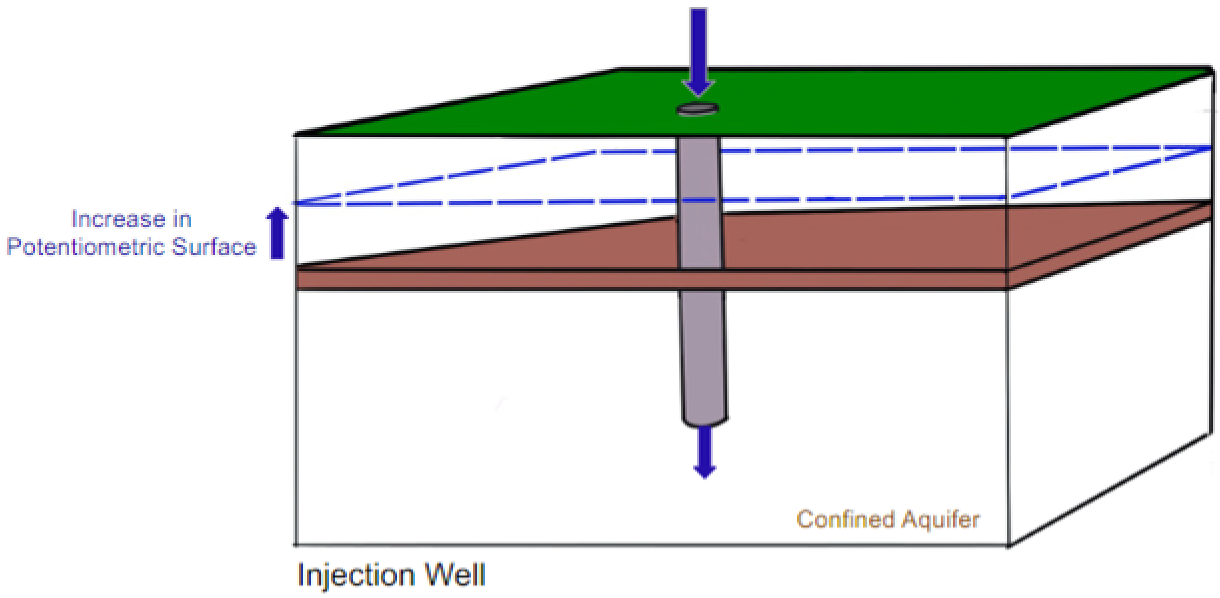
Introduction

Injection well usage as part of a managed aquifer recharge (MAR) program (typically an aquifer storage and recovery (ASR) well) became widespread in the 1990s. Injection wells (see figure below) developed as part of a MAR project are used to directly recharge water into deep porous or fractured geologic formations. Typically, the injected water serves to provide a future source for supply; however, the water may be injected to halt saltwater intrusion or alleviate subsidence issues. Injection wells are used for additional purposes that are not associated with water, such as carbon sequestration; injection of hazardous, radioactive, and nonhazardous wastes; injection of fluids for mineral solution mining and oil recovery (fracking); and injection of media for remedial action. However, for the purposes of this fact sheet, injection wells discussed will be limited to the three aquifer recharge purposes mentioned above (storage, saltwater intrusion, and subsidence control). As with the uses of injection wells, installation (various drilling methods), construction (various completion methods), permitting, operation, and closure of injection wells are important considerations and are regulated through the U.S. Environmental Protection Agency (USEPA) Underground Injection Control (UIC) program as required by the Safe Drinking Water Act (SDWA) (Clark, Bonura, and Van Voorhees 2005) or states with primacy.



Compared with typical recharge technologies that use surface infiltration as the recharge mechanism, injection wells require a significantly smaller footprint and can be advantageous in areas where land is scarce. A relatively high rate of recharge can be attained via injection wells.

Injection well depths can range widely depending on the target aquifer being recharged. Sources of water can vary (river, stormwater, mountain runoff, groundwater) and need to be analyzed for geochemical compatibility with the aquifer groundwater prior to injection. Because injection wells can be hundreds to thousands of feet deep and water is injected under pressure, their construction is important so that the well can be maintained throughout a long service life. In addition, ASR wells used for both injection and extraction may be subject to a high potential for corrosion and clogging. The operation and maintenance of an injection/extraction well, typically consisting of backwash cycling at a frequency determined by individual well performance and plugging rates, is crucial to sustain successful operational ability.

Applicability

Injection wells can be applied in any situation where it is desirable to introduce source water into an underlying shallow or deep aquifer; however, injection wells provide the greatest advantage where:

- the target aquifer is confined or beneath low-permeability deposits that impede surficial recharge
- real estate costs are prohibitive for surface recharge facilities
- there is a lack of groundwater availability

Replenishing groundwater supplies by artificial recharge through wells has been practiced in many areas, including many sites in California and more than a thousand recharge wells on Long Island, New York (Todd 1959; Signor, Growitz, and Kam 1970).

Aquifer Storage and Recovery (ASR)

As the benefits of employing MAR techniques continue to be developed and documented, wells are being used more often for aquifer recharge. ASR programs consist of dual-purpose wells that are used for both injection and extraction of water. ASR wells are designed and operated to store surface water supplies underground with the intention of later recovery during times of less surface water or groundwater availability (for example, dry seasons and drought periods as shown on Figure 1 and Figure 2). Conceptually, ASR well programs are developed where groundwater level gradients are relatively flat to allow for the formation of a “bubble” of stored water that can be captured with an acceptable percentage recovery. Pyne (2005) provided a thorough reference for the full life cycle process of developing ASR wells and programs.

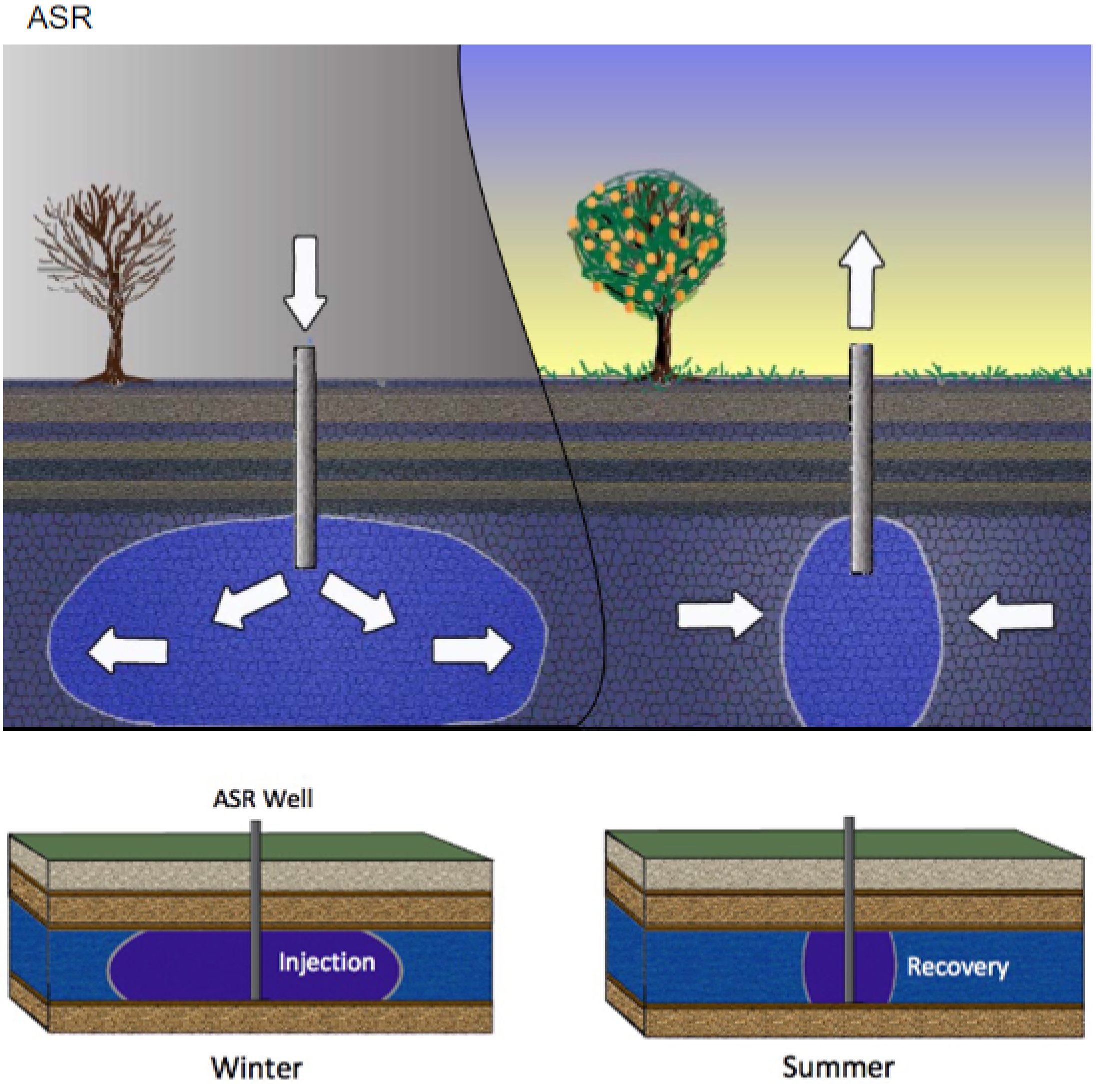


Figure 1. ASR system typically uses wells that are capable of injection and extraction.

Source: Gibson and Campana (2014)

Conceptually, ASR wells are typically used to inject water when surplus surface water is available, or demand is low (winter) and withdraw recharged groundwater during peak demand season (summer), as illustrated in the figure below. ASR wells may also be used to store water at night for recovery during the daily peak demand periods or during wet years and floods for recovery during dry years and droughts. Stored water may also be recovered during emergencies, such as waterline breaks, freezes, or power failures.

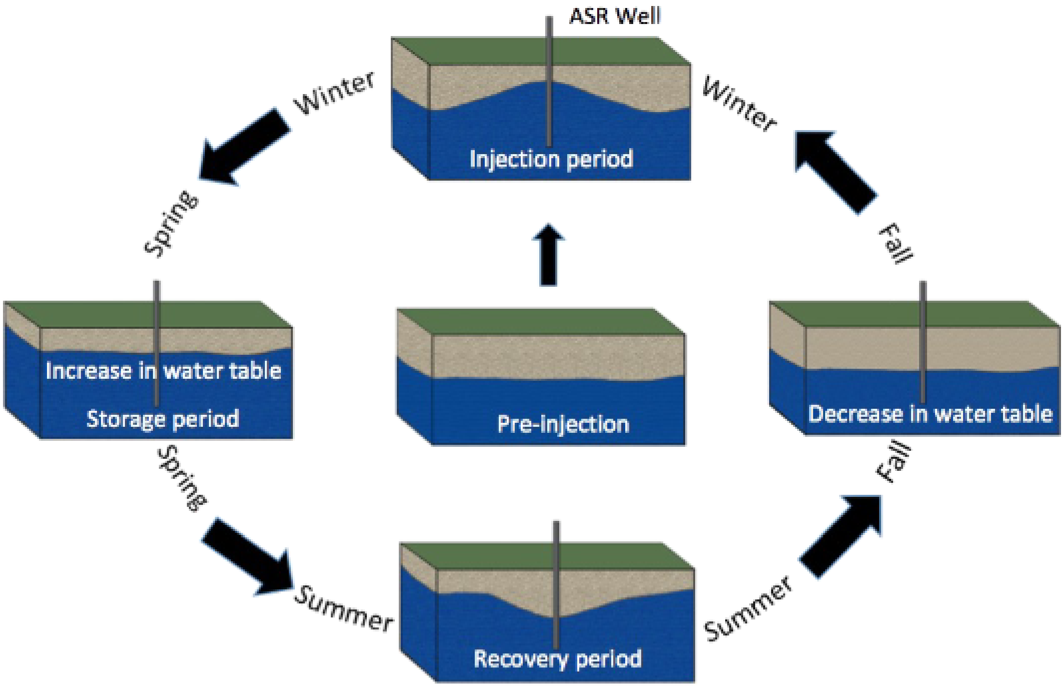


Figure 2. ASR wells inject water when surplus surface water is available and withdraw recharged water during peak demand season.

Source: Gibson and Campana (2014)

Aquifer Storage, Transfer, and Recovery (ASTR)

An ASTR system uses separate injection wells and extraction wells because the injected water migrates or "transfers" from the injection area to the extraction well (Figure 3). The primary advantage of ASTR over ASR is that it provides more uniform residence times and travel distances, which allow for more predictable attenuation of contaminants (Pavelic et al. 2005; Rinck-Pfeiffer, Pitman, and Dillon, 2005; Maliva 2020). The distance between the injection well and the extraction well, however, is typically small—around 300 feet or less—so that the extraction well is contained within the storage "bubble" radius of the recharge well. This distance is particularly important for attenuation in brackish and saline aquifers, or freshwater aquifers where there is a significant difference in water quality characteristics. The Parafield ASTR research project in South Australia is an example of an ASTR system that follows the Australian guidelines for MAR and demonstrated the ability to lower the salinity of the target brackish aquifer over the course of a couple years (Page et al. 2010).

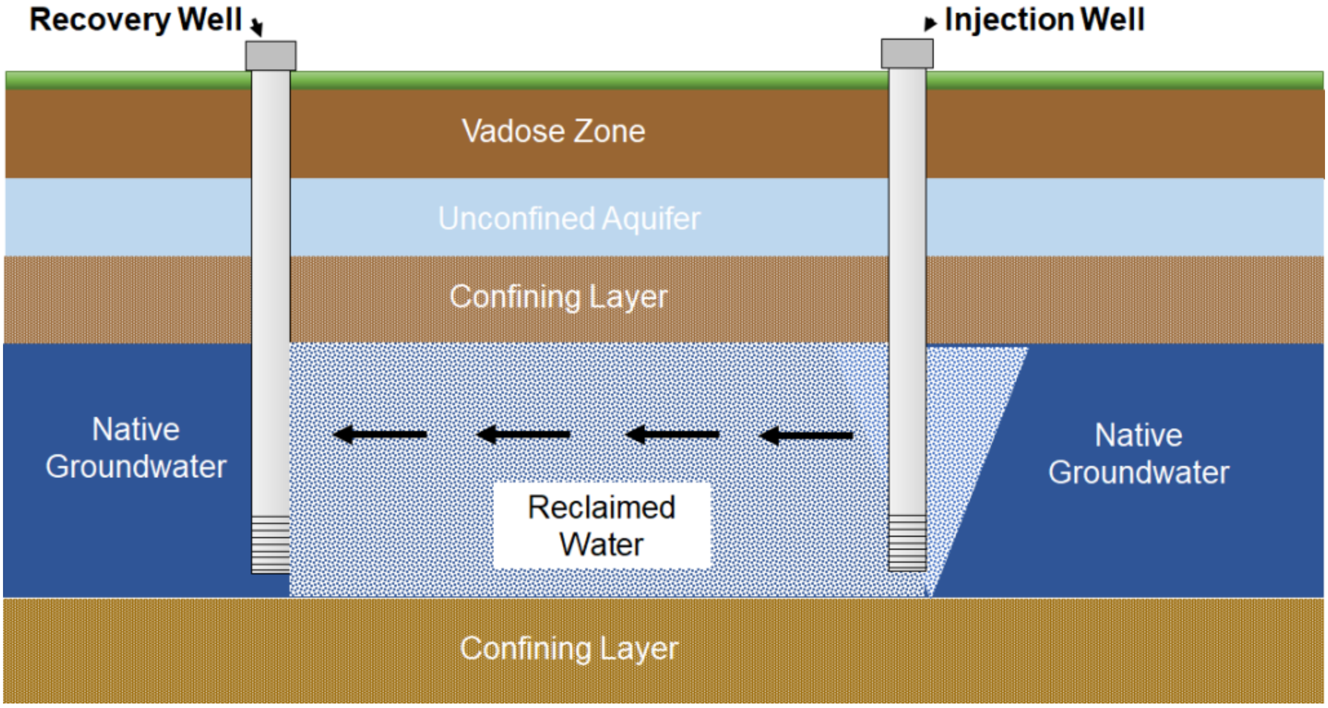


Figure 3. Conceptual diagram of ASTR system in a confined aquifer.

Saltwater Intrusion Barrier

Although rules and regulations vary by state for injection wells used for aquifer recharge and saltwater intrusion, in coastal areas saltwater intrusion into water supply and domestic wells is a common problem—particularly for areas where long-term pumping has significantly lowered the water table (NGWA 2023). To reduce the likelihood of saltwater intrusion, injections wells pump fresh water into an aquifer potentially affected by saltwater intrusion in an attempt to create a freshwater barrier. In some cases, the objective of injecting fresh water may solely be for reducing salinity of an aquifer or increasing water quality, and not to function as a barrier. An example of combating seawater intrusion with injection wells is provided in a case study of Orange County Water District's (OCWD) recharge program (Kiparsky et al. 2021). Another successful application of injection wells for mitigating seawater intrusion has been in operation in Los Angeles County since the early 1950s (Johnson 2007).

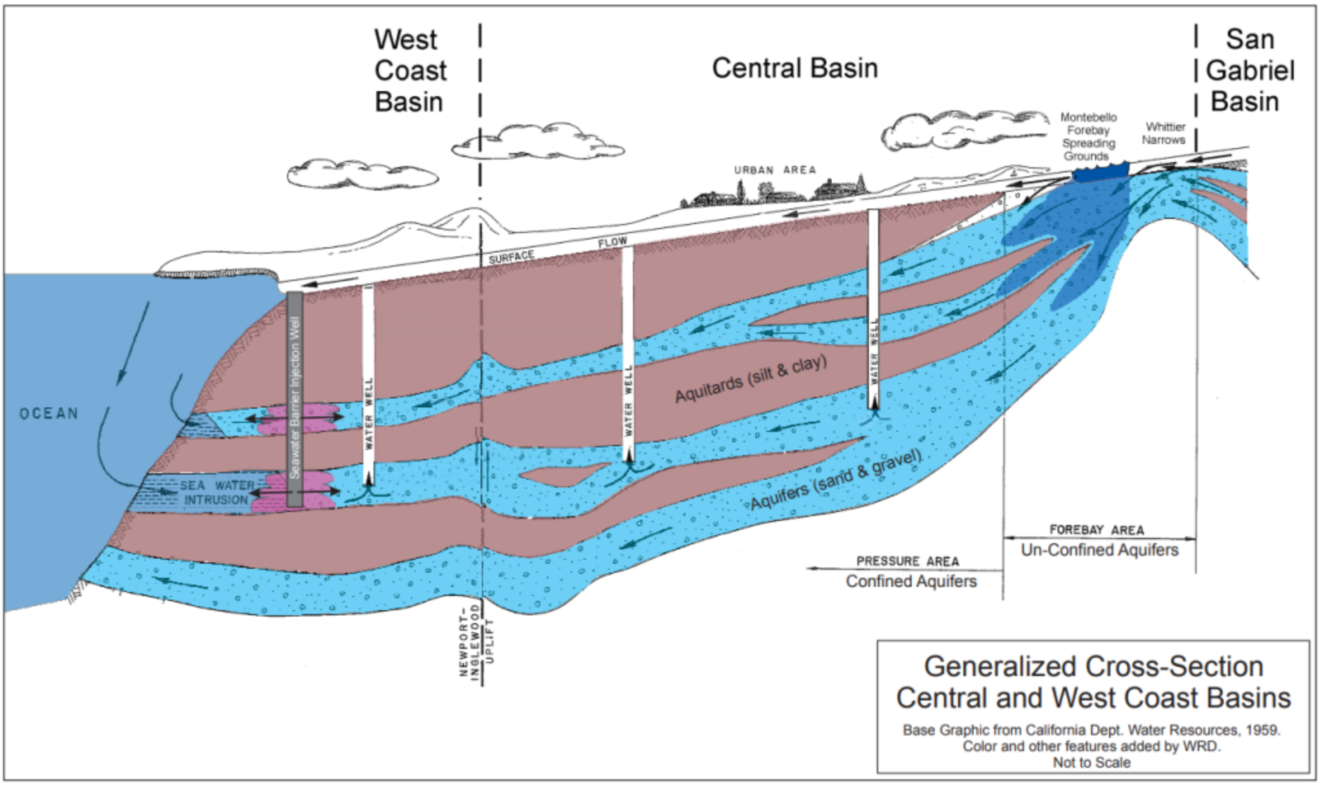


Figure 1.

Figure 4. Injection wells that are used to mitigate seawater intrusion in southern Los Angeles County, California.

Source: DWR (1959)

Today the West Coast Basin Barrier Project and Dominguez Gap Barrier Project are operated in by the Los Angeles County Department of Public Works and Water Replenishment District (WRD) (see Case Study 5.3). The West Coast Basin Barrier Project was designed and constructed in the early 1950s to prevent seawater from intruding into the underlying aquifers of the West Coast Groundwater Basin in Los Angeles County, while the Dominguez Gap Barrier Project injects clean water into the groundwater basin to prevent seawater from mixing into the drinking water supply. The Dominguez Gap Barrier is located along the Dominguez Channel in the cities of Wilmington and Carson. These projects are increasingly using recycled source water (advanced treated water (ATW)) to offset the reliance on surface water imported by the Metropolitan Water District of Southern California (MWD) from sources originating several hundred miles away (for example, the San Joaquin Delta in Northern California and the Colorado River). (*Figure 4*)

Subsidence Reduction

A common method to mitigate land subsidence involves repressurization of depleted aquifer layers. Injection wells are used to create a hydraulic barrier to ameliorate the extent of the cone of depression and generate an overpressure in geological units unaffected by pumping. This is done to build a hydraulic obstacle (or barrier) to mitigate or even reverse the compaction of aquitards and the subsequent changes in ground surface elevations (Gambolati and Teatini 2021). Aquitards are susceptible to subsidence. An example of this is in Long Beach, California, where injection wells have been relied upon for several decades to pressurize the aquifer to compensate for land subsidence due to oil production from shallow aquifers.

Advantages

As compared with other MAR technologies, injection wells have many advantages:

- The footprint of an injection well is relatively small; the wellhead is often a few feet in diameter. A slightly larger footprint will be necessary if a wellhouse is constructed as part of the system; however, the space for a wellhouse can be minimized to a 10-foot by 10-foot area. This small footprint allows flexibility in the location of the well installation.
- An injection well can be constructed to deliver the source water to a targeted aquifer that is hundreds or thousands of feet deep, or multiple aquifers, providing a significant amount of flexibility, especially as compared

to a surface infiltration method or a dry well.
- Unlike surface infiltration techniques or dry wells, an injection well can also be constructed to perform water extraction as well, as is typically done for ASR. The design of an ASR well, however, is different from the design of a well that is used only for injection. Another option is to construct a separate extraction well or well network downgradient of the injection well, which is the standard design for an ASTR system.
- The cost associated with constructing an injection well will vary depending on several factors: target aquifer depth, well diameter and materials, water treatment, and location (for example, an urban area). Due to the relatively fewer factors influencing the construction cost of an injection well, it could be considered a less expensive option (in comparison to the construction of a large reservoir for water storage).

Limitations

Limitations of injection wells include:

- Construction time for an injection well can also be considered a limitation because in comparison to an infiltration basin, drillers may be more difficult to schedule since it is a more specialized field as compared to earthmoving and infrastructure for conveyance of source water, lengthening the schedule and increasing costs.
- Injection wells will require routine operation and maintenance upkeep. Although a well-functioning injection well may run for years without any significant maintenance, an injection well will likely need more operation and maintenance attention than an infiltration basin.
- Another limitation of utilizing injection wells for aquifer recharge is the necessity for the investigation of favorable aquifers. The geochemical compatibility of the source water to be injected and the aquifer water must be evaluated to confirm that the recharge process does not negatively impact the aquifer (USEPA 2022d). Examples of negative impacts to groundwater quality due to injection of recharge water include the release of compounds, such as arsenic, particularly if the recharge water is relatively low in TDS.
- Construction costs for an injection well may be the least expensive option in comparison to the construction of a surface water reservoir. However, costs can be more significant when an injection well network is to be constructed, so the wells and their supporting infrastructure will generally cost more than other smaller recharge technologies. Also, injection wells can be less economical, costing more dollars per acre-foot of water delivered, if the conditions for an infiltration basin are available.

Performance

An injection well or injection well field can recharge water into a confined aquifer, which infiltration techniques using gravity feed cannot. This is similar to the soil infiltration capacity limitation of surface infiltration techniques. Injection of water into an aquifer; however, is dependent on the aquifer characteristics and injection pressures. Rancilio (1977) described in detail the typical design of a successful injection well, operating conditions and costs, injection rates and heads, clogging problems, and redevelopment of injection wells. High formation pressures can develop within the receiving aquifer, especially in confined aquifers, and significantly reduce how rapidly water can be recharged. An example range of typical injection rates for the Los Angeles seawater intrusion barrier is about 95–450 gpm (Rancilio 1977; Poland 1984).

Regulatory Considerations

The USEPA regulates the construction, operation, permitting, and closure of injection wells through the UIC program as required by the Safe Drinking Water Act (USEPA 2022c). Most states have primacy—authority to implement and oversee their own UIC programs; the USEPA directly implements programs in the remaining states (Figure 5) and tribal lands. For objectives such as ASTR or ASR, the state may have additional permitting and regulations in addition to those of the USEPA UIC program.

The USEPA conducted a study of Class V underground injection wells to develop background information the agency can use to evaluate the risk that these wells pose to underground sources of drinking water (USDWs) and to determine whether additional federal regulation is warranted (USEPA 1999).

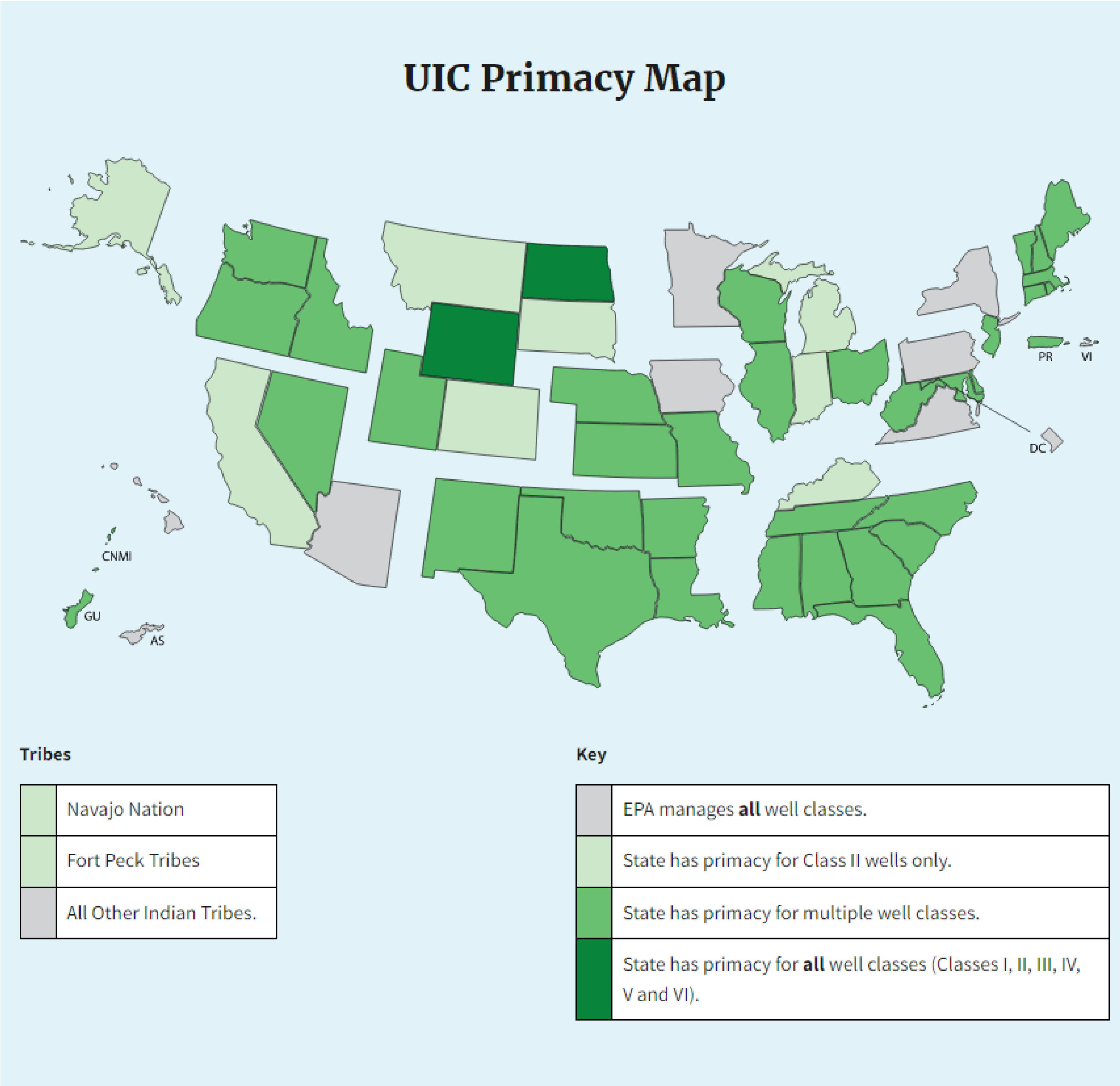


Figure 5. UIC program implementation (tribes are not depicted on map, colors for tribes relate to key—Navajo Nation and Fort Peck Tribes have primacy for Class II wells; USEPA manages all well classes for all other tribes).

Source: USEPA (2022)

A review of laws or agencies that may be involved in implementation of an injection well program includes the following:

- USEPA UIC program (Aquifer Recharge and Aquifer Storage and Recovery | USEPA), specifically injection wells that target USDW
- USEPA Source Water Protection (SWP) (Source Water Assessments | USEPA), including state source water assessment programs (SWAPs) under the Clean Water Act
- Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA)
- state agencies
- local governments
- tribal governments

In California, the State Water Resources Control Board (SWRCB) has general waste discharge requirements for ASR projects that inject drinking water into groundwater (California Water Boards 2021), which include considerations for the California

Environmental Quality Act. Since 2015, the state has issued 22 temporary permits, primarily in the San Joaquin River watershed.

Stakeholder Considerations

Injection wells can have impacts on aquifers that provide significant water resources to an area. These can be of concern to stakeholders worried about supply and water quality. The source water may also concern stakeholders regarding water rights, source water protection (SWP), and water table fluctuations. The concerns are often addressed with modeling and analysis of water level, water quality, and tracer data. Periodic testing and monitoring of water quality and the injection well may also address public concerns. The Alamitos seawater barrier injection system, operated jointly by the Los Angeles County Department of Public Works, WRD, and OCWD, has some water that eventually migrates inland and is captured by production wells (effectively creating an ASTR component).

Lessons Learned

Injection wells can be critical components of a MAR program for recharge (replenishment) of confined and unconfined aquifers and can be coupled with recovery technologies (for example, ASR and ASTR) to provide greater water supply resilience and operational flexibility. Injection wells are well suited for introducing large volumes of water into compatible aquifers in short periods of time. An injection well program can also be a cost-effective way of managing an aquifer recharge program even in high population centers. The successful implementation of an injection well program requires a thorough aquifer characterization, an understanding of the geochemical compatibility of the source and aquifer waters, and effective monitoring and maintenance on the system.

Case Studies (FS-3)

- San Antonio, Texas—San Antonio Water System H2Oaks Center ASR Project (SWIFT Home | HRSD.com) (see Case Study 5.4)
- DeLand, Florida—Using a Simple, Low-Cost, Injection Water Pretreatment System to Reduce the Concentration of Naturally Occurring Arsenic and Other Trace Metals in Recovered Water during ASR Operations, City of DeLand, Florida, Airport ASR Facility (see Case Studies 5.2)
- Moorpark, California—Las Posas Basin ASR program (Ventura County), Las Posas Basin-Groundwater Geek (Beamer, Kendall, and Mulligan 2012)