

Aquifer Storage and Recovery

First Edition



American Water Works
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Aquifer Storage and Recovery



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Aquifer Storage and Recovery

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Sr. Manager, Editorial, Development and Production: Gay Porter DeNileon

Senior Manuals Specialist: Molly Beach

Production: TIPS Technical Publishing, Inc.

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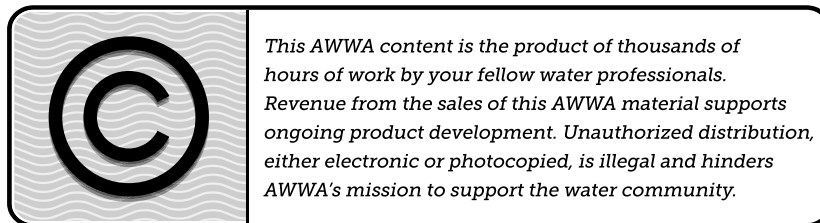
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Foreword



M63, *Aquifer Storage and Recovery*, is a new addition to the Manuals of Water Supply Practices produced by the American Water Works Association. This manual is the culmination of two years of effort by a subset of the members of the Groundwater Resources Committee. M63 was written to provide the reader with a general understanding of the principles involved with aquifer storage and recovery (ASR). The contents of this manual focus on the concept, the general rules as they are applied nationally and by state, basic design criteria, and the results of an inventory of ASR well sites nationally. Most of these wells are used to store potable water, and as a result are intended to require only limited treatment prior to use in the water distribution system. At the same time, a quarter of the wells are currently inactive for a variety of reasons.

The intention of the ASR subcommittee was to create a document that provides a general overview, without the detailed mathematical analyses and equations that are available in many other groundwater textbooks and references, including M21, *Groundwater*, AWWA Standard A100 Water Wells, and the AWWA publication *Siting, Drilling, and Construction of Water Wells* (Bloetscher et al. 2007). This manual will provide operators and engineering staff with an understanding of ASR that will help them make decisions on investigations and installations when problems or the need to expand supplies arise. ASR is a new frontier for many states and utilities. We do know that aquifers and wells vary across the country, ASR does not work everywhere, and it is not a panacea for all water-supply issues. But ASR can be a useful tool in the utility manager's toolbox.

The scope of this manual is as follows:

Chapter 1 is an overview of aquifer injection programs and how they are differentiated from ASR systems.

Chapter 2 is an overview of the rules set forth by the Safe Drinking Water Act (SDWA) and the subsequent delegation of the enforcement authority to states. Because a number of states do not have underground injection control (UIC) primary enforcement authority, USEPA directly implements the UIC programs (including ASR wells) for these states. ASR rules change periodically so only an overview has been provided.

Chapter 3 summarizes the experience in the United States with ASR, including locations and characteristics, with a much-improved expansion from previous ASR surveys.

Chapter 4 outlines the challenges of ASR projects, including metals leaching, plugging, and recovery issues.

Chapter 5 outlines the basic guidelines for design and construction of ASR wells, with emphasis on the testing protocol and expectations that must be conveyed to the client. ASR testing takes time (up to five years), so for ASR to be successful, implementation must be carefully considered and planned. Chapter 5 also outlines the evaluation methods and parameters for ASR wells, including:

- Aquifer parameters
- Transmissivity and storage coefficient
- Collection of test data

- Analysis
- Well design

Well losses, yield, and modeling techniques are covered in detail in other publications, including those mentioned previously, and are not covered in detail herein.

Chapter 6 outlines issues associated with maintenance of ASR wells. Note, maintenance experience is limited because most wells are less than 20 years old.

Chapter 7 details specific examples of ASR experiences, both successful and those facing challenges since overcoming the challenge is often more informative than the successes.

Chapter 8 summarizes the manual and outlines how aquifer recharge can be accomplished by other means. Aquifer recharge is expected to be a topic for a future manual.

This manual should help operators and engineers gain enough background on the subject of ASR to improve their decision making in the United States. M63 should help these professionals answer many questions about complex aquifer systems and improve their response to problems. The Groundwater Resources Committee is hopeful that this manual will meet the industry needs of the new millennium.

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Technical Review Board Members

Frank Getchell, Leggette Brashears & Graham Inc., Upper Saddle River, N.J.
Lindsey Geiger, American Water Works Association, Denver, Colo.
Stephen A. Hubbs, University of Louisville, Louisville, Ky.
Albert Muniz, Hazen and Sawyer P.C., Boca Raton, Fla.
Joseph M. Nattress, CH2M, Philadelphia, Pa.
Susan Roberts, Vice Chair, Abengoa-Abeinsa, Chesterfield, Mo.

Contributors

Frederick Bloetscher, Chair, Florida Atlantic University, Hollywood, Fla.
Fred M. Blumberg, ARCADIS U.S. Inc., San Antonio, Texas
Richard E. Cowles, Malcolm Pirnie, Sarasota, Fla.
Frank Getchell, Leggette Brashears & Graham Inc., Upper Saddle River, N.J.
Jeffrey W. Henson, Black & Veatch, Kansas City, Mo.
Stephen A. Hubbs, University of Louisville, Louisville, Ky.
Timothy P. Karlstrand, Carollo Engineers, Walnut Creek, Calif.
Mark C. Lucas, CH2M, Fort Lauderdale, Fla.
Bryan B. McDonald, CH2M, Gainesville, Fla.
Albert Muniz, Hazen and Sawyer P.C., Boca Raton, Fla.
Joseph M. Nattress, CH2M, Philadelphia, Pa.
Peter E. Petersen, Milwaukee Water Works, Milwaukee, Wis.
Susan Roberts, Vice Chair, Abengoa-Abeinsa, Chesterfield, Mo.
Laura L. Simons, New Jersey American Water, Voorhees, N.J.
Kevin Spencer, R. W. Harden & Associates Inc., Austin, Texas
Timothy M. Thomure, HDR Engineering, Phoenix, Ariz.

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These people provided data, information, or contacts:

Bassad Ahmadi, Valley Water, Fresno, Calif.
Randy Albright, R.G., L.H.G., Portland Water Bureau, Portland, Ore.
Brian P. Austin, Wisconsin Department of Natural Resources, Madison, Wis.
Steven G. Bayley, City of Tracy, Tracy, Calif.
Marcel Belaval, USEPA Region I, Boston, Mass.
Craig Boomgaard, USEPA Region 7, Denver, Colo.

Bruce Bunch, City of Fresno, Fresno, Calif.
Gus Cicala, East Bay MUD Library Services, Oakland, Calif.
David Cole, R.G., Oregon DEQ Northwest Region, Portland, Ore.
Brian A. Dickinson, Elsinore Valley Municipal Water District, Lake Elsinore, Calif.
Alan R. Dulaney, City of Peoria Utilities Department, Peoria, Ariz.
Kelley A. Dyer, City of Santa Barbara, Santa Barbara, Calif.
Denice Enochs, Elsinore Valley Municipal Water District, Lake Elsinore, Calif.
Robert J. Eustice, Florida Atlantic University, West Palm Beach, Fla.
William Ferguson, City of Santa Barbara, Santa Barbara, Calif.
Anna L. Garcia, Mojave Water Agency, Apple Valley, Calif.
Robert C. Garcia, City of Peoria, Peoria, Ariz.
Michael E. Garrod, Sweetwater Authority, Chula Vista, Calif.
Carolyn German, Irvine Ranch Water District, Irvine, Calif.
Gary M. Gin, City of Phoenix, Water Services Department, Phoenix, Ariz.
Mary Shaleen Hansen, Washington Department of Ecology, Water Resources Program, Olympia, Wash.
Gary Hilliard, Los Angeles County Department of Public Works, Stanton, Calif.
John Izbicki, USGS, San Diego, Calif.
Elizabeth Janes, USEPA Region 9, San Francisco, Calif.
Matt Katen, Zone 7 Water Agency, Livermore, Calif.
Dave J. Kaunisto, E. Cherry Creek Valley Water and Sanitation, Aurora, Colo.
Jordan Kear, Kear Groundwater, Santa Barbara, Calif.
Karl Kennedy, Calvin Giordano & Associates, Fort Lauderdale, Fla.
J. Bart King, Los Angeles County Department of Public Works, Huntington Beach, Calif.
Susan King, Sweetwater Authority, Chula Vista, Calif.
Nicole Lance (Dailey), City of Gilbert, Gilbert, Ariz.
Jeffrie Madland, City of Camarillo, Camarillo, Calif.
Craig Maples, Chesapeake Public Utilities, Chesapeake, Va.
Robert Marks, Pueblo Water Resources, Ventura, Calif.
Joseph May, FDEP, Southeast District, West Palm Beach, Fla.
Andy McDonald, N.J. Department of Environmental Protection, Trenton, N.J.
Gary McSmith, Cape Fear Public Utility Authority, Wilmington, N.C.
Kirk D. Medina, North Las Vegas Utility, Las Vegas, Nev.
Michelle Moreno, Arizona Dept. of Water Resources, Phoenix, Ariz.
Tom M. Morris, ASR Systems, Las Vegas, Nev.
Behrooz Mortazavi, Eastern Municipal Water District, Perris, Calif.
Jim Murphy, Chief, N.J. Department of Environmental Protection, Trenton, N.J.
Dave Nazy, Washington Department of Ecology, Water Resources Program, Olympia, Wash.
Richard M. Noble, P.E., Hansen, Allen & Luce Inc., American Fork, Utah
Joe Oliver, Monterey Peninsula Water Management District, Monterey, Calif.
Alan E. Packard, Jordan Valley Water Conservancy District, West Jordan, Utah
Tony Perez, City of Fresno, Fresno, Calif.
Terry Pilawski, N.J. Department of Environmental Protection, Trenton, N.J.

David Pyne, ASR Systems, Gainesville, Fla.
Cher Quinones, Development & Records Coordinator, EVMWD, Lake Elsinore, Calif.
Laurie Richards, Carpinteria Valley Water District, Carpinteria, Calif.
Claudia Sandoval, Irvine Ranch Water District, Irvine, Calif.
Chi Ho Sham, The Cadmus Group Inc., Waltham, Mass.
Scotty D. Sorrells, Tennessee Dept. of Environment and Conservation, Groundwater Management Section, Nashville, Tenn.
Kimberly Swan, Clackamas River Water, Clackamas, Ore.
Linda Townes, Jordan Valley Water Conservancy District, West Jordan, Utah
Dana Walker, City of Phoenix, Phoenix, Ariz.
Daniel Wendell, Groundwater Dynamics, Oakland, Calif.
Kathy Wright, State of Delaware, DNREC, Wilmington, Del.
Mark Wuttig, CH2M, Thousand Oaks, Calif.

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Frederick Bloetscher, Ph.D., P.E., Chair,
Groundwater Resources Committee

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Acronyms

AFA	acre-ft annually
AGWT/HC/FGS	American Groundwater Trust/Hydrogeology Consortium/Florida Geological Survey
ASCE-EWRI	American Society of Civil Engineers – Environmental & Water Resources Institute
ASR	aquifer storage and recovery
CAP	Central Arizona Project
CBOD ₅	5-day carbonaceous biological oxygen demand
CERP	Comprehensive Everglades Restoration Plan
CFR	Code of Federal Regulations
DBPs	disinfection by-products
DWR	Department of Water Resources
FAC	Florida Administrative Code
fpd	feet per day
GEFA	Georgia Environmental Finance Authority
gpd/ft	gallons per day/foot
gpd/ft ²	gallons per day/square foot
gpm	gallons per minute
gpm/ft	gallons per minute/foot
GSWSA	Grand Strand Water and Sewer Authority
H ⁺	hydrogen ion
HAAs	haloacetic acids
ID	internal diameter
K	hydraulic conductivity
LVV	Las Vegas Valley
MCL	maximum contaminant levels
mgd	million gallons per day
mi ²	square miles
MLGW	Memphis Light Gas and Water
Mn	manganese
NOM	natural organic matter
NPSH	net positive suction head
NTU	nephelometric turbidity units
OD	outside diameter
OH ⁻	hydroxide ion
ORP	oxidation–reduction potential
PAD	prior appropriation doctrine
PRRWSF	Peace River Regional Water Supply Facility

PVC	polyvinyl chloride
POS	plan of study
SCADA	supervisory control and data acquisition
SDWA	Safe Drinking Water Act
SFWMD	South Florida Water Management District
SWPP	source water protection program
TDH	total dynamic head
TDS	total dissolved solids
THMs	trihalomethanes
TOC	total organic carbon
TSS	total suspended solids
TSWB	Texas State Water Board
TTHM	total trihalomethanes
UIC	underground injection control
USDW	underground sources of drinking water
USEPA	United States Environmental Protection Agency
USGS	United States Geological Survey
VFD	variable-frequency drive
WCASF	Water Conservation Areas of South Florida
WEFTEC	Water Environment Federation Technical Exhibition and Conference
WWTP	wastewater treatment plant
ZOC	zone of contribution

Chapter **1**

Groundwater Recharge and Storage Programs

In some areas of the world, vast amounts of treated or treatable water are being pumped below ground and stored beneath the earth's surface to preserve current water resources, prepare for future droughts, protect water resources, recharge wellfields, and store water for use at a later time to sustain development. Belowground storage holds an advantage over surface reservoirs because no evaporation losses occur. Water resources are also conserved because water not needed presently is stored, instead of being discharged into rivers, oceans, or other surface waterways.

Groundwater recharge and storage programs are divided into four categories: artificial aquifer creation, aquifer recharge, aquifer reclamation, and aquifer storage and recovery (ASR). All methods can be part of a water supplier's program of ensuring that sustainable water supplies are available for agricultural, environmental, and urban uses. Most methods are employed in arid or coastal areas or in areas with seasonal wet and dry periods, and also serve as a supplemental source in the event of emergency outages, low fire flows, and water quality issues (via blending). These strategies are employed in Australia, Europe, the Middle East, and the United States. At present, all of these strategies have proven cost effective and capable of successfully augmenting existing water sources for long-term water supply under certain conditions.

ARTIFICIAL AQUIFER CREATION AND AQUIFER RECHARGE

Artificial aquifer creation technologies involve the introduction of large quantities of water into an aquifer or aquifer zone for retrieval down-gradient of the point of injection. Prior to injection, the aquifer is generally either devoid of water or contains low-quality water. In areas with limited demand, but where porosities or strata may allow for water storage, artificial aquifer recharge is applicable because it is specifically meant to encourage

recharge and therefore requires high-quality water for injection. Because groundwater movement is generally slow, the recharge program may be able to supply either small quantities of water or supplement existing water during times of high demand that could cause aquifer stress.

Where an aquifer has been depleted by overpumping (mining of the aquifer), aquifer recharge, also termed artificial recharge, is a viable concept. This concept uses water of a given quality introduced at a point that enables existing water supplies to flow into a wellfield production zone. The aquifer head is raised enough to create a driving force that pushes water into the aquifer formations, where the water can be eventually pumped via a wellfield, which could be many miles away (Figures 1-1a and 1-1b).

Sometimes a surface area is simply flooded to create an artificial aquifer head at the point of recharge. The higher surface water head increases the percolation rate into the aquifer. One drawback with flooding areas is that surface water has a higher evapotranspiration rate than do other forms of aquifer recharge. However, downstream well fields benefit from the resulting higher water levels with increased total water supplies.

The Water Conservation Areas of South Florida (WCASF) are examples of aquifer recharge via flooding. The WCASF store water at higher-than-normal levels to force recharge of the Biscayne Aquifer system. The aquifer's natural gradient toward the coast allows the recharge to serve most of the South Florida utilities in some manner. Other such programs exist in Texas, Arizona, Utah, California, and other states, but artificial aquifer creation and aquifer recharge programs are outside the scope of this manual.

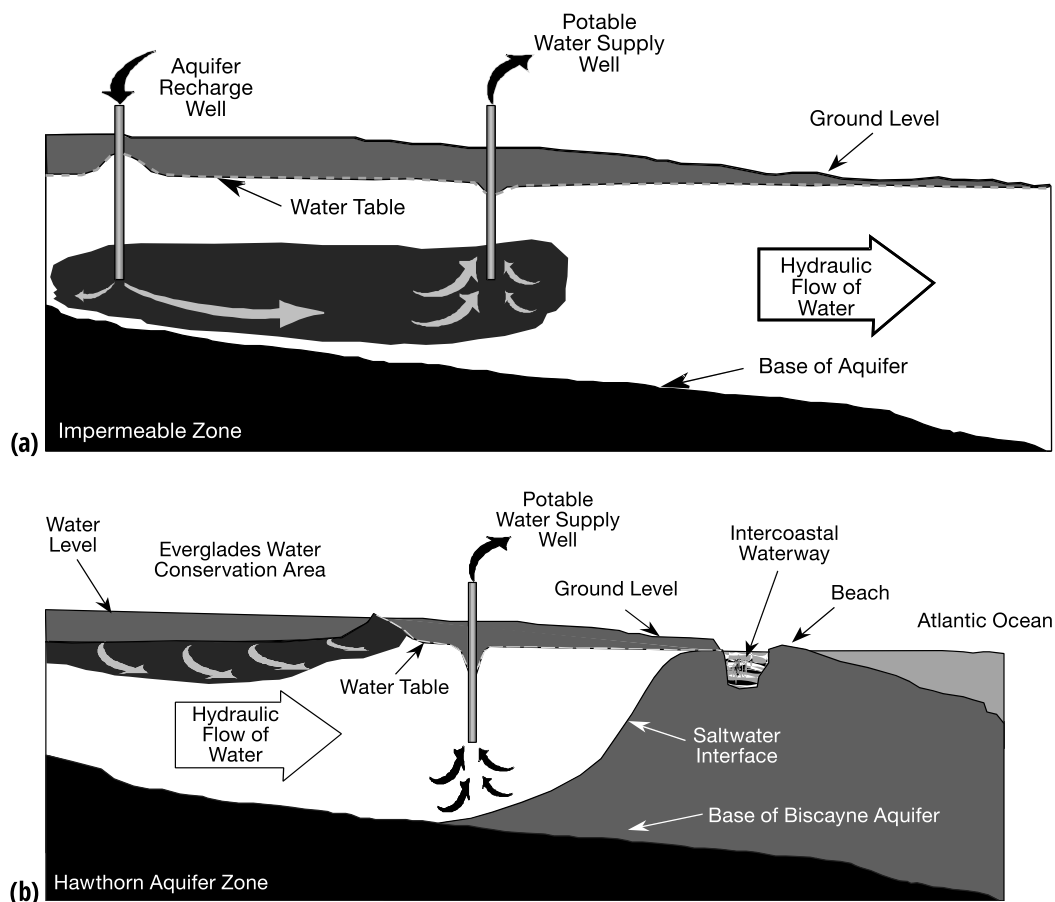


Figure 1-1 (a) Aquifer recharge; (b) Aquifer recharge via flooding

Source: AWWA 2014

AQUIFER RECLAMATION

Aquifer reclamation involves injecting large quantities of higher-quality waters into a compromised aquifer. One application of this technology is injection of freshwater into aquifer zones that have been compromised by brackish water (water containing 1,000 to 10,000 ppm of total dissolved solids) intruding into the formation (USEPA 2002). The freshwater serves to stabilize the water quality at a given chloride (isochlor) concentration or forces the brackish water to retreat toward the source—typically the ocean, but also lower formations where *upconing* is a problem. Upconing is the process by which saline water underlying freshwater in an aquifer rises upward into the freshwater zone as a result of pumping water from the freshwater zone. Aquifer reclamation has not been used in North America to a great extent except in California, but the technical concept has wide applicability in coastal areas with transmissive formations where saltwater intrusion has occurred or has the potential to occur, as a result of lowered surface water levels or where *connate water*—water trapped within the pores of rock formations—may be present. The method can also be applied to well fields where upconing of brackish or water containing high total dissolved solids from lower aquifer regions is a potential problem, thereby allowing withdrawals of larger quantities without inducing upconing.

Artificially-induced saline encroachment (intrusion) can be initiated when the aquifer head in a given area is sufficiently reduced by aquifer withdrawals, development over surface recharge areas reduces permeability (as a result of buildings and paving), or drainage canals discharge surface water that might otherwise percolate into the aquifer. Saltwater can continue to migrate inland over time, contaminating the aquifer. Initially the water movement is slow, but it accelerates as the saltwater draws closer to withdrawal (discharge) points. A hydrogeologically sound injection program, properly designed and constructed, can mitigate the landward migration of the saltwater. Under certain scenarios, the movement of the saltwater can be reversed (Figures 1-2a, 1-2b, 1-2c, and 1-2d). Chapter 11 of M21, *Groundwater* (AWWA 2014), and Bloetscher et al. (2005) discuss this concept in more detail.

AQUIFER STORAGE AND RECOVERY

That leaves us with the topic of this manual: aquifer storage and recovery, or ASR. ASR involves the management of water supplies for both potable (drinking water) and non-potable water supply systems. While the purpose of both aquifer reclamation and aquifer recharge is to sustain long-term demands in an existing or potential source, ASR is intended to store water until such time as it is needed to meet peak needs, long-term growth demands, or emergency conditions, or because of poor water quality.

More than 200 sites in 27 different states in the United States have either implemented or investigated ASR. Most existing systems involve storage of potable water, but a number of wells use untreated raw surface water or groundwater in an ASR system for later withdrawal and treatment. The goal of these projects is to store current water supplies for later use, both long and short term. As water supplies have become more limited in more areas of the country, additional interest has developed in the practice of incorporating ASR into potable water, irrigation, and reclaimed systems.

Employing ASR technology can increase the efficiency of water system operation. During a wet or low-demand time of the year, some or all of the unused water treatment plant capacity can be used to treat water and inject the treated water into an aquifer for future recovery and use. The potable water to be stored is injected into the aquifer (Figure 1-3) where it displaces the native groundwater in the aquifer. The storage zone should have good overlying confinement, underlying semi-confinement, and a transmissivity commensurate with the storage and recovery capacity goals of the program. In the ASR concept, native water is theoretically displaced and replaced in the injection zone,

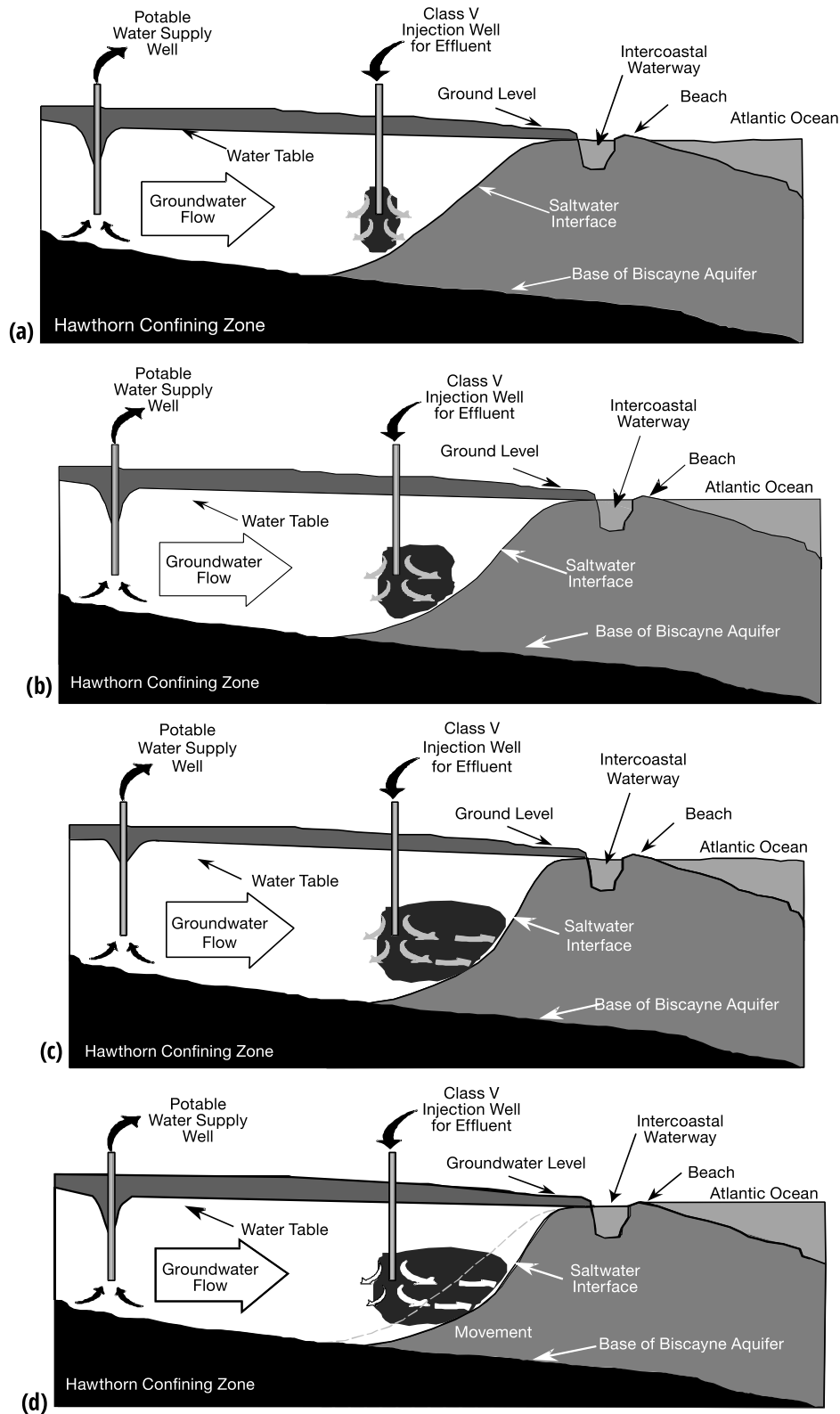


Figure 1-2 (a) Biscayne Aquifer reclamation after start of injection; (b) Biscayne Aquifer reclamation water movement after injection; (c) Biscayne Aquifer reclamation water movement toward saltwater after injection; (d) Biscayne Aquifer reclamation water movement pushing isochlor line toward the ocean

Source: AWWA 2014

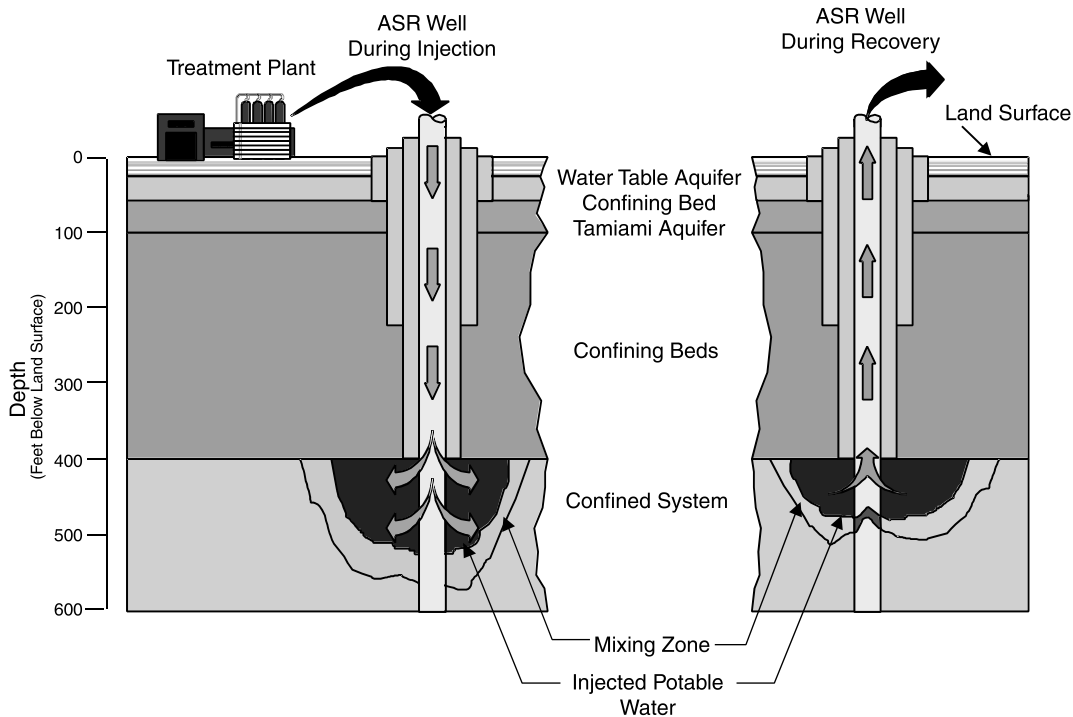


Figure 1-3 Aquifer storage and recovery conceptual diagram for brackish water aquifers where freshwater bubble creates mixing transition zone that increases with time

Source: AWWA 2014

as shown in the figures. With good underground conditions the injected water will hold together to create an underground bubble, depicted as a cone or half cylinder of fresh water in the native water. In theory, 100 percent recovery can be obtained from injection into a freshwater aquifer because of the minimal mixing zone caused by density stratification between the two waters, but geochemistry and other issues can frustrate this objective. Brackish aquifers are more challenging (see chapter 4).

The successful development of ASR projects depends upon both technological and regulatory factors. Both physical and chemical properties of the injected water may change after injection as a function of chemical reactions between water and the aquifer. The stored water has the potential to change as a result of

- increased aquifer pressure,
- temperature (increases or decreases),
- the potential for microorganism metabolization and secretions, and
- geochemical reactions.

Economic factors also impact the success of ASR projects. Technological and economic success depend on geology, excess water supply capacity (generally at least 1 mgd of excess capacity is needed, based on the data gathered from ASR sites across the country), and variations in water needs throughout the year. ASR is a water management strategy—it does not create water; it stores water underground instead. However, ASR can make managing supplies more effective under certain conditions. While ASR can be an attractive alternative to aboveground storage, the combined challenges of meeting requirements

for drinking water storage and groundwater injection, and the need to establish ownership of the stored water, have created several challenges that must be addressed by regulatory agencies within each state/territory where ASR is used.

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Chapter **2**

Regulatory Requirements

The United States Environmental Protection Agency (USEPA) is tasked with protecting underground sources of drinking water (USDWs) as a part of the Safe Drinking Water Act (SDWA), which includes the authority to regulate underground injection projects. A USDW is an aquifer containing groundwater with total dissolved solids (TDS) less than 10,000 mg/L (USEPA 2012). The Underground Injection Control (UIC) program—specific regulations promulgated at 40 CFR 144 to 148—protects USDWs from endangerment from injected fluid migration (USEPA 1983). Aquifers that are adjacent to the injection zone but are not USDWs are not subject to UIC regulations, but states may regulate injection under the auspices of their antigradation rules (Bloetscher et al. 2005).

Groundwater protection is achieved through rules that govern the construction and operation of injection wells in such a way that the injected fluid does not migrate into a USDW. The UIC rules regulate disposal of waste, particularly hazardous waste, via underground injection. The delineation of a USDW, as well as the requirements for construction wells to prevent migration, indicate that the regulations are focused on preventing injection of constituents that might impact USDWs.

Because the set of rules dealing with underground injection is lengthy, the intent of this chapter is to provide an overview of the various rules and their intent, with references to the complete federal rules and state rules for more information. The following topics are covered:

- Federal regulations
 - 40 CFR 144, 146, and 148 – Underground Injection Control
- Aquifer exemptions
- Zones of discharge

- Water rights and allocations by rule
- Wellhead protection
- State regulations for injection control
- Uses of waters of impaired quality

FEDERAL REGULATIONS – UIC

Federal regulations include an extensive set of definitions concerning the types and purposes of injection wells. Much of this oversight relates to the type of well proposed and its use. In addition, regulations have set forth types of materials that are permitted for use in well construction and minimum design criteria and testing to ensure well integrity. Federal regulations 40 CFR 144, 146, and 148 governing underground injection control (UIC) were established under the authority of SDWA approved in 1974 and amended in 1986 and 1996 (Tiemann 2010). These regulations segregate the wells into six classes, as described in Table 2-1 and illustrated in Figure 2-1.

Typically, Class V wells are shallow wells used to place a variety of fluids directly below the land surface. Examples of Class V wells are (from 40 CFR 146):

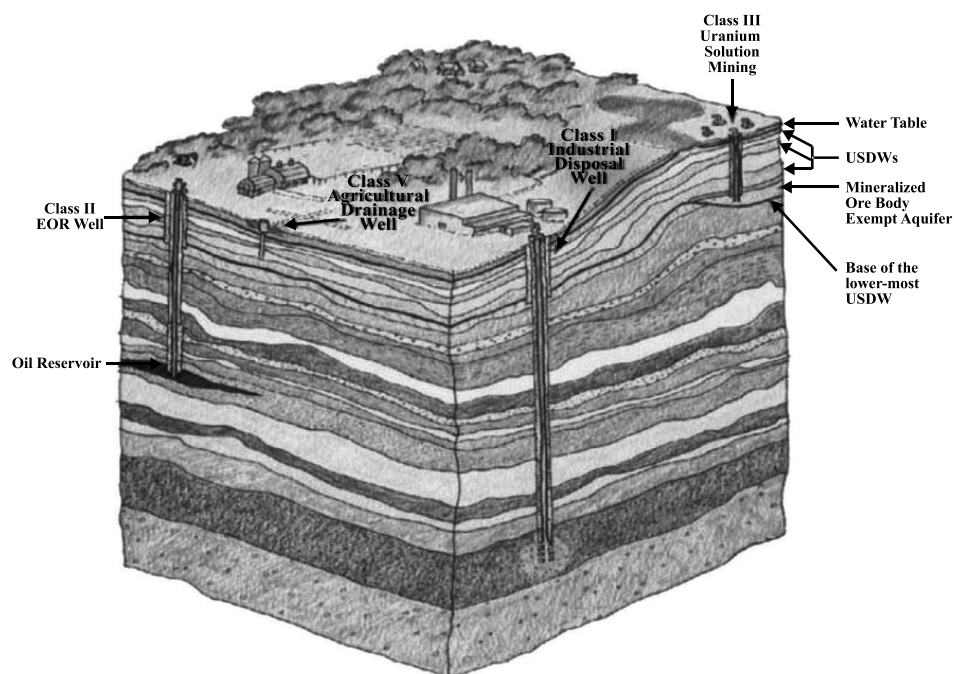
- Air conditioning return-flow wells used to return to the supply aquifer the water used for heating or cooling in a heat pump
- Cooling water return-flow wells used to inject water previously used for cooling
- Drainage wells used to drain surface fluids, primarily storm runoff, into a subsurface formation
- Dry wells used for the injection of wastes into a subsurface formation (injection of hazardous wastes into or above a USDW is prohibited by UIC rules)
- Recharge wells used to replenish the water in an aquifer
- Saltwater intrusion barrier wells used to inject water into a freshwater aquifer and create a subsurface density buffer zone to prevent the intrusion of saltwater into the freshwater
- Sand backfill and other backfill wells used to inject a mixture of water and sand, mill tailings, or other solids into mined-out portions of subsurface mines, whether the injectate contains radioactive waste or not
- Septic systems used to inject the waste or effluent from multiple dwellings and/or business establishments into a septic tank (UIC requirements do not apply to single family residential septic systems, nor to nonresidential septic system wells serving fewer than 20 persons a day used solely for the disposal of sanitary waste)
- Subsidence control wells (not used for the purpose of oil or natural gas production in those zones) used to inject fluids into a zone to reduce or eliminate subsidence associated with the overdraft of groundwater
- Injection wells associated with the recovery of geothermal energy for heating, aquaculture, and production of electric power
- Wells used for solution mining of conventional mines such as stope leaching
- Injection wells used for in situ recovery of lignite, coal, tar sands, and oil shale
- Wells used to inject spent brine into the same formation from which it was withdrawn after extraction of salts

Table 2-1 USEPA classification system for injection wells (Adapted from 40 CFR 144.6)

Injection Well Class	Uses
Class I	Class I injection wells are either wells used by generators of hazardous waste or owners and operators of hazardous waste management facilities that inject hazardous waste beneath the ground's surface. The waste is required to be injected beneath the lower-most formation of an underground drinking water source and more than 1/4 mile horizontally from it. This requirement includes other industrial and municipal disposal wells that inject fluids beneath the lower-most underground sources of drinking water (USDW). Class I wells can also be radioactive waste disposal wells.
Class II	Class II wells are used for the injection of fluids that are brought to the surface in connection with conventional oil and natural gas production, or the enhancement of recovery of oil and natural gas and the storage of hydrocarbons. A third subtype can only be used for liquid hydrocarbon storage; gaseous hydrocarbons are not included. At the state level, they are overseen by state oil and gas commissions and departments of natural resources. At the federal level, USEPA is the oversight agency.
Class III	Class III wells are utilized for the extraction of minerals.
Class IV	Class IV wells are for the injection of hazardous or radioactive materials into or above a USDW. Class IV wells are banned with the exception of wells associated with waste site cleanup under RCRA* or CERCLA† programs.
Class V	Class V wells are all wells that are not included in Class I, II, III, IV, or VI. The wells described herein for underground injection programs such as aquifer storage and recovery (ASR), saltwater intrusion barrier, or managed aquifer recharge, are all Class V wells.
Class VI	Class VI wells are used for sequestration of carbon dioxide.

* Resource Conservation and Recovery Act

† Comprehensive Environmental Response, Compensation, and Liability Act

**Figure 2-1 Different classes of wells**

Source: USEPA, <http://www.epa.gov/region9/superfund/navajo-nation/pdf/stakeholders/UraniumPermits-DaveBasinger-USEPA.pdf>

The 1999 Class V Rule bans and restricts large-capacity cesspools and motor vehicle waste disposal wells.

States apply to USEPA to take on oversight and enforcement authorities (i.e., primacy) of the UIC program under SDWA Section 1422 (all well classes, with the exception of Florida where USEPA runs the Class II program) and SDWA Section 1425 (Class II for oil- and gas-related activities). 40 CFR 144.7 describes the means by which an aquifer may be designated as a USDW and refers to the specific USDW criteria presented in 40 CFR 144.3. The initial UIC regulations of 40 CFR 144.1(g) authorized the UIC Program Director to identify aquifers and portions of aquifers that are actual or potential sources of drinking water to help protect all USDWs. The regulations make clear that “[a]n aquifer is a USDW if it fits the definition, even if it has not been ‘identified.’”

If an aquifer has not been specifically classified by the US Geological Survey (USGS) as a drinking water aquifer, it is assumed to be an underground source of drinking water. Narrative descriptions, illustrations, maps, or other geographic or geometric terms (such as vertical and lateral limits and gradient) are used to define the extent of USDWs.

AQUIFER EXEMPTIONS

Because the violation of any water quality standard may lead to the potential abandonment of a project, USEPA has established an aquifer exemption process. 40 CFR Section 144.7 establishes the process for state program exemption determinations. Aquifer exemptions are referred to as substantial and non-substantial (40 CFR 144.7(b)(3) and 40 CFR 145.32). USEPA may designate “exempted aquifers” using the criteria in 40 CFR 146.4. 40 CFR 144.1(g) as defined:

[Exempted] aquifers are those which would otherwise qualify as “underground sources of drinking water” to be protected, but which have no real potential to be used as drinking water sources. Therefore, they are not USDWs. No aquifer is an “exempted aquifer” until it has been designated under the procedures in 144.7.

Otherwise, the SDWA does not mention aquifer exemptions explicitly, nor does the statute expressly preclude the exemption of an aquifer that is not currently used for drinking water purposes. The key provisions of the statute speak in terms of regulation, not absolute prohibition.

USEPA’s aquifer exemption mechanism was promulgated in 1980 as a means of balancing underground disposal and mineral production needs with drinking water resource protection needs. USEPA believed that the most protective course was to adopt this broad definition and allow exemptions of aquifers from classification as USDWs on a case-by-case basis after review and public comment. This case-by-case approach was developed through the criteria for aquifer exemptions set forth in the regulations at 40 CFR 146.4 and 40 CFR 144.7 to provide the agency, after thorough site-specific analysis and public comment, a way to remove a USDW from UIC Program oversight.

An aquifer exemption is required if the water proposed for injection does not meet the water quality standards of the receiving water, based on its regulatory classification and a series of other conditions. In the final UIC regulations published on June 24, 1980, USEPA outlined four specific standards (40 CFR 146.4) to be met for the exemption of aquifers. The state is not required to designate an aquifer or portion of an aquifer as a USDW if:

1. It is not a current water supply, or cannot now or in the future serve as a water supply because it is mineral, oil, or geothermal energy producing

2. It is situated at depths or locations that make it economically and technologically impractical to produce drinking water
3. The aquifer is so contaminated that it would be economically or technologically impractical to render the water fit for consumption
4. In the case of a Class III well mining area, an exemption could be approved where the area would be subject to subsidence or catastrophic collapse in the absence of an exemption

Since the 1980 promulgation, the UIC regulations for exempted aquifers have been amended three times:

1. A modification of 40 CFR 146.4(c) to permit the UIC Program Director to exempt an aquifer not currently a source of drinking water if it contains between 3,000 and 10,000 mg/L TDS and “is not reasonably expected to supply a public water system”
2. A modification to the exemption provision in 40 CFR 144.7(b)(1) to allow the UIC Program Director to identify (by narrative description, illustrations, maps, or other means) and describe in geographic and/or geometric terms (such as vertical and lateral limits and gradient) all aquifers or parts thereof which the Director proposed to designate as exempted aquifers using the criteria in 40 CFR 146.4
3. A modification of 40 CFR 146.4 to state that the area covered by an aquifer exemption for a Class II enhanced oil recovery (EOR) or enhanced gas recovery (EGR) well may be expanded for Class VI injection wells for geologic sequestration, but that new aquifer exemptions for Class VI wells are not allowed

A substantial aquifer exemption is required if the proposed injection zone contains fluids with TDS of less than 3,000 mg/L. All substantial aquifer exemptions must be issued by USEPA in Washington, D.C., and a notice must be published in the *Federal Register*. Non-substantial requests may be issued by regional USEPA administrators.

Except in defining USDWs and aquifer categories, the federal regulations do not specify the technical criteria that are used by USEPA to judge aquifer exemption requests. As a result, USEPA developed additional criteria to evaluate each type of exemption request. USEPA will approve aquifer exemptions only for specific purposes. All exemption requests must include a description of injection activities allowed and a statement that additional approvals would be needed for other injection activities (e.g., hazardous waste disposal into an aquifer exempted for mineral production). Exemption requests must include economic criteria that address the availability of alternative supplies and their adequacy to meet present and future needs as well as the major costs for treatment and/or development associated with the use of the aquifer, including well construction and water conveyance (e.g., pumps and piping). The economic evaluation submitted by the applicant should consider these factors, as well as the following (Kimm 2000):

1. Distance from the proposed exempted aquifer to public water supplies
2. Current water supply sources for potential users of the proposed exempted aquifer
3. Availability and quality of alternative water supply sources
4. Analysis of future water supply needs within the general area
5. Depth of proposed exempted aquifer
6. Quality of the water in the proposed exempted aquifer

Approvals for aquifer exemptions can be difficult to acquire, especially for substantial exemptions. The most common reason for an exemption request occurs when the proposed injectate is of “lesser quality” because it contains one or more secondary drinking water quality parameters not found in the native water. Common constituents of concern with raw or reclaimed water are total organic carbon (TOC), fecal coliforms, disinfection by-products (DBPs), and nitrate. Microbiological constituents are not a major factor in the UIC program except for fecal coliforms, which are deemed to be an appropriate indicator organism.

Limited aquifer exemptions have been granted when the proposed injection zone contains TDS between 3,000 mg/L and 10,000 mg/L. Processing of applications for limited aquifer exemptions are a less lengthy process than for minor aquifer exemptions, and are oriented toward raw water ASR and reclaimed water applications. Rules designed for limited aquifer exemptions of alternative groundwater technologies primarily concern technical issues, where the original intent of the Safe Drinking Water Act is queried. A significant regulatory issue remains concerning whether the water quality standards should be measured at the wellhead or at the USDW (Bloetscher et al. 2005).

ZONES OF DISCHARGE

Occasionally, a state may permit the groundwater standards to be exceeded for some distance from the well. This is called a *zone of discharge* or *mixing zone*. A zone of discharge would be included in the permit to meet secondary criteria in the aquifer (Bloetscher et al. 2005). For example, Florida permits zones of discharge in G-II aquifers where the total dissolved solids is above 3,000 mg/L (Florida Administrative Code [FAC] sections 62-522.500 and 62-520). As applied, the injection system must be operated so the groundwater quality will be no worse than the natural background groundwater quality at the edge of the zone of discharge and the secondary sodium standard. In Florida, the extended zone of discharge can extend radially to the permit holder’s property line, which may be greater than the 100 ft normally allowed for a zone of discharge (FAC 62-522.500 and 62-520).^{*} The applicant may request an extended zone of discharge that extends beyond the property boundary at the time of initial permit application or with subsequent permit renewals or permit modifications, but the zones are not permitted to extend into a potable-well setback. The zone of discharge would generally be applied to parameters listed as secondary drinking water standards or for sodium. Zones of discharge are not generally provided for parameters listed as primary drinking water standards (except for sodium). Each state, where allowed, will define this differently, so local rules should be consulted.

WATER RIGHTS AND ALLOCATIONS BY RULE

The method of allocating water can be an issue in ASR programs from two vantage points: ownership of the injected water and rights to water in excess of permits or needs. In the eastern states, water allocations are typically administered under a riparian system of water law. Generally the water is owned by the state, not individuals, and water use above a specified amount may be required to be reported. In some eastern states, groundwater withdrawals may be regulated within specific aquifers. States where water withdrawals from designated aquifers are regulated include Georgia, South Carolina, North Carolina, Virginia, Maryland, Delaware, and Florida.

^{*} Classification is specific to Florida; Class G-II waters are still potable, but have a total dissolved solids content up to 10,000 mg/L.

The picture is different in the western 18 states where water use rights are governed by the prior appropriation doctrine (PAD) of water law which, depending on the state regulations, may be applied. In most western states, the doctrine applies to surface waters and groundwater, but in Texas it applies to surface waters only. The PAD of water law establishes the right of a water user to use a specific amount of the state's water resources for a specific beneficial use or as associated with correlative land rights, such as in California, as stated in the water right by rule or statute. The water right holder has a priority date determined by a court or agency. The water users with older or more senior water rights have the right to use their water first. If the demand for water is greater than the available supply, the senior water rights holders can "place a call" on the water source (typically a river), which may result in junior water rights holders being prevented from using their water if doing so would impact senior water rights holders. Water users are restricted from changing the way they withdraw, divert the flows, or use their water to avoid a negative impact on existing water rights holders, including junior water rights holders.

For example, removing water from streams for placement in an ASR well is a water rights diversion that could conflict with the intent of western ASR rules. In addition, some states do not regulate groundwater except by regulations or special districts that restrict pumping levels to prevent land subsidence, so carefully laid plans might be frustrated by unregulated or unknown withdrawals by other entities. Little water law exists on how such migration of injected water would be evaluated with respect to water rights. Therefore, in a water rights state, the utility wanting to pursue an injection program may be required to acquire two water rights: one allowing it use of the source water injected and a second allowing it to withdraw that same water later. ASR facilities can apply for junior rights during times when excess water is available so they can withdraw the water from storage at times when water would typically only be available to senior water rights holders. The injection program also must demonstrate that the operations of the facility will not impact more senior water rights holders.

Water rights and permit issues change constantly with court cases and legislative actions. Refer to additional publications for more information on water rights. For example, Bernosky's *Overview of Environmental Laws and Regulations* (2011) provides an introduction to environmental laws that directly or indirectly affect water and wastewater utilities including selected state environmental regulations, riparian water rights, prior appropriation rights, and ordinances. Other resources can be found in the references section at the end of this chapter.

WELLHEAD AND SOURCE WATER PROTECTION

Wellhead protection is a potential regulatory concern for ASR programs. The protection of public water supply wells through wellhead protection programs is considered an important component of comprehensive state programs to protect groundwater from contamination. Many states have merged wellhead protection with source water protection. Other states are maintaining their wellhead protection program because of a specific federal grant fund.

Either way, the genesis of protection came in the 1986 amendments to SDWA, which increased the authority and responsibility for drinking water protection. Section 1428 of SDWA created the wellhead protection program (WHPP). Subsequent amendments in 1996 further strengthened drinking water protection by establishing the source water protection program (SWPP). Because of the duplicative nature of WHPP and SWPP, many states have replaced their WHPPs with the updated SWPPs or incorporated their WHPPs into their SWPPs. Wellhead protection areas (WHPAs) can encompass land areas with different criteria. For example, in many states protection can be enforced by a specific radius

from the wellhead location to ensure runoff from surrounding areas does not introduce contaminants that can reach the groundwater via the well bores and poorly constructed wells. In other cases, WHPA's are recharge zones or zones of contribution (ZOC) for the underlying aquifers that supply water to the pumping wells. Depending on the hydrogeological parameters, a recharge zone or ZOC for a deep drinking water well may not be contiguous to the wellhead and must be located far from the withdrawal point.

Each state must prepare a WHPP and submit it to the USEPA for approval. Many states have promulgated minimal rules, which delegate implementation of the program to local or regional entities. Consult state and local authorities regarding specific wellhead protection efforts when developing an ASR program.

Delineation of a WHPA is typically done through numeric computer modeling of groundwater travel time and pollutant (solute) transport. Numeric models can be complex and cover large areas. Within those areas, local governments often prohibit certain land uses which may conflict with the local interpretation of private property rights. In some states, private property rights laws dictate that if an outside agency's activity on the property impacts more than 10 percent of the property, the offending agency must pay. This could be a significant impediment for utilities seeking source water protection within private property boundaries. Other wellfield protection ordinances prohibit the use and/or storage of certain hazardous materials in zones around wells. AWWA has addressed wellhead protection under emergency planning for utilities and source water protection in G300 Standard for Source Water Protection. The standard is designed to provide guidance to utilities in dealing with this issue. The companion guidance document, *Operational Guide to AWWA Standard G300, Source Water Protection*, and AWWA Manuals of Water Supply Practices M21, *Groundwater*, and M50, *Water Resources Planning*, also provide discussion on numeric models.

STATE REGULATIONS FOR INJECTION PROGRAMS

During the Reagan administration (1980–1988), the federal government delegated a series of programs for administration by the states. The UIC program was delegated to 33 states, partial primacy was given to seven states, and USEPA is currently running 10 state programs. There are additional programs in various US territories, Washington, D.C., and tribal nations. For the most part, the rules set forth standards for the federal UIC program that are mirrored in the states, territories, and tribes. Where specific state rules may differ somewhat from the federal requirements, they must be at least as stringent.

UIC rules focus on the permitting aspects of an injection project. Some states add the caveat that the injectate must remain in the injection zone, and that no unapproved interchange of water between aquifers occur. ASR programs may have other caveats to address, especially where waters of impaired quality—stormwater, reclaimed wastewater, industrial wastes, and others—may have more stringent requirements. Where the UIC program was delegated to the states, significant ongoing issues often require continued input by USEPA into the program.

Where the states are involved in this activity, the regulation may be separated into two regulatory programs or agencies: one for regulation of water resources and the other for regulation of groundwater protection. In states with UIC primacy, the UIC program is typically integrated into the state groundwater protection program. However, UIC authority can be split between the environmental protection programs and oil and gas programs, especially in the western states. For ASR wells in those circumstances, UIC programs are typically regulated by an environmental protection program, but, especially in the western states, these agencies do not handle water quantity and water rights issues, so their water resources or management programs also would be involved. In some states (e.g.,

Oregon and California), state agency programs are divided into regional offices and regulated by a regional representative. While 27 states have ASR projects, Figure 2-2 shows those states with ASR activity or have ASR-specific statutes or rules, those states with no rules (that may or may not include ASR wells), and states with no rules or ASR wells. California, Colorado, Montana, South Dakota, Indiana, and Florida have UIC programs that are regulated by a joint program between the state and USEPA. Arizona, Iowa, Minnesota, Michigan, Kentucky, Tennessee, Virginia, Pennsylvania, and New York have USEPA-regulated ASR programs. All of the remaining states have ASR programs that are regulated by the state.

Washington has at least three fully operational ASR facilities and allows them to operate under temporary permits while the regulations are under development. South Carolina, Texas, and Wisconsin have developed ASR-specific rules based on experience in the state. Other states regulate ASR projects under their existing regulatory programs, although statutes or rules may be on the books that refer to ASR. California only has rules governing ASR projects that use treated effluent. Arizona has a separate regulatory program governing treated effluent ASR projects in addition to its program for raw water ASR projects. Florida has one ASR system that proposes to use treated wastewater effluent, but reclaimed water is regulated in FAC Chapter 62-610. In Kansas, the regulations were developed initially by the state water rights agency. In New Mexico, the state legislature passed the law, and the state water rights agency adopted regulations in 2013.

Only Georgia prohibits ASR wells. In 2000, the Georgia Legislature placed a moratorium on the development of ASR projects until the state could complete a study of ASR's potential environmental effects because of issues related to the Savannah River. The moratorium expired in 2014 and the state legislature continues to hold hearings on the issue. The Georgia Environmental Finance Authority (GEFA) has proposed a contract to conduct an ASR demonstration project in the southwestern portion of the state. The ASR facility would store water from a shallow aquifer in a deep, confined aquifer. GEFA will recover the water to augment local streamflow during dry portions of the year. The legislature has not yet given the go ahead to the project.

The majority of ASR systems are sought for seasonal water supplies. Seasonally available water, whether due to climate (including natural weather phenomena such as

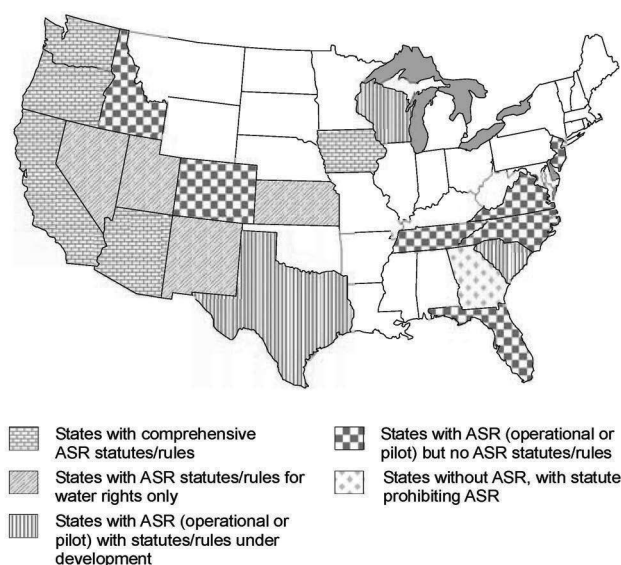


Figure 2-2 States with ASR-specific statutes or rules

Source: AWWA 2002

snow-melt) or periods of low demand, is used for injection periods, and the stored water is then recovered during another season with lower water availability and/or higher demands. Where long-term storage is expected, limitations on the amount of water that can be withdrawn after long-term storage may be set informally, based on ongoing monitoring by the ASR facility, or may formally be included in the agency permit provisions. For example, in Arizona, all ASR facilities using Central Arizona Project (CAP) water are subject to a 5 percent loss of storage per year as part of the state's efforts to recover ground-water levels in Arizona aquifers.

In some respects, the growth of rules has mimicked the growth in ASR sites nationally. Figure 2-3 shows ASR wells from the 1980s to date. As will be discussed in chapter 3, the 1990s and 2000s were active ASR periods in many states.

USE OF WATERS OF IMPAIRED QUALITY

Waters of impaired quality are nonpotable sources such as reclaimed water, stormwater, and raw water. There are no federal rules on the specific use of waters of impaired quality in Class V injection programs, so permitting of Class V wells is at the discretion of the UIC administrator (at the USEPA Region or state level). The federal regulations and many states have no specific permit requirements for ASR wells. As a result, state rules can allow the permitting and operation of Class V wells using reclaimed water as the injectate. For Class V wells, the required inventory requirement would allow the UIC administrator to determine if a specific Class V well may endanger USDWs and thus require it to be permitted. A water utility planning to develop an ASR well should discuss it with the primary agency to determine permit requirements.

ASR can be an effective and environmentally sound approach to the storage of reclaimed water for reuse systems, and would be considered a component of the overall

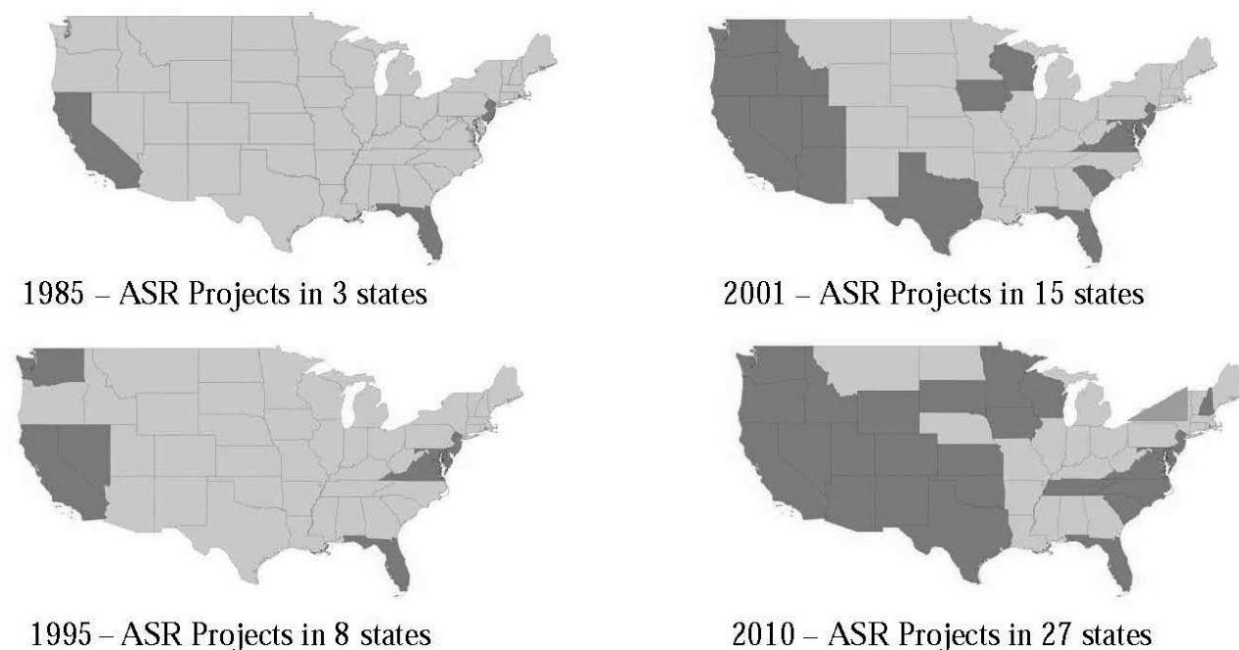


Figure 2-3 United States ASR projects from 1985–present

reuse system. Three states, California, Florida, and Arizona, specifically encourage the development of reclaimed water systems that integrate treated effluent as a part of state efforts to encourage water conservation and reuse. California has rules specifically addressing regulation of treated effluent. In Arizona, the extensive aquifer protection program encourages the reuse of effluent for nonpotable purposes, such as irrigating golf courses. Florida has one ASR system that proposes to use treated wastewater effluent (Englewood Water District, FAC 62-528).

The New Mexico Environment Department is currently exploring regulatory requirements for treated effluent ASR facilities with some water supply companies in the state. North Carolina and South Carolina regulatory staff have indicated that they would not allow ASR facilities that use treated effluent as the source water. Texas has one active reclaimed water ASR program.

ASR systems using reclaimed water must meet the technical and permitting requirements of the UIC program for Class V wells, including a construction and operation permit in addition to any permits required under the reuse rules. The water recovered from an ASR system typically must meet the quality standards for fecal coliforms before distribution.

Typically the reclaimed water recovered from the aquifer storage and recovery system will be monitored for total suspended solids (TSS), 5-day carbonaceous biological oxygen demand (CBOD₅), and fecal coliforms at the same frequency as a treatment facility providing reclaimed water to the reuse system. If reclaimed water withdrawn from an ASR system fails to meet one or more water quality standards, additional treatment, disinfection, and/or increased monitoring may be required to ensure compliance with these standards.

The distance between ASR wells using reclaimed water and potable water supply wells may pose a problem. The regulatory approach has been to require the ASR system to demonstrate that it will not adversely affect the quantity or quality of water withdrawn from the potable water supply well because confinement exists between the aquifer used for reclaimed water ASR and the potable water supply well. Some states require that the injection system be designed and operated to preclude movement of the injected reclaimed water to potable water supply wells.

Other injection programs plan for the use of reclaimed water to augment surface or groundwater resources used for public water supplies. Water quality in the receiving water and the classification of the aquifer drive the water quality of the injectate, as noted previously.

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Chapter **3**

Summary of ASR Programs in the United States

This chapter summarizes the first complete study (conducted for this manual) of all of the known ASR sites in the United States, regardless of their planning, testing, or operating status. As of July 1, 2013, a total of 204 sites have been identified. The focus of the survey was on US ASR wells because Canada has only one (see Appendix B) and Mexico has none. Outside the United States, the regulations—where present—vary widely, as do construction methods. When an apples-to-apples comparison is not applicable, methods have not been discussed, although some of these methods are discussed in other literature.

ASR SITES IN THE UNITED STATES

ASR facilities are found in 27 states, most of which have fewer than five sites (many have only one or two). Figure 3-1 shows the number of sites in each state with ASR programs. The state with the most ASR programs, either completed or in process, is Florida, with more than 50, followed by California, New Jersey, Arizona, and Oregon. These five states account for the majority of ASR programs in the nation. Notably, most ASR programs in Oregon appear to be relatively new ventures, while many of the programs in Florida and California were initiated pre-2000. Figure 3-2 shows the growth of ASR installations since the 1960s by decade. There was a marked rise in the 1990s and early 2000s, but the number of new sites added appears to have decreased.

Figure 3-1 identifies the number of ASR sites by state but does not indicate the number of wells that are currently in use in each state. The 204 total sites include wells that

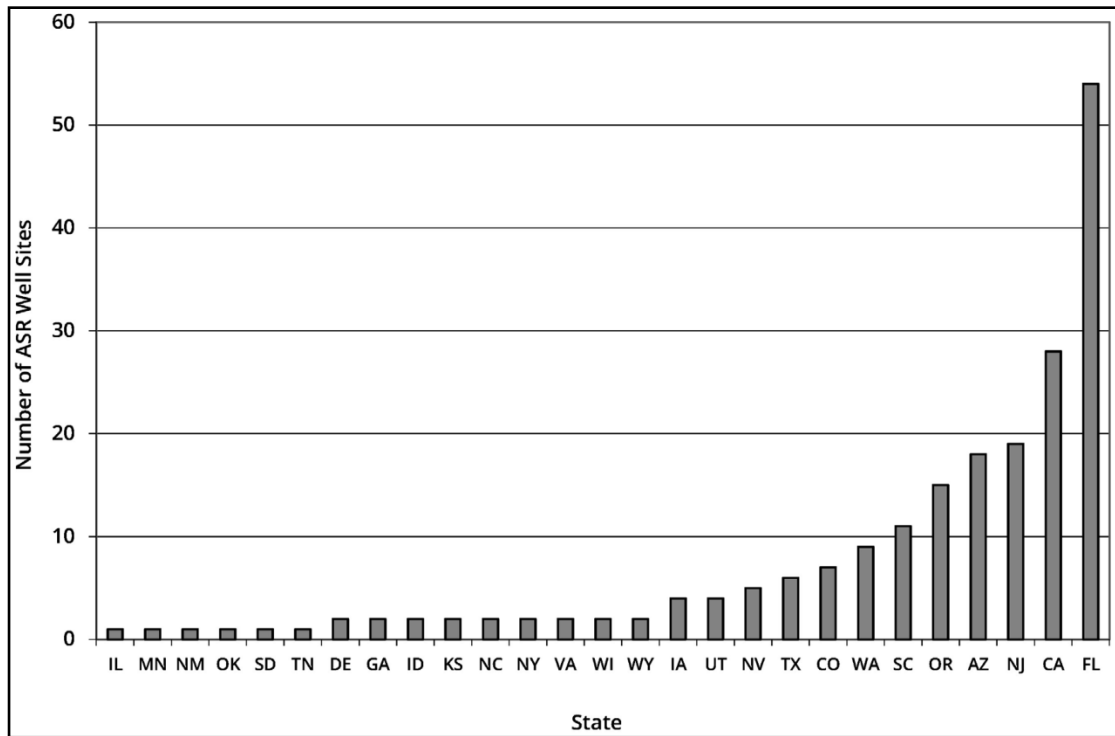


Figure 3-1 Number of ASR sites by state

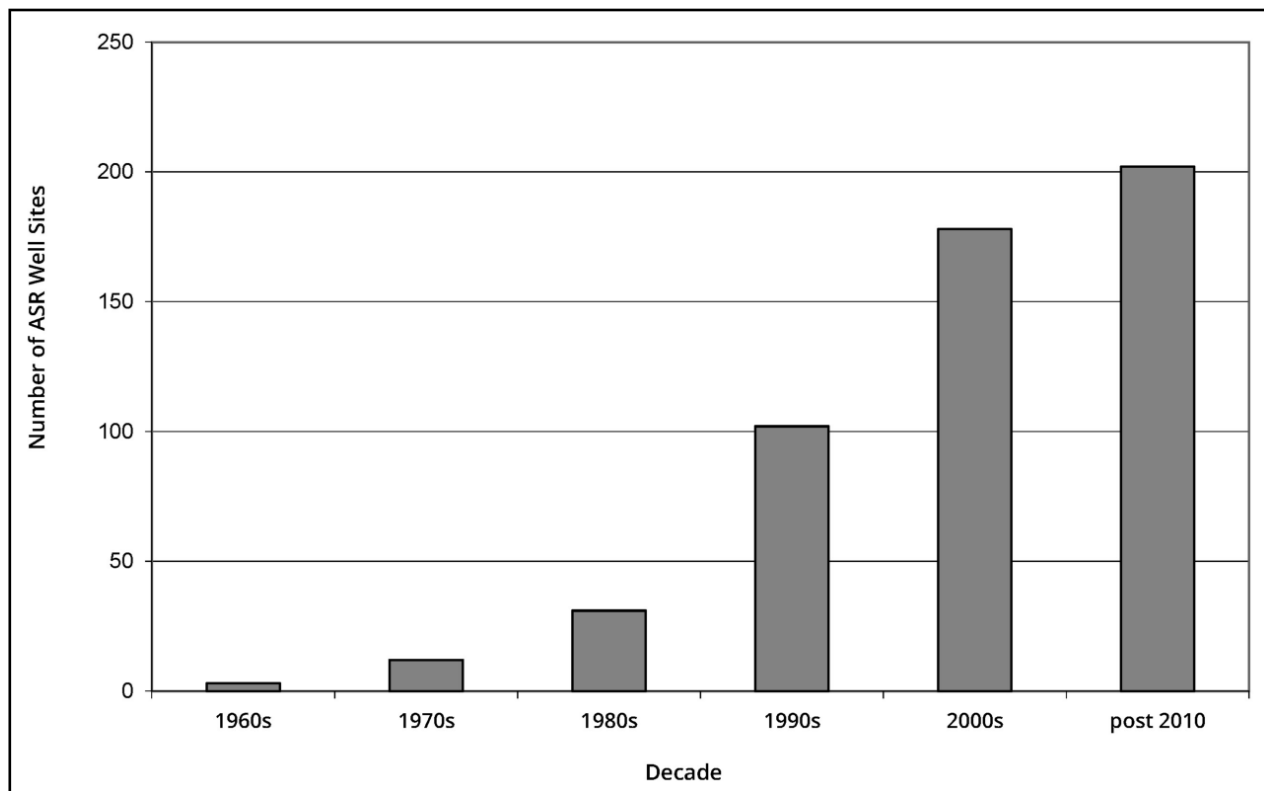


Figure 3-2 Cumulative ASR sites by decade

are no longer in service, were converted to other uses, were not pursued after testing, are dormant or inactive for a variety of reasons, or were plugged with concrete and formally abandoned. These wells are relevant because they point toward challenges encountered with the ASR concept as explored in chapter 4.

Water Use

Figure 3-3 shows the sources of water used for ASR programs, which tend to vary geographically. The largest source of injected water is surface water, followed by ground and reclaimed sources. In older projects, the ground and surface waters are normally treated to potable standards before injection. For example, Florida (groundwater) and South Carolina (surface water) have primarily focused on storing treated potable drinking water for later retrieval during peak-use seasons. In both cases most of the injected water is potable, having been treated in a water treatment facility. California has mostly used surface water flows as distributed by Metropolitan Water District of Southern California or that occur during the spring to be stored for potable water supplies during drought periods. Florida, Nevada, and Arizona use reclaimed water for irrigation purposes in some of their ASR programs.

The different uses of water recovered from ASR projects is depicted in Figure 3-4. The most common use of the recovered water is for potable purposes. Some of this water is retreated to address water quality changes introduced by the ground formation (such as metals, suspended or dissolved solids), but many potable supplies are simply disinfected and have stabilizing chemicals added. Raw water that needs to be treated is the second most common use of the recovered water.

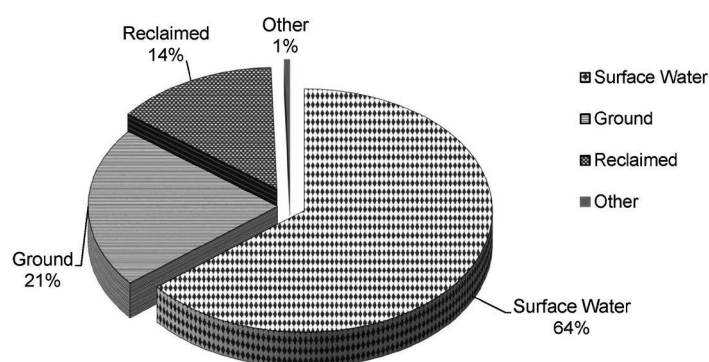


Figure 3-3 Sources of water used for ASR programs

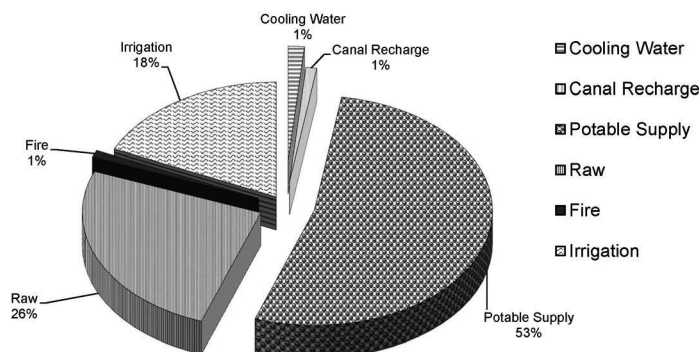


Figure 3-4 Uses of water recovered from ASR wells

Geology

ASR wells require the appropriate geology to function effectively. Important characteristics include rock matrix type and the hydraulic conductivity/transmissivity of the formation. These characteristics indicate how well water moves through the rock. Hydraulic conductivity (K , gpd/ft³ or m/s) is a measure of the ease with which fluid is transported through a porous media, while transmissivity (T , gpd/ft² or m/day) is the aquifer characteristic that is defined by the rate of flow per unit width through the entire thickness of an aquifer per unit gradient. The transmissivity of the injection horizon (zone) varies widely, but is most commonly less than 10,000 gpd/ft². More than 80 percent of the ASR systems now in use have transmissivity under 100,000 gpd/ft².

A number of different formations are preferred for injection. The most common formations are limestone and alluvial (sand and gravel aquifers of glacial origin), although sand, sandstone, and basalt formations are also used (Figure 3-5). Although data are lacking for many wells, the confining unit information indicates clay, dolomite, and shale are common (Figure 3-6). A confining unit is a low-permeability geologic unit that forms either the upper or lower boundary of a groundwater flow system. Confinement, particularly vertical confinement, is critical to success as it prevents migration of the water out of the injection horizon. The injection zone is the geological formation, group of formations, or part of a formation receiving fluids through a well.

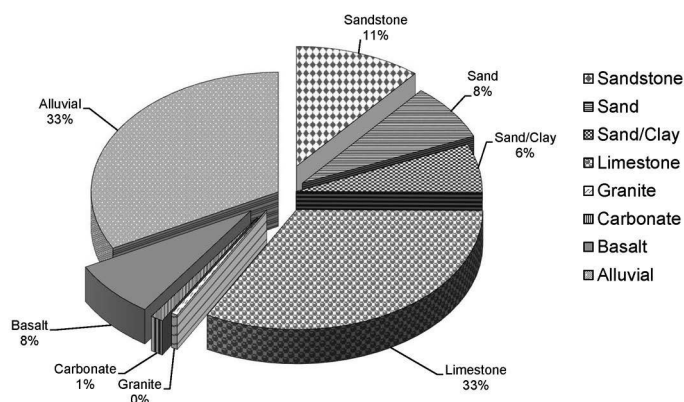


Figure 3-5 Injection horizon formation type

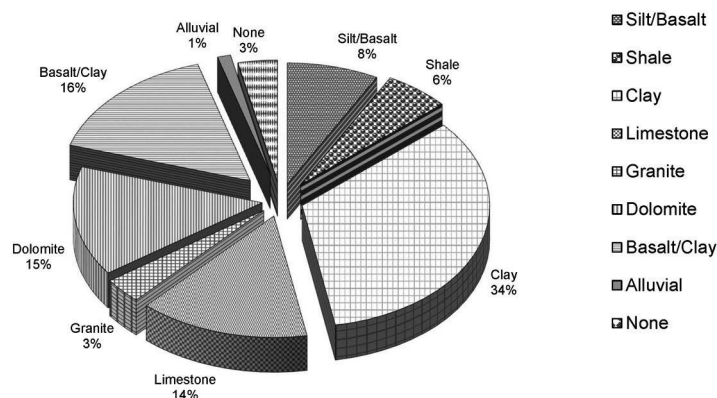
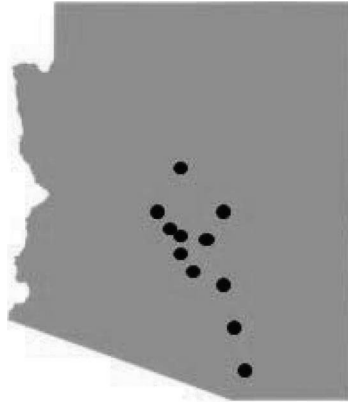


Figure 3-6 Confining unit formation type

INDIVIDUAL STATE ASR SYSTEMS

This section summarizes the ASR data collected from individual sites, by state for the period from June 30, 2012, to July 1, 2013. (When pursuing new projects, check with state regulatory agencies for more recent data.) The major issues each state faced when investigating the use of ASR are addressed to the extent possible.

Arizona

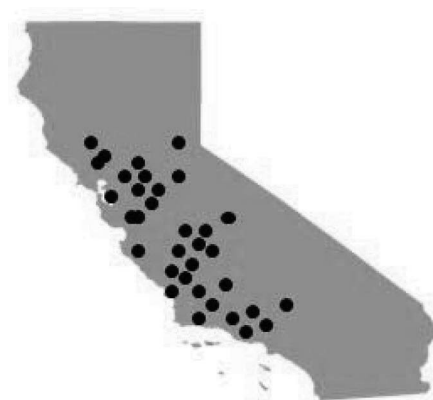


The state of Arizona has investigated the program at 18 sites. Fifty percent of Arizona's ASR projects inject raw water (i.e., Central Arizona Project [CAP] water) and the other half uses reclaimed water. Most of the projects were started in the late 1990s or early 2000s. All projects inject into alluvial sand/gravel formations, many of which are not confined. The systems are primarily in the Tucson and Phoenix areas.

Arizona has the greatest variation in construction; older wells typically are made of steel, while newer wells are constructed with PVC, stainless steel, and fiberglass casings. PVC is primarily a vadose zone (unsaturated portion of the aquifer) option. The typical well is 12 or 18 in. in diameter, but that can vary. The vadose zone wells are generally less than 200 ft deep because of large drawdowns of the aquifer from past use, but some ASR wells are deeper than 1,000 ft. Injection rates are generally under 1 mgd, although four projects were designed to inject more than 2 mgd. Withdrawal rates match or exceed the injection rates. Given the large number and age of the projects, most have had more than 10 injection/withdrawal cycles.

The oldest ASR system began in 1995 as a part of the Salt River replenishment project. Phoenix Water currently operates a large potable ASR project that has received several awards. The City of Chandler operates two ASR sites, including the largest operational system in Arizona with a total of 21 ASR wells at two sites: Tumbleweed and Ocatillo. Sun Lake City has five operational ASR wells and an additional two in development. Fountain Hills, Gilbert, Glendale, Honeywell, Peoria, Tuscon, and Gillette also have ASR projects. Of the 13 active ASR sites in Arizona, 10 use reclaimed water as their source for injectate.

California



The state of California has 28 ASR systems. The largest and oldest is Calleguas (1993) with 18 wells, followed by Goleta with 12 wells. The California ASR projects are typically designed to capture excess surface water, much of which is treated prior to injection. However, in the ensuing years excess water was rarely available, so a number of projects have not injected in years. Most projects inject into alluvial sand and gravel formations. Some are confined by clay, but many do not appear to be confined.

The typical California well has a 16-in. diameter. Well depths typically are 300 ft to 500 ft deep because of large drawdowns of the aquifer from groundwater use in the past, but four wells exceed 1,000 ft. Most California wells are constructed with perforated steel. Victorville

has an epoxy-coated stainless steel well. Injection rates are generally just under 1 mgd, although several were designed to take more than 2 mgd. Withdrawal rates range from equaling to doubling the injection rates. Fifteen projects were started in the mid-2000s, with the remaining initiated between 1990 and 2000. The number of injection cycles was difficult to determine as most are not reported. Given the limitations in the availability of excess water available from Metropolitan Water District of Southern California (the largest distributor of raw water in the state) because of drought and pricing considerations, many projects have had only limited injection. Two have converted ASR wells to raw water supply wells.

The most successful injection programs in the state, the Orange County and West Basin Groundwater Injection programs, were excluded from the survey and discussion in this manual because they do not recover water from the wells into which water is injected and thus are not true ASR systems. California has had success with ASR and continues to develop ASR projects in Santa Barbara, Foothills, Monk Hill, Long Beach, and Tracy.

Colorado

The Denver basin, which overlies four aquifers including the Arapahoe Aquifer, contains all but one Colorado ASR project. These projects inject potable water from surface water sources into sandstone or limestone formations. The typical well diameter is small (under 10 in). The Arapahoe Aquifer is far more favorable for accepting injected water than overlying formations, so the wells here tend to be deep—exceeding 650 ft for the casing and over 1,000 ft for the bottom of the well. The deepest reported ASR well is 1,538 ft, serving the East Cherry Creek Valley Water and Sanitation District.

The goal, in part, of the Colorado ASR projects is to help reverse impacts from large aquifer drawdowns from past groundwater use. Injection rates are generally under 1 mgd, with withdrawal rates about 50 percent higher. Most of the projects were started in the late 1990s and have had more than 10 injection/withdrawal cycles. The City of Centennial has continuously expanded its ASR wellfield since the 1990s, and now has 36 wells in operation. All the ASR wells in the state are steel except the newest Centennial wells, which are PVC.

Disinfection by-products were an emerging issue of ASR projects in the 1990s because of the injection of chlorinated potable water into formations that contained organics. In 1995, extensive work at the Willows Water District system (now part of the East Cherry Creek Valley Water and Sanitation District) demonstrated that trihalomethanes (THMs) dissipate in the formation with time. Since then, however, ASR exploration in the area has diminished considerably, primarily because of the lack of recovery and the ease in securing excess water in the 1990s. Douglas County, which is where the bulk of the Denver aquifer exists, is the fastest growing county in the state, and the ease in securing excess water from seasonal runoff and other sources is ending and ASR may become attractive again. Only the Centennial system is operating at more than 1 mgd, although the East Cherry Creek Valley Water and Sanitation District wells are operational.

Delaware

Delaware has two ASR projects. Both inject potable water into sand formations. The wells have a 12-in. diameter with an injection zone 250 ft to 560 ft deep. The wells are steel with stainless steel screens. Injection rates are generally under 0.4 mgd. Withdrawal rates match the injection rates. United Water's project, begun in 2008, is currently active. The Artisan project in Wilmington is listed as operational, but little information is available.

Florida



As noted, the state of Florida has more wells than any other state with installations at 54 sites. The Florida projects have injected raw, surface, ground, potable, and reclaimed waters, and as a result have the most variations of any state. Most of the wells were started in the 1980s and 1990s, but activity continues to this day. Virtually all projects inject into the limestone formations of the Upper Floridan Aquifer, although a couple of west coast systems use

limestone seams in the Hawthorn clays as injection zones.

The typical well diameters are 12 in., 16 in., and 24 in., depending on the source water and goal of the project. The depths vary with the gradient of the injection zone formation, so the wells may be only 300 ft to 400 ft deep in central Florida, but more than 1,000 ft deep in southeast Florida. In theory, all the wells are confined below clays, although data from the Class I study (Gao 2010) indicates the confinement may be limited in central Florida. The state matches Arizona in terms of the variety of construction materials, although most Florida wells are made of steel with no screens. A smattering of PVC, epoxy-lined steel, and fiberglass wells exist. Injection rates vary greatly, but most injection is at a rate around 1 mgd. Withdrawal rates from ASR wells in fresh aquifers generally matches the injection rate; in brackish aquifers, the rate may be half the injection rate because of the migration upward of the freshwater in the formation. Successful long-term projects have had 20 or more cycles.

There are several studied, successful projects in Collier County, Cocoa Beach, Peace River, Rome Avenue, and Boynton Beach, among others, and a number have undergone expansions. Where issues about recovery, metals leaching, or other problems have arisen, the ASR wells generally have had less than 10 injection/recovery cycles.

Issues have arisen at a number of the 54 ASR sites in Florida; arsenic leaching and lack of recovery from brackish aquifers are the most common. Success varies considerably even among wells that are in close proximity. For example, the ASR well in Broward County was in close proximity to the successful Boynton Beach sites, but recovery from the Broward well was poor, and it was subsequently abandoned.

ASR expansion is on hold for a number of Florida systems because of arsenic leaching. A September 2013 memorandum from USEPA to the state attempts to address this issue. The memorandum applies only to potable ASR wells and permits the state to develop a mechanism to allow withdrawal of water with arsenic levels above the 0.01 mg/L standard if other tools are in place to limit public exposure. Those measures are left to the state to determine. The memorandum also notes that the utilities must maintain control of the aquifer to prevent unintended withdrawals by others. Exactly how the utilities can demonstrate control of water injected underground remains an ongoing discussion item with the permitting agency. The order may activate a number of stalled Florida ASR projects.

Georgia

As noted in chapter 2, Georgia is the only state that has had a law that specifically prohibits ASR wells. The law was allowed to expire in early 2014 as lobbyists worked the state legislature to lift the ban because the Georgia Environmental Finance Authority (GEFA) is proposing to conduct an ASR demonstration project in the southwestern portion of the state (Flint River). This ASR facility would transfer water from a shallow aquifer to a deep, confined aquifer for storage. GEFA would recover the water to augment local stream flow

during dry months. The project is on hold until the legal issues are addressed. A potential challenge is that the formation proposed for injection is reportedly the same one that leaches arsenic in Florida. The ban has been reintroduced into the 2015 Georgia legislature.

Iowa

Iowa has the deepest ASR wells; all are over 1,500 ft deep. Four sites have installed ASR wells in Iowa. Two use treated groundwater for injection and two inject treated surface water. The two surface water sites have been in operation since the 1990s. The groundwater systems, Grimes and North Liberty, were established in 2012 and 2009, respectively. The receiving zone is sandstone with an overlying confinement of sedimentary rocks for all four sites.

The Grimes site is permitted for a well 2,110 to 2,602 ft deep in a sandstone aquifer. The injection rate is 1.1 mgd. The North Liberty site is proposed to inject into a horizon 1,575 to 1,673 ft below the surface into a sandstone aquifer. The capacity of the system is 1.1 mgd. Both wells are in the test stage.

Both surface water systems are in Des Moines and have one well each. Both wells are over 2,500 ft deep. The transmissivity is 10,000 to 30,000 gpd/ft. Both wells are 6 in. in diameter and made with steel casings. Injection rates are 1.0 and 1.5 mgd at the two sites, with recovery rate double that of the injection rate at both sites. More than five cycles have occurred at each site.

Idaho

Two sites have explored ASR in Idaho, and both have been in operation since the 1990s. One is an industrial facility (Micron Technologies) that uses the ASR-recovered water for cooling purposes. The other is a United Water–Boise project that was initiated in 1991.

The Micron Technologies project stores more than 8 billion gallons of water in three wells, which are drilled into a basalt formation. The transmissivity is 30,000 to 60,000 gpd/ft. All three wells are 8 in. in diameter and made with steel casings. Injection rates total 1.4 mgd with recovery rates of 2.1 mgd. Over 20 cycles have occurred at this site.

The United Water project was started in 1999 and includes four operating wells and one well that was deactivated due to clogging. The wells store treated surface water in a basalt formation with overlying basalt/clay layers; the injection zone is open from 70 to 220 ft below the surface. The wells are 10 in. in diameter. Only 15 million gallons of water have been stored in this project, although the capacity of the system is 1.1 mgd. Clogging is a reported issue with these wells.

Illinois

An ASR site was considered in Highland Park, Illinois, but it appears to have been inactivated before any construction occurred. There are no surviving details.

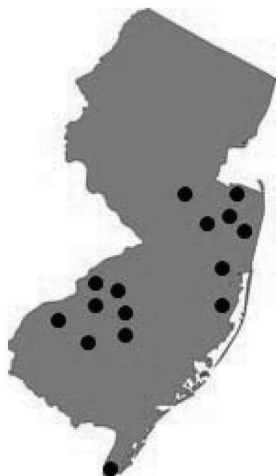
Kansas

Two sites have been investigated as potential ASR locations in Kansas, but wells have been constructed only for Wichita's Equus Beds project. The Equus Beds project includes four shallow vadose zone wells that store raw surface water in an alluvial formation in an injection zone open from 60 to 130 ft below the surface. The wells are 18 in. in diameter. Over 70 million gallons of water was stored. The injection capacity of the system is 10 mgd. The Republican River project was initiated in 2008 to investigate storing raw surface water, but no published data is readily currently available on its status.

Minnesota

The Joint Powers of Albertville utility has the only ASR well in Minnesota. It was constructed in 2007. It injects surface water into an alluvial aquifer 500 ft below the surface. The injection rate is 0.3 mgd, with recovery at 0.45 mgd. Limited information is available on the project, but it is operational.

New Jersey



New Jersey is home to the United States' oldest ASR system; the Wildwood ASR system has been in use since 1968. Currently four operational ASR wells are located there. Since its inception in Wildwood, ASR has steadily grown and is considered a viable water storage option in the state. New Jersey has 19 ASR sites, with successfully operating wells in Gordon's Corner (2), Matchaponix (1), Brick Township (1), Evesham (1), and Mt. Laurel Municipal Utility Authority (1). An ASR project in Evesham Township is no longer active. Fifteen of these systems use treated surface water as the injection source. The remaining use treated groundwater. Additional projects are being developed in New Jersey, including projects in testing as of publication in Woolrich (Aqua New Jersey) and Swimming River and in development by Moorestown Department of Public Works.

The state requires a certain percentage of water to remain in the formation and the injection/withdrawal cycles are calculated on a calendar year. Most of the projects inject into a sand or sandy clay formation. The typical well is 12 in. in diameter; most are stepped down from 18 in., so 18×12 are common notations, while 24×16 and 20×14 exist. Some of these wells store as much as 2 billion gallons of water. The average depth is 550 ft for the casing and 690 ft for the well. The deepest system is 1,756 ft at Tom's River. All but one are steel, with many having stainless steel screens. Injection rates average 1.4 mgd, with withdrawal rates averaging 1.8 mgd. Most projects were started in the late 1990s. Given the large number of projects, and the age, most have had more than 10 injection/withdrawal cycles.

Nevada

Nevada has the most ASR wells of any state outside of Florida. There are five systems comprising 125 wells in Nevada, with the largest in Las Vegas Valley (LVV), which with 87 wells is also the largest ASR system in the country. The LVV project was initiated to offset prior aquifer depletion, but limited recharge water has been available in recent years due to other demands for reclaimed wastewater, which is the primary injection source.

North Las Vegas has 10 wells. The North Las Vegas and LVV projects were started in the late 1980s. The first Truckee Meadows project started in 1990. The remaining sites in the Truckee Meadows area near Reno came on line in the mid-2000s. A total of 28 wells have been constructed near Reno. The northern Nevada ASR projects use potable water derived from surface water for injectate. All projects inject into an alluvial sand and gravel formation.

The typical Nevada well diameter is 12 in., 16 in., or 18 in., but a variety of sizes exist. The depths range from vadose zone wells that are generally under 250 ft in Washoe County (the Truckee/Reno wells), to deeper wells, up to 1,200 ft in Las Vegas Valley. All but one well (Dayton) are steel; the outlier is PVC. Injection rates are generally under 1 mgd. Withdrawal rates match the injection rates except in the Las Vegas Valley, where

withdrawal rates are lower than injection rates. The Las Vegas projects have had more than 10 injection/withdrawal cycles.

New Mexico

New Mexico has one inactive site, but significant work was done at this site. In Alamogordo, a study was conducted to evaluate historical spring flows and surface water supply that was available for injection into the La Luz wellfield aquifer and later recovered to augment the groundwater supply and provide for drought protection. One 18-in. steel-cased test well was constructed and tested. The project used potable water derived from groundwater as the injectate. The formation was limestone between 750 and 850 ft below land surface. Data at an injection rate of 0.8 mgd was collected for 30 days and a groundwater flow model was developed to simulate a full-scale ASR program. The study determined that ASR was feasible. No ASR well appears to be in place, however.

Utility managers in Rio Rancho and Albuquerque are looking at ASR in the future, but state regulatory staff did not identify either site as an ASR site.

New York

Two New York ASR projects were started more than 20 years ago on Long Island. The Bay Park investigation was conducted in 1968. The Bay Park project used potable water supplies derived from surface sources. Bay Park was a deep aquifer (418 ft to 480 ft) that clogged after 19 cycles and was subsequently discontinued. Injection rates were 0.3 mgd, while withdrawal rates were 0.6 mgd. The steel casing for the well had a 16-in. diameter. The formation was alluvial with a transmissivity of 1,000 gpd/ft².

The East Meadow ASR well used reclaimed water as the source that was injected into a surficial sand. The well had a 12-in.-diameter steel casing, open from 65 to 96 ft below land surface. Injection rates and withdrawal rates were 0.5 mgd. Fewer than five cycles occurred at this site. The transmissivity was 3,000 gpd/ft². This site is also no longer active.

North Carolina

North Carolina has two projects—one about 15 years old in Greenville and a new one that recently received a permit in Wilmington. Both projects inject potable water. About 15 years ago, Greenville was faced with a dewatered aquifer, requiring conversion to surface water supplies, and peak summer demands that required excess capacity in the system. The formerly dewatered Black Creek aquifer now acts as a reservoir for excess surface water that occurs seasonally.

The Greenville well, drilled in 1996, is a 12-in.-diameter steel well with open zones from 315 to 375 ft and 440 to 460 ft into a limestone formation. The formation has historically been productive. The well is injected at 0.4 mgd and recovers at a rate of 0.6 mgd. To date, 75 million gallons have been injected and stored. The well has been on hiatus for the last 10 years, but recent efforts to restart the well are underway. The success in South Carolina should bolster the prospects for this well because the Greenville well draws from the same aquifer (Black Creek) and suffers the consequences from the depletion of that aquifer.

The Wilmington wells are new. As of late 2014, one cycle test had been conducted in the first well and the second well was in testing. The injection rate is 1.3 mgd, with recovery at 1.9 mgd. These wells are 24-in. stainless-steel casings, with an injection horizon from 1,150 to 1,750 ft below the surface. The aquifer is listed as sand and gravel with a transmissivity of 10,000 gpd/ft.