Manual of Water Supply Practices

M63

Aquifer Storage and Recovery

First Edition

American Water Works Association

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American Water Works
Association

Contents

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.

ARTIFICAL 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.

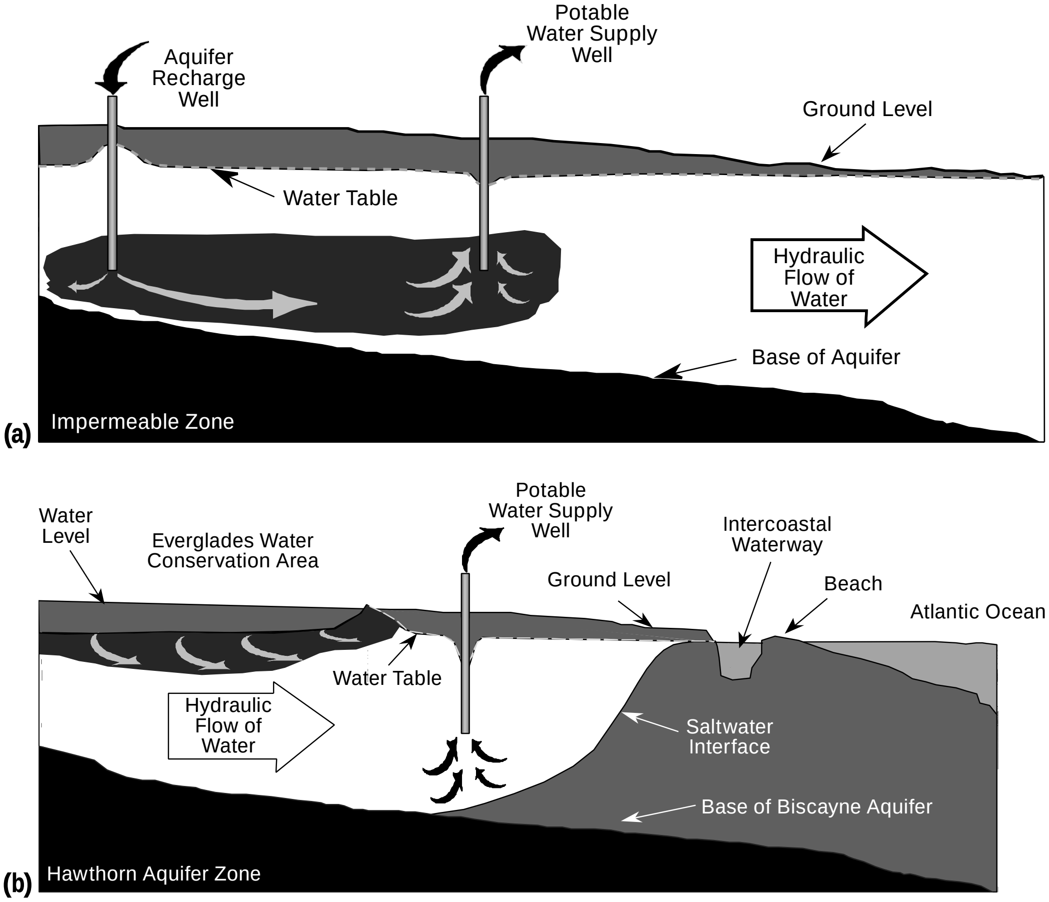

Figure 1-1 (a) Aquifer recharge; (b) Aquifer recharge via flooding

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,

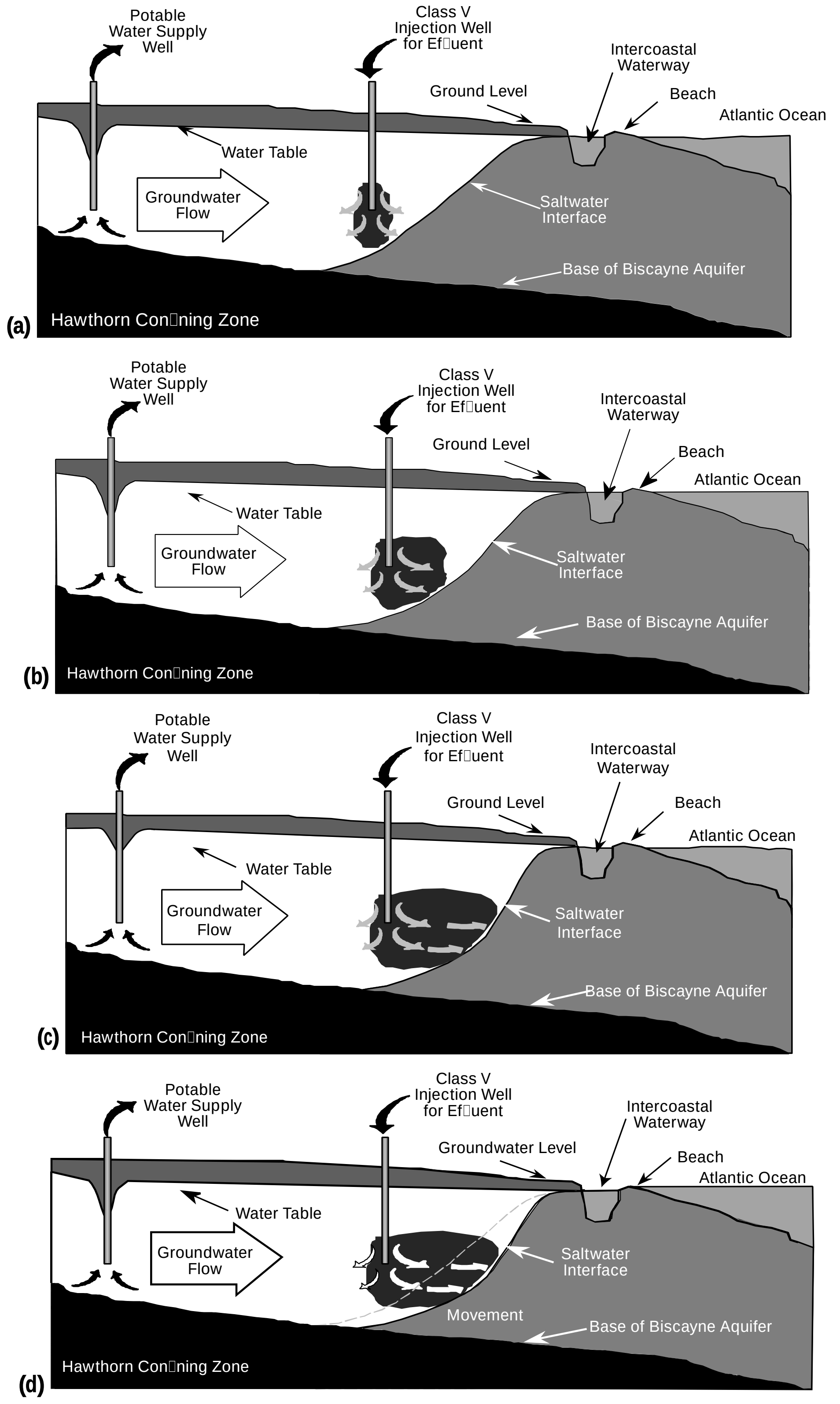

Figure 1-2 (a) Biscayne Aquifer reclamation after start of injection; (b) Biscayne Aquifer reclamation water movement after injection; (c) Biscayne Aquifer reclamation water movement toward saltwater after injection; (d) Biscayne Aquifer reclamation water movement pushing isochlor line toward the ocean

Source: *AWWA 2014*

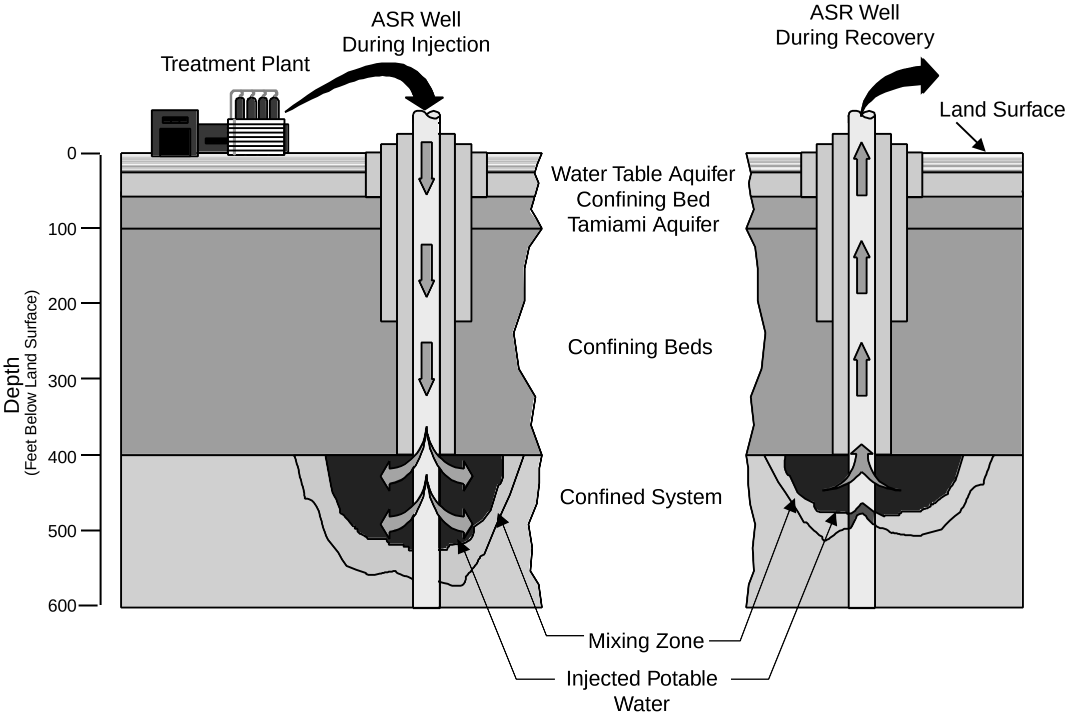

Figure 1-3 Aquifer storage and recovery conceptual diagram for brackish water aquifers where freshwater bubble creates mixing transition zone that increases with time

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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