Aquifer Storage and Recovery Case Study

Site: Des Moines and Ankeny, Iowa

Highlights

"DMWW became acutely aware of how reliant it was on a single treatment plant when it was unable to provide water to customers for 11 days during the flood of 1993."

-As stated in Miller and Beaver (1997)

- The Des Moines Water Works (DMWW) is a regional municipal water utility that supplies water to 500,000 people in central Iowa.
- The DMWW expanded its water production capabilities after the 1993 flood to avoid future production crises which included the establishment of five Aquifer Storage and Recovery (ASR) wells in collaboration with the City of Ankeny Water Utility.
- The five ASR wells maintained by the DMWW and the City of Ankeny Water Utility all exceed a depth of 2,500 ft and are some of the deepest ASR wells in the world.
- The recharge water sources for the ARS wells are treated potable water from the DMWW water treatment plants.
- The ASR wells are permitted under the EPA Underground Injection Control (UIC) Program and also must comply with permits required by the state including approval of engineering drawings and specifications, management of stored and recovered water, and a National Pollutant Discharge Elimination Standard (NPDES) permit.

Summary

The Des Moines Water Company was established as a private company in 1871 to provide a stable supply of water to the city of Des Moines, Iowa. The company continued to function privately with different owners and managers until 1919, when the city bought the water company, changed the name to Des Moines Water Works (DMWW) and converted it to a public utility owned by ratepayers. The first DMWW water treatment plant (Fleur Drive site) was constructed in 1948. Levees were constructed around the treatment plant in 1950 and fluoridation of water was initiated in 1959. The DMWW had already identified the need for additional water treatment capacity during long range planning conducted in 1991 and 1992 (Miller and Beavers, 1997). The urgency of expanded water treatment capacity became obvious in the wake of the historic flood of 1993 which resulted in water levels that breached the levees surrounding the treatment plant (Figure 1; DMWW, 2013). This prevented access to tap water for 11 days and safe drinking water for almost three weeks for 250,000 customers (Thompson, 2018).

The DMWW pursued development of additional treatment and storage capacity to avoid similar crises situations in the future. This strategy was described in a Regional Water Supply Reliability Study published in 1994 that included expanded water treatment plant capacity and development of additional storage via ASR wells (Miller and Beavers, 1997). This ultimately resulted in ASR well development as described below and two new treatment plants:

(1) the 25 million gallon per day (MGD) Maffitt Lake facility in 2000, which was renamed the L.D. McMullen Water Treatment Plant in 2007, and (2) the 10 MGD Saylorville Water Treatment Plant in 2011, which serves customers in the northern part of the DMWW distribution network. The DMWW is now a municipal water utility owned by the 500,000 customers who live within the greater Des Moines area, and is the largest such utility in Iowa and among the largest 100 utilities in the United States. Further details regarding these and other aspects of DMWW historical development are reported at Wikipedia (2020) and DMWW (2020a; 2020b).

Figure 1. Aerial photo of Des Moines Water Works (foreground) inundated with flood water during record breaking 1993 flood event (Source: DMWW, 2013).

Initial ASR well testing and development

The initial exploration of ASR feasibility within the overall DMWW system focused on the conversion of a 1961 production well that was extended to a depth of 2,700 ft in the Jordan Sandstone aquifer (Bates, 2007)(Figure 2). The well was previously used by the City of Ankeny Water Utility but was abandoned in 1992 when the utility became a wholesale customer of the DMWW (Bates et al., 2007). Approval to pursue testing was granted by the U.S. Environmental Protection Agency (USEPA) through a demonstration grant that was issued in 1995 under the Safe Drinking Water Research and Demonstration Program (Miller and Beavers, 1997). The overall testing process was performed during 1995 to 1998, using the deepest aquifer that had ever been tested for an ASR well up to that time (Bates et al., 2007). Conversion of the production well to an ASR well was completed in spring 1997, followed shortly by initial testing (Miller and Beavers, 1997).

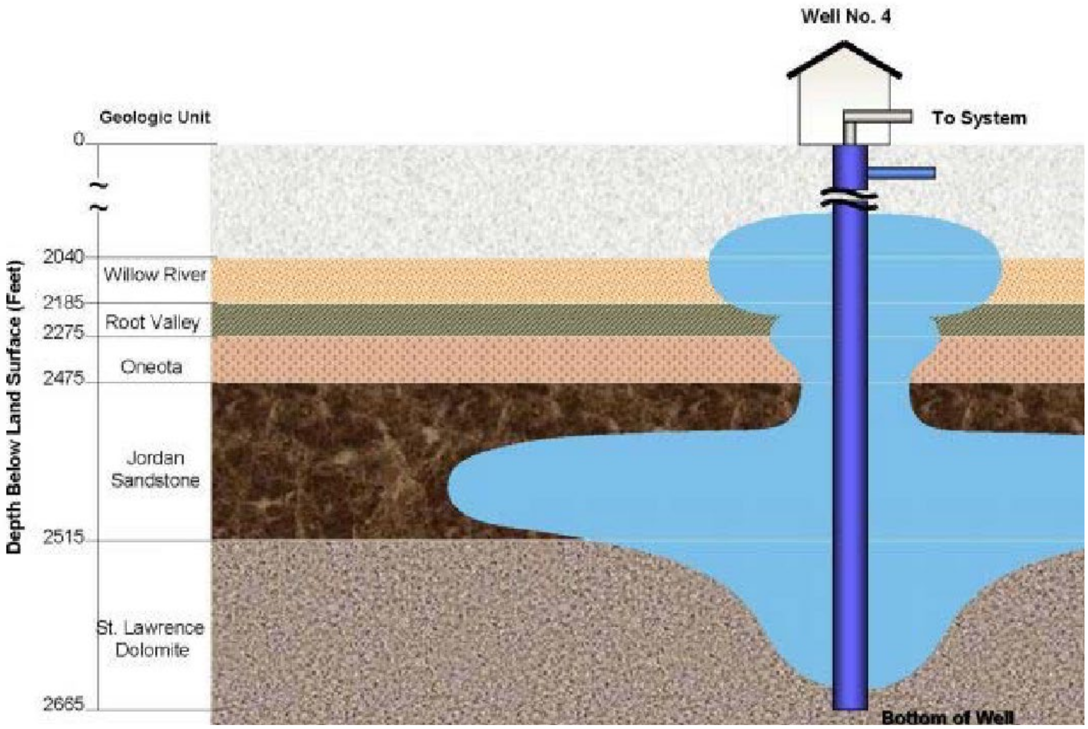

Figure 2: Generalized Stratigraphy for the ASR wells; hypothetical volumes of stored water in the aquifer is represented in light blue (Source: DMWW, 2018).

Testing of the ASR well focused on several parameters:
1) Water must remain potable after interaction between treated recharge water and existing aquifer water,
(2) determination if disinfection or other treatment would be needed for recovered ASR water, (3) economic feasibility of the process, and
(4) resolution of regulatory and permitting issues
(Miller and Beavers, 1997; Bates et al., 2007).

This was accomplished in two phases. Phase one was a preliminary feasibility study that evaluated the geological and geochemical adequacy of the Jordan a quifer to support ASR wells, and phase two was a series of complete recharge, storage and recovery cycle tests of the Ankeny ASR well (Miller and Beavers, 1997).

The feasibility study was conducted on the basis of a potential DMWW system-wide expansion that envisioned the incorporation of multiple ASR wells (Miller and Beavers, 1997). A key goal was to determine the number of ASR wells and corresponding aquifer storage that was needed to meet an emergency goal of 30 MGD over a 90-day period. A water-quality analysis of 30 constituents was performed which indicated that the Jordan aquifer was suitable for hosting ASR and that problems would not be expected based on the composite chemistry of the recharge and aquifer water. The feasibility study also reported that 15 ASR 2-MGD capacity wells: (1) could inject 3.7 billion gallons into the Jordan aquifer to meet the emergency goal; (2) could increase seasonal peak capacity by 20 MGD for up to 48 days, and (3) could be developed for roughly

$0.53/gallon/day of peak capacity if converting existing production wells and installing additional wells.

The tests of the Ankeny ASR well were initiated in April 2007 and designed to be performed over a period of 10 months in a series of three relatively short cycles followed by a cycle test that reflected a full season of operation (Miller and Beavers, 1997; Bates et al., 2007). The first two cycles required between 8 to 16 days and achieved an 85% recovery rate resulting in the conclusion that the third short cycle did not need to be executed (Bates et al. (2007). The full production cycle was then conducted which included 128 days of recharge, 30 days of storage and 67 days of recovery, which resulted in an 70% overall recovery rate which was considered successful for an initial complete test (Bates et al., 2007). Further confirming the success of the Ankeny ASR well demonstration was: (1) the absence of adverse geochemical reactions, (2) satisfactory water quality of the recovered water, (3) no discernible impacts on the Jordan Aquifer or other wells in the region, and (4) a recharge storage bubble or target storage volume (Figure 3) that was limited to a radius of 270 to 380 ft (Bates et al, 2007).

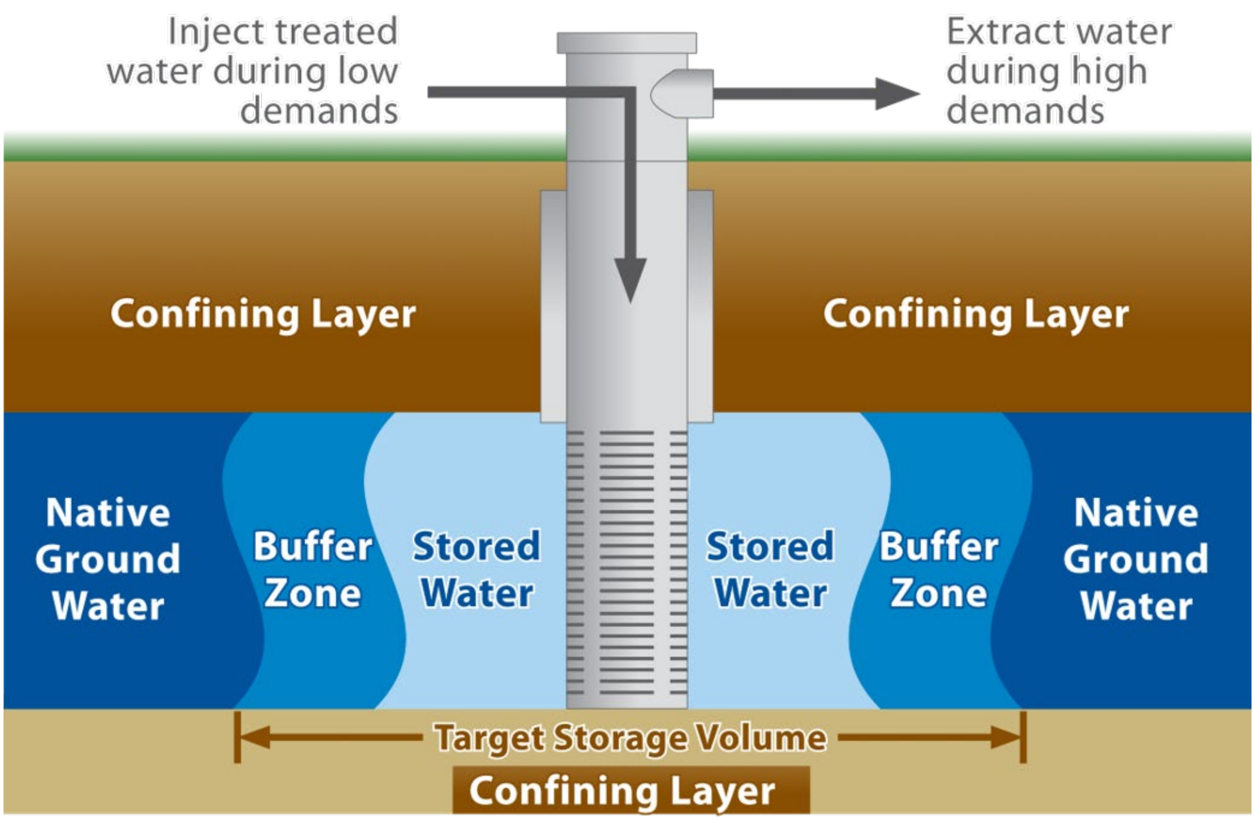

Figure 3. Schematic of injected recharge water, target storage volume (stored water and buffer zone) in confined aquifer, and recovery during high demand periods (Source: TWRD, 2019).

Current DMWW ASR wells

The success of the original Ankeny ASR well resulted in additional ASR wells within the DMWW water distribution system, although not as many as were envisioned in the original feasibility study. At present, five ASR wells are in operation within the overall DMWW system including three that are managed by the DMWW and two that are managed by the City of Ankeny Water Utility (Table

1). These wells all extend at least 2,500 feet into the Jordan Sandstone and St. Lawrence formations (Figure 2) and are the deepest ARS wells in the world, with the exception of an ARS well constructed by Polk County Utilities in Florida that is drilled to a depth of 2,944 feet and is used for reclaimed (non-potable) water purposes (Gierok et al., 2015). The recharge water sources for the ARS wells are the DMWW water treatment plants; e.g., Saylorville water treatment plant for Well #4 and Well #6 (Buckner, 2020). The recharge water rates range from 737 gallons per minute (gpm) for Well #4 to 1,725 gpm for the three DMWW wells (Table 1). The design production capacity of the wells vary from 1.5 MGD for Well #4 to 3.0 MGD for the other four wells (Table 1), although the operation capacities for Well #4 and Well #6 are 1.32 and 2.7 MGD, respectively (Buckner, 2020). Recovery rates currently vary considerably between the five wells for the water extraction process (Figure 3) and are highest for the longest operating wells (e.g., Well #4 and Well #6). For example, the recovery rates for Well #6 (Table 1) gradually increased from 54% to 89% between 2011 and 2016 and have stabilized at about 95% during 2017 to 2018 (Buckner, 2020).

Geosam #	Well owner	Well name	Drilling date	Bedrock depth (ft)	Well depth (ft)	Total depth (ft)	Recharge rate (gpm[b])	Production Capacity (MGD[b])
59746	DMWW	LP Moon ASR	11/04/2004	115	2,674	2,674	1,725	3.0
63127	DMWW	McMullen Treatment Plant ASR	12/20/2006	50	2,518	2,518	1,725	3.0
81129	DMWW	Army Post Road ASR Well	01/29/2016	28	2,525	2,525	1,725	3.0
12574	City of Ankeny	Well #4 (ASR #1)[c]	06/22/1961	140	2,522	2,715	737 to 770	1.5[d]
64763	City of Ankeny	Well #6 (ASR #2)[c]	03/12/2008	270	2,530	2,530	1,195 to 1,215	3.0[d]

[a]Source: IDNR (2020a; 2020b)
[b]gpm = gallons per minute; MGD = million gallons per day
[c]Well #4 and Well #6 are the names used by the City of Ankeny Water Utility (Buckner, 2020); the names in the parentheses are additional names listed by IDNR (2020b).
[d]Production capacities = 1.32 and 2.7 MGD for Well #4 and Well #6, respectively (Buckner, 2020).

Table 1. Well owner, name, drilling date and depths for DMWW/Ankeny ASR well cluster[a]

Policy Connections

The Ankeny ASR well (Well #4, Table 1) was permitted under the EPA Underground Injection Control (UIC) Program as a Class V injection well, based on relatively strict criteria due to the fact that it was the first ASR well in EPA Region VII (Miller and Beavers, 1997). The permit requirements included: (1) "*Identification of all useable sources of groundwater near the site", (2) "an inventory of all wells within a 1-mile radius", (3) "calculations showing the fracture pressure of the storage zone", (4) "a mechanical integrity test on the ASR well casing", and (5) "full Safe Drinking Water Act water quality parameter analytical results for each recharge period.*" (Miller and Beavers, 1997) Ultimately, the USEPA granted a UIC operating permit for a period of five years for Well #4.

The DMWW also had to comply with other permits required by the state including approval of engineering drawings and specifications, management of stored and recovered water, and a National Pollutant Discharge Elimination Standard (NPDES) permit for water discharged to a storm sewer during the demonstration test (Miller and Beavers, 1997). Current Iowa regulations for aquifer injection wells were established after the completion of the demonstration test in 1999 (EPC, 1999), which were largely adopted from regulations previously developed in Nevada and Oregon (Anderson, 2020). The regulations focus primarily on oversight of ASR wells used for potable water purposes and cover 10 different categories as follows (repeated verbatim from EPC, 1999): (1) "aquifer pretesting", (2) "engineering report", (3) "hydrogelogic evaluation", (4) "protection of nearby existing water sources", (5) "MCL exceedance limitation", (6) "reporting and record keeping", (7) "follow-up analysis by permittee", (8) "vacating a permit for failure to construct and nonuse", (9) "mechanical integrity", and (10) "revocation." Iowa ASR wells must also comply with USEPA Region 7 UIC requirements (USEPA, 2020).

Economic considerations

Miller and Beavers (1997) reported original cost estimates for ASR well adoption in the DMWW water distribution system which assumed average construction costs of $1.05 million for an ASR well that had a recovery capacity of 2 MGD. However, the final construction cost of the second City of Ankeny Water Utility ASR well (well #6, Table 1) was approximately $3 million (Anderson, 2020), which can be partly attributed to a higher capacity of 3 MGD. Similarly, the original construction cost estimate for the Army Post Road ASR well (Table 1) was $3,591,132 in December, which was revised to $4,281,000 in May 2016 and ultimately cost $6.1 million (DMWW, 2016; 2018). However, it is also important to note that the City of West Des Moines and West Des Moines Water Works paid $4.655 million of the total Army Post Road ASR well construction costs (DMWW, 2018). The cost increase trends experienced by the DMWW underscore the need to factor in inflation of material costs and other factors for utilities contemplating development of ASR wells.

Several operational costs must also be accounted for in the annual operation of the ASR wells within the DMWW water-distribution system. For example, annual water-quality-testing costs for Well #4 and Well #6 are approximately $3,900, and the annual electric cost per million gallons of treated water ranges from roughly $325 to $392 between Well #4, Well #6 and the Army Post Road ASR well (Buckner, 2020). The costs of injecting recharge water and subsequently recovering drinking water also vary between wells and between years. Considering Well #6 as an example, the annual costs per thousand gallons during 2011 to 2019 ranged between $196,656.68 (2012) to $344,871.34 (2019) for the injection process versus $8,749.44 (2017) to $106,924.36 (2011) for the recovery phase.

The operation of the ASR wells can also provide an economic benefit owing to the ability to mix the treated water extracted from the Jordan aquifer with surface water obtained from the Raccoon and Des Moines rivers. This blending process results in dilution of surface water nitrate concentrations during the spring or other periods of high nitrate flux in the surface water (Rash, 2020). This in turn can reduce the need for operation and associated expense of the DMWW nitrate removal system, which is the largest system of its kind in the world (White, 1996; McMullen, 2008).

Future projections

It was originally envisioned that the DMWW and City of Ankeny Water Utility would collectively develop upwards of 15 Jordan aquifer ASR wells (Miller and Beavers, 1997; Bates et al., 2007). To date that target has not been achieved. However, the five ASR wells that have been constructed (Table 1) underscore the importance of the technology in the DMWW water distribution system. Up to 450 mg of treated water can be introduced to the aquifer through each of these wells during the low demand period over the winter months (DMWW, 2018). The water can then be extracted during the high demand summer months and distributed throughout the water system to customers throughout the DMWW service area. Well #4 (Table 1) is nearing the end of its lifespan and will need to be replaced within the decade (Buckner, 2020; City of Ankeny, 2018). The City of Ankeny has published initial plans to also replace Well #6 (Table 1) and to construct a third ASR well by 2055 (City of Ankeny, 2018).

A key aspect of the DMWW's development of ASR wells has been its close relationship with other water utilities in the greater Des Moines metropolitan area. This can be clearly seen with the two ASR wells that have been constructed and managed by the City of Ankeny Water Utility.
A similar relationship has also developed with the City of West Des Moines and West Des Moines Water Works, who covered the majority of the Army Post Road ASR well construction costs as noted above. Further collaboration has occurred between the DMWW and other central Iowa water utilities through the Central Iowa Drinking Water Commission (CIRDWC), which was established in 2001 to facilitate collaborative efforts among 22 communities in the Des Moines metropolitan area regarding water needs (CIRDWC, 2016). Discussion has intensified during the past few years within CIRDWC regarding the need for a regional water production utility (CIRDWC, 2016; Cannon, 2019). The formation of a regional utility may prove to have implications per the adoption of additional ASR wells in the metropolitan region

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