AQUIFER STORAGE RECOVERY IN THE SANTEE LIMESTONE /BLACK MINGO AQUIFER, CHARLESTON, SOUTH CAROLINA, 1993-2000

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Abstract. The U.S. Geological Survey is investigating the potential for implementation of several Aquifer Storage Recovery systems on the Charleston, South Carolina, peninsula. A pilot study, conducted in the Santee Limestone/Black Mingo aquifer during 1993-95, indicated that the recovery efficiency, based on the national drinking-water standard for chloride, varied between 38 and 61 percent during nine Aquifer Storage Recovery cycles. A second study, initiated in 1998 at a site in downtown Charleston, is evaluating the geochemical and hydrologic effects of storing potable water in the aquifer for 1 to 6 months. Preliminary results from cycles with 1-month storage periods indicate recovery efficiencies as great as 81 percent. Decreased transport time from the production well to observation wells has been observed, indicating a probable increase in the permeability of the aquifer. Analysis and geochemical modeling of water-quality data collected from the site wells are planned to determine the dominant geo-chemical reactions taking place during Aquifer Storage Recovery cycling in the aquifer.

INTRODUCTION

The primary source of potable water for the city of Charleston, S.C., is treated surface water from the Edisto and Back Rivers. Although the Charleston Commissioners of Public Works (CCPW) has a treatment capacity that far exceeds normal demand, there is concern that demand may exceed delivery capacity in the event of damage to the water-distribution system. For this reason, the CCPW, in cooperation with the U.S. Geological Survey (USGS), is evaluating the geochemical and hydrologic effects of an Aquifer Storage Recovery system on the Charleston peninsula.

Aquifer Storage Recovery (ASR) is the concept of storing injected water in an aquifer for later recovery. A typical ASR system consists of at least one production well that is open or screened in the aquifer of interest. The production well is equipped with an injection line to transport water from land surface to the aquifer through the screens or open-hole portion of the well, and a pump to transport the water from the aquifer back to the land surface. Screened or open-hole observation wells are located near the production well to assess the spatial distribution of injected water and to sample injected water.

The feasibility of ASR technology to store potable water was tested at a pilot site located in Charleston, west of the Ashley River (fig. 1) between 1993-95 (Campbell and others, 1997). During this pilot investigation, nine successive cycles (injection, storage, recovery) were conducted to evaluate hydrologic and water-quality changes resulting from injection of treated water into the Santee Limestone/Black Mingo (SL/BM) aquifer.

Pilot study results showed that ASR implementation on the Charleston peninsula is feasible, with recovery of potable water that ranged between 38 and 61 percent of the total volume injected (Campbell and others, 1997; Mirecki and others, 1998). During the pilot project, storage typically was short, with durations less than 6 days. Significant questions, however, remained unanswered after completion of the pilot project involving (1) injectant water-quality changes during long-term storage, (2) changes in hydraulic properties of the SL/BM aquifer resulting from injection, and (3) the feasibility of ASR methods in the SL/BM aquifer on the Charleston peninsula, approximately 2 miles east of the pilot site (fig. 1).

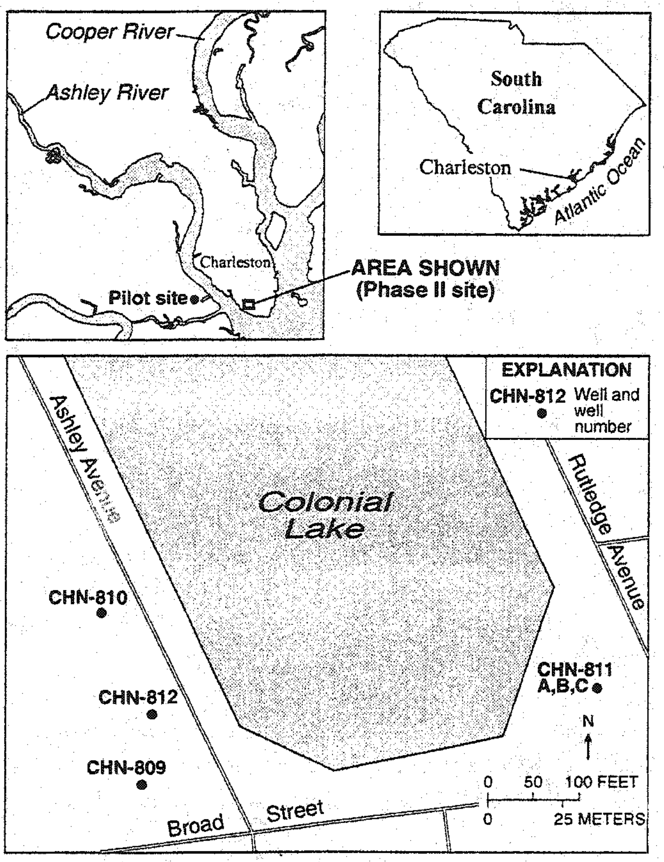

Figure 1. Aquifer Storage Recovery site and well locations, Charleston, South Carolina.

This paper describes the results of an ASR investigation (Phase II) in downtown Charleston. The investigation results include water quality and hydraulic properties for two complete ASR cycles with 1-month storage periods. The Phase II study will define the approximate percentage of potable water that is retrievable with long-term storage in the SL/BM aquifer, and indicate how the mixing of the two water bodies affects the water quality of the recovery water. In addition, this study will evaluate geochemical processes during long-term storage and quantify any changes in the SL/BM aquifer properties in the Charleston area resulting from ASR implementation.

HYDROGEOLOGY

The SL/BM aquifer consists of fracture-dominated semi-consolidated sandstone, and interlayered crystalline limestone characterized by carbonate rock-type solution openings. The aquifer is confined by the underlying Black Creek confining unit and the overlying SL/BM confining unit, which is a 340-foot (ft) thick section comprising the Cooper Group and Cross Formation (fig. 2). The SL/BM aquifer is the northernmost equivalent of the Floridan aquifer system (Park, 1985). Transmissivity of the SL/BM aquifer varies regionally between 130 and 3,700 feet squared per day (Aucott and Newcome, 1986; Campbell and others, 1997; Newcome, 1993; Park, 1985). Storage coefficients between 1.0×10^{-4} and 5.5×10^{-4} have been reported for this aquifer (Campbell and others, 1997; Newcome, 1993). Overall, aquifer properties of the SL/BM aquifer are not well documented on the Charleston peninsula and these properties can be expected to change during ASR testing. The change and rate of change in aquifer properties requires quantification.

PHASE II INVESTIGATION

In 1998, a second ASR system was constructed on the Charleston peninsula to investigate changing hydraulic properties and water quality during long-term (1- to 6-month) storage of injected water. The second ASR site consists of a single production well (CHN-812) and three observation wells (fig. 1). The production well is equipped with a 4-inch injection line and a 25-horsepower pump, is cased with ductile steel, and is screened at the same intervals as the observation wells. Observation wells CHN-809, CHN-810, and CHN-811 are installed at distances of 76, 122, and 487 ft, respectively, from the production well, specifically to facilitate aquifer hydraulic-property characterization and also to monitor injected water movement and water-quality changes occurring during ASR cycles. Two observation wells are instrumented with probes to measure water-quality properties within the permeable zones. Water-quality samples are obtained from the discharge line at the production well head, and also directly from the permeable zones in the observation wells. A piston-driven submersible pump and low-flow (micropurging) sampling techniques (U.S. Environmental Protection Agency, 1995) were used to ensure the collection of representative ground-water samples.

Each ASR cycle consists of an injection, storage, and recovery period. The length of the injection phase—volume of injected water—is determined by the breakthrough of "fresh" (low chloride concentration) water at the proximal observation well CHN-809 (fig. 1). Water from the SL/BM aquifer contains chloride concentrations of about 2,000 milligrams per liter (mg/L). Treated drinking water, with chloride concentrations of 22 mg/L, is injected at an approximate rate of 11 gallons per minute (gal/min). Injection proceeds until

System	Series	Geologic formation		Aquifer or confining unit	Character of material	Thickness, in feet
Quaternary	Pleistocene	Wando Formation		Surficial aquifer	Gray, fine quartz sand to shelly-clayey sand	40
Tertiary	Miocene	Marks Head Formation		Santee Limestone/ Black Mingo confining unit	Gray, sandy clay to shelly-clayey sand	342
	Oligocene	Ashley Formation	Cooper Group		Greenish-yellow sandy calcareous clay	
	Eocene	Parkers Ferry Formation				
		Harleyville Formation				
		Cross Formation			White fossiliferous calcilutite	
		Santee Limestone		Santee Limestone/ Black Mingo aquifer	Light-gray sandy fossiliferous limestone	70
	Paleocene	Williamsburg Formation	Black Mingo Group	Black Creek confining unit	Gray to black micaceous, calcareous clay; calcareous, silty clay; clayey sand	373
		Rhems Formation				
Cretaceous	Upper	Peedee Formation				

Figure 2. Generalized stratigraphic and geohydrologic correlation chart for Charleston, South Carolina.

the chloride concentration decreases below the U.S. Environmental Protection Agency (USEPA) National Drinking Water Standard,. Secondary Maximum Contaminant Level (SMCL) for chloride (250 mg/L) (U.S. Environmental Protection Agency, 1988) at well CHN-809 (fig. 3). Breakthrough curves are defined using specific conductance trends measured by probes placed within the permeable zones, supplemented with water-quality data from ground-water samples collected weekly at depths of 370- and 430-ft below land surface. The duration of storage is 1-month, 3-months, or 6-months, during which water-quality samples are collected biweekly from the observation wells. Injected water is recovered at a pumping rate of about 130 gal/min. Recovery continues until samples show chloride concentrations and specific conductance values equal to pre-test conditions. Water-quality samples are collected biweekly from the observation wells and the production well head during the recovery stage.

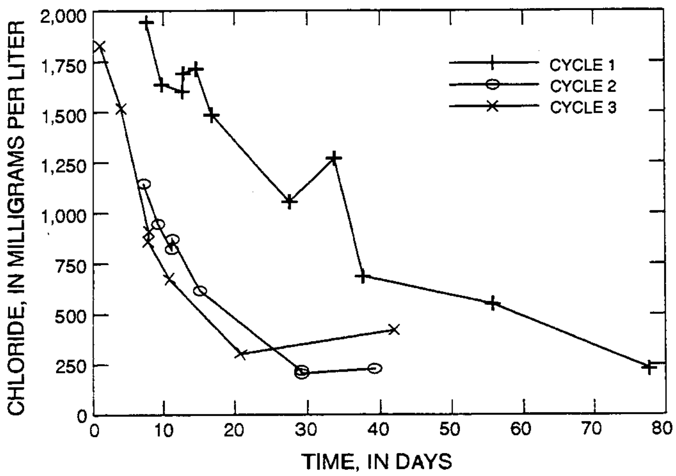

Figure 3. Dissolved chloride concentrations collected from well CHN-809 during the injection phases of Aquifer Storage Recovery cycles 1-3, Charleston, South Carolina.

PRELIMINARY RESULTS

As of December 2000, two complete ASR cycles (with 1-month storage periods) and the injection phase of a 3-month storage cycle have been completed. During the second ASR cycle, chloride concentration decreased to the USEPA SMCL more rapidly (29 days) during breakthrough at well CHN-809 than the first ASR cycle (78 days). Injection during the third ASR cycle required the same amount of injecting time for the freshwater breakthrough as the second cycle. Injected water appears to be moving through the ASR system (from production well to observation well CHN-809) faster with successive injections, suggesting that permeability is enhanced by mineral dissolution. This decreased travel time also was observed during the pilot ASR project (Mirecki and others, 1998).

Enhancement of aquifer permeability is also suggested by increases in recovery efficiency with successive ASR cycles (table 1). Recovery efficiencies during the Phase II investigation are relatively higher than those measured during the pilot study. Whether these higher efficiencies are due to the lower injection rates, greater volume of injected water, differences in the design of the production wells (open-hole well construction at the pilot site), or longer storage periods has yet to be determined.

CONTINUATION OF PHASE II ASR TESTING

Upon completion of ASR cycles at the downtown site, Phase II investigation results will be used to determine whether SL/BM aquifer properties are enhanced or degraded during long-term storage of treated drinking water. Water-quality characteristics measured during storage periods of increasing duration will allow quantification of reaction rates between water and aquifer material. The USGS geochemical model code PHREEQC (pH-redox-equilibrium; Parkhurst, 1995) will be used to quantify the extent and rate of dominant geochemical controls on water quality, including carbonate and silicate mineral dissolution, and sulfate reduction.

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Table 1. Recovery efficiencies during selected aquifer storage recovery cycles (ASR) at the pilot and Phase II study sites, Charleston, South Carolina, June 1994 to September 2000

ASR cycle number	Dates	Volume injected (gallons)	Storage period (days)	Volume of potable water recovered (gallons)	Total volume recovered (gallons)	Recovery efficiency (percent)	Injection rate (gallons per minute)	Withdrawal rate (gallons per minute)
Pilot test 1	06/06/94 – 06/07/94	15,132	0.33	5,789	19,014	38	30	130
Pilot test 9	09/07/94 – 09/17/94	160,154	6	86,186	153,744	54	40	135
Phase II—1	10/26/00 – 04/10/00	1,233,926	30	650,720	8,367,879	53	11	140
Phase II—2	05/08/00 – 09/11/00	623,753	34	508,032	8,970,454	81	11	128