SIMULATION OF RECLAIMED-WATER INJECTION AND PUMPING SCENARIOS AND PARTICLE-TRACKING ANALYSIS NEAR MOUNT PLEASANT, SOUTH CAROLINA

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Abstract. The effect of injecting reclaimed water into the Middendorf aquifer beneath Mount Pleasant, South Carolina, was simulated using a groundwater-flow model of the Coastal Plain Physiographic Province of South Carolina and parts of Georgia and North Carolina. The scenarios were simulated to evaluate potential changes in groundwater flow and groundwater-level conditions caused by injecting reclaimed water into the Middendorf aquifer. Maximum pumping rates were simulated as 6.65, 8.50, and 10.5 million gallons per day for the Base Case, Scenario 1, and Scenario 2, respectively. For Scenarios 1 and 2, simulated injection of reclaimed water at 3 million gallons per day begins in 2012 and continues through 2050.

The simulations indicated a general decline of groundwater levels in the Middendorf aquifer in the Mount Pleasant, South Carolina, area between 2004 and 2050 for the Base Case and two injection scenarios. For Scenarios 1 and 2, although groundwater levels initially increased in the Mount Pleasant area because of the simulated injection, these higher groundwater levels declined as Mount Pleasant Waterworks pumping increased until 2050. Reclaimed water injected into the Middendorf aquifer at three hypothetical injection wells moved to the Mount Pleasant Waterworks production wells in 18 to 256 years as indicated by particle-tracking simulations.

INTRODUCTION

Groundwater use in the Charleston, South Carolina (SC) area, such as municipal supply in Mount Pleasant, irrigation pumpage at Kiawah Island, past use by the town of Summerville, and private industrial use has created a large, regional cone of depression in the potentiometric surface of the Middendorf aquifer. This cone of depression, which represents groundwater-level declines from predevelopment levels of 106 feet (ft) above land surface (Aucott and Speiran, 1984) to levels as low as 144 ft below land surface (U.S. Geological Survey, 2009a), has led to water-management concerns for Mount Pleasant Waterworks (MPW), the town's public works agency. As a result of these water-level declines, groundwater levels in MPW production wells have been as low as several hundred feet below land surface. Previous groundwater modeling results (Petkewich and Campbell, 2007) indicate that continued pumping in the Charleston, Berkeley, and Dorchester County area at 2000–2004 average annual rates would result in additional declines in groundwater levels in the area. Simulations also indicate that reductions in MPW pumping rates by more than 25 percent of the average annual rates would be required to eliminate excessive groundwater-level declines in wells near Mount Pleasant.

Reclaimed water, also known as recycled water, is wastewater or stormwater that has been treated to an appropriate level so that the water can be reused (U.S. Environmental Protection Agency, 2004). Reclaimed water is being used throughout the world for many purposes, including agricultural and golf-course irrigation, cooling of industrial equipment, and recharging aquifers (O'Reilly, 1998; Aiken and Kuniansky, 2002; U.S. Geological Survey, 2009b). In addition to reducing pumpage from the Middendorf aquifer to alleviate the stress on this water source, MPW is investigating the possibility of injecting highly treated reclaimed water into the Middendorf aquifer where it would be available for future use.

To evaluate the effect of injecting reclaimed water into the Middendorf aquifer, the U.S. Geological Survey (USGS), in cooperation with MPW, updated an existing groundwater-flow model (Petkewich and Campbell, 2007) to incorporate water-use data from 2005 through 2008 and simulated three water-management scenarios to the year 2050 (Petkewich and Campbell, 2009). The results of

Petkewich and Campbell (2009) will provide MPW and groundwater users of other aquifers of Cretaceous age in the Charleston area with an indication of the overall hydraulic effects of injecting reclaimed water over time. The groundwater-flow system of the Coastal Plain Physiographic Province of South Carolina and parts of Georgia and North Carolina was simulated using the USGS finite-difference code MODFLOW-2000 (Harbaugh and others, 2000) and the conceptual model described in Petkewich and Campbell (2007; 2009). The model consisted of 54 stress periods that simulated a steady-state predevelopment (1900) period followed by a transient period beginning in 1901 and ending in 2050.

RECLAIMED-WATER INJECTION AND PUMPING SCENARIOS

The groundwater-flow model was used to simulate three predictive water-management scenarios for 2009–2050 for the Middendorf aquifer in the Mount Pleasant, SC, area. Scenario results show the effect of injecting reclaimed water into the Middendorf aquifer (fig. 1) and facilitate water-management plans to use the Middendorf aquifer for water resource and storage. Injection wells were simulated at locations near where MPW infrastructure currently exists or could be constructed if needed. Average annual pumping rates for the individual MPW wells were apportioned on the basis of the best estimates for future water use. For all three scenarios, the total MPW pumping rate changed uniformly from the 2008 rate of 3.50 million gallons per day (Mgal/d) to 5.00 Mgal/d for the year 2018. Between 2018 and 2023, the MPW rate changed uniformly from 5.00 to 6.65, 8.50, and 10.50 Mgal/d, for the Base Case and Scenarios 1 and 2, respectively. The 2023 MPW pumping rate was maintained through 2050 for all three simulations. The following scenarios were simulated to 2050:

• Base Case—Increase MPW pumping rates from that reported in 2008 to an annual average rate equal to that reported for 2000–2004 (6.65 Mgal/d)

• Scenario 1—Moderate expansion of MPW groundwater use; increase MPW pumping rates from that reported in 2008 to an annual average rate of 8.50 Mgal/d; reclaimed water injection at 3.00 Mgal/d starting in 2012

• Scenario 2—Maximum expansion of MPW groundwater use; increase MPW pumping rates from that reported in 2008 to an annual average rate of 10.50 Mgal/d; reclaimed water injection at 3.00 Mgal/d starting in 2012.

Results of these simulations included estimated hydrographs, potentiometricsurface maps, groundwater-level change maps, water budgets, and particle-tracking analysis.

Base Case

Base Case pumping rates caused a general decline of about 90 ft in the simulated potentiometric surface of the Middendorf aquifer in the Mount Pleasant area. The greatest changes in groundwater level occurred at the model grid cells containing the MPW production wells and produced a minimum simulated 2050 groundwater altitude of 348 ft below the National Geodetic Vertical Datum of 1929 (NGVD 29). Simulated hydrographs for two area observation wells, CHN-14 and BRK-431, illustrate the gradual decline in groundwater levels with overall changes in water-level levels of –93 and –78 feet, respectively (fig. 2). Simulated groundwater levels at an imaginary well representing the general center of the MPW well field declined 75 ft between 2004 and 2050.

Scenario 1

Simulated groundwater levels for Scenario 1 declined to altitudes as low as –363 ft NGVD 29 in 2050. The lowest altitudes were located in model grid cells where MPW production wells were located. The simulated injection created small injection mounds in the potentiometric surface for this scenario. Compared to the 2050 Base Case simulation, groundwater levels for Scenario 1 are between

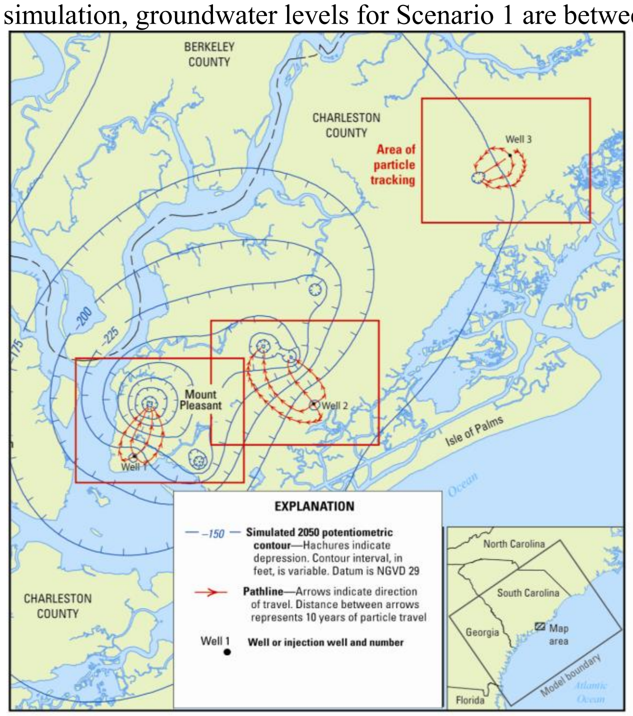

Figure 1. Simulated 2050 potentiometric surface map of the Middendorf aquifer near Mount Pleasant, South Carolina, and particle-tracking results using a 30-percent porosity for Scenario 2 for particles released at three proposed injection wells.

15 ft lower and 23 ft higher at the MPW production wells and between 41 and 77 ft higher at the injection wells. For Scenario 1, simulated hydrographs for CHN-14, BRK-431, and the imaginary well show an initial recovery of groundwater levels in the Mount Pleasant area due to injecting reclaimed water (2012–2014; fig. 2). From 2012 to 2025, groundwater levels at CHN-14 and the imaginary well are between 11 and 37 ft higher for the Scenario 1 simulation compared to the Base Case simulation (fig. 2). As MPW pumping increases through time, however, these higher groundwater levels decline, but are still higher than the Base Case. Simulated hydrographs for CHN-14, BRK-431, and the imaginary well show higher groundwater levels in 2050 for Scenario 1, even though total MPW pumping is greater for Scenario 1 (8.50 Mgal/d) compared to the Base Case (6.65 Mgal/d; fig. 2). Hence, injecting 3.00 Mgal/d of reclaimed water into the Middendorf aquifer more than compensates for the 1.85 Mgal/d higher pumping rate for Scenario 1. While the general decline in groundwater levels are still present for these wells, 2050 groundwater levels are between 9 and 23 ft higher for Scenario 1 than the Base Case (fig. 2).

Scenario 2

Simulated 2050 groundwater altitudes for Scenario 2 declined to as low as -454 ft NGVD 29. Compared to the 2050 Base Case simulation, groundwater levels for Scenario 2 are between 14 and 106 ft lower at the MPW production wells and between 11 and 27 ft higher at the injection wells. Simulated hydrographs for area observation wells show an initial recovery of groundwater levels in the Mount Pleasant area due to injection, with groundwater levels at well CHN-14 and the imaginary well between 5 and 37 ft higher for the Scenario 2 simulation compared to the Base Case simulation from 2012 to 2022 (fig. 2). As the withdrawal rates are increased to 10.50 Mgal/d, however, the hydrographs decline to levels between 2 and 38 ft lower that those simulated for the Base Case.

Particle-Tracking Analysis

Particle-tracking simulations using MODPATH (Pollock, 1994) were completed for Scenario 2 only and represent the worst-case (fastest travel time) situation for the two injection scenarios. The higher simulated pumping for Scenario 2 creates the steepest head gradients and fastest transport times between injection and production wells (fig. 1). Grid cell dimensions within the area of particle-tracking analysis were 1,000 ft by 1,000 ft near injection wells 1 and 2, and variable-spaced (1,000 ft by 1,500 ft; 1,000 ft by 2,400 ft; and 1,000 ft by 2,880 ft) for cells near injection well 3. The approach used was to release four imaginary water particles within the Middendorf aquifer at the model cells of the three proposed injection-well locations in the year 2012 and track them through time until they reached a discharge point within the simulated flow field. In this case, the discharge points are the MPW production wells, and time of travel for a given particle ends when that particle reaches the cell boundary where a production well is simulated. Flow directions and time of travel were calculated for each of the particles. Injecting water produced a mounding effect as the injected water moved away from the well and resulted in both direct and circuitous particle routes. The slow time of travel associated with some of the particles necessitated extending the

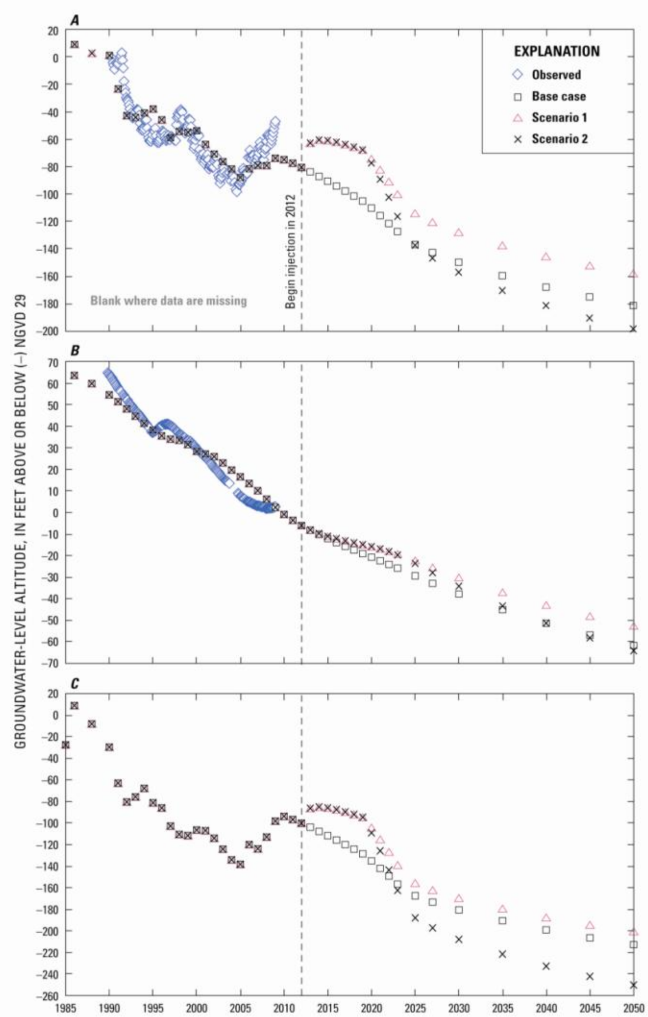

Figure 2. Simulated hydrographs from 1985 to 2050 for (A) CHN-14, (B) BRK-431, and (C) an imaginary well for three model scenarios.

total simulation time of the model beyond 2050 until the slowest particles reached a discharge point. For simulated time periods after 2050, pumping rates for all modeled wells were maintained at the same rates as used for 2050.

Particle-tracking results indicate that reclaimed water injected into the Middendorf aquifer at the three hypothetical injection wells will move to the MPW production wells in 18 to 256 years. The times of travel and groundwater-flow paths were calculated for particles released at the injection wells using estimated aquifer porosities of 20 and 30 percent. Times of travel varied from 18 to 179 years for a uniform aquifer porosity of 20 percent and between 25 to 256 years for a porosity of 30 percent.

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