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Review of Aquifer Storage and Recovery in the Floridan Aquifer System of Southern Florida

Introduction

Interest and activity in aquifer storage and recovery (ASR) in southern Florida has greatly increased during the past 10 to 15 years. ASR wells have been drilled to the carbonate Floridan aquifer system at 30 sites in southern Florida, mostly by local municipalities or counties in coastal areas (fig. 1). The Upper Floridan aquifer of the Floridan aquifer system, the aquifer of most interest, is either being used or planned for use at 29 of the sites. The strategy for use of ASR in southern Florida has been to store excess freshwater available during the wet season in an aquifer and recover this water during the dry season when needed for supplemental drinking water supply. Additionally, expanded use of ASR in southern Florida has been proposed under the Comprehensive Everglades Restoration Plan (CERP) on a large, unprecedented scale as a cost-effective water-supply alternative that can help meet the needs of agricultural, municipal, and recreational users and be used for Everglades ecosystem restoration (U.S. Army Corps of Engineers and the South Florida Water Management District, 1999). Under CERP, the construction of about 330 ASR wells is proposed in southern Florida, each with an assumed pumping capacity of 5 million gallons of water per day during recharge (injection) or recovery. Currently, test wells have been drilled at five sites as part of the CERP program (fig. 1); at four of these sites, large diameter ASR injection wells have been constructed and pilot testing is planned.

Several current or potential problems with ASR in southern Florida have been identified, including: (1) poor recovery due to mixing within the aquifer; (2) issues concerning the quality of water allowed for recharge into the aquifer; and (3) the release, or potential for release, of water-quality constituents of concern, such as arsenic and radionuclides, into the stored water, due to the interaction between injected freshwater and the aquifer matrix. This study focuses only on the recovery issue. The Upper Floridan aquifer is continuous throughout southern Florida; its overlying confinement is generally good; and the depth to its top ranges from 500 to 1,200 feet below land surface. However, the aquifer contains brackish to saline water in this area, which can greatly affect the recovery of the freshwater recharged and stored because of mixing within the aquifer.

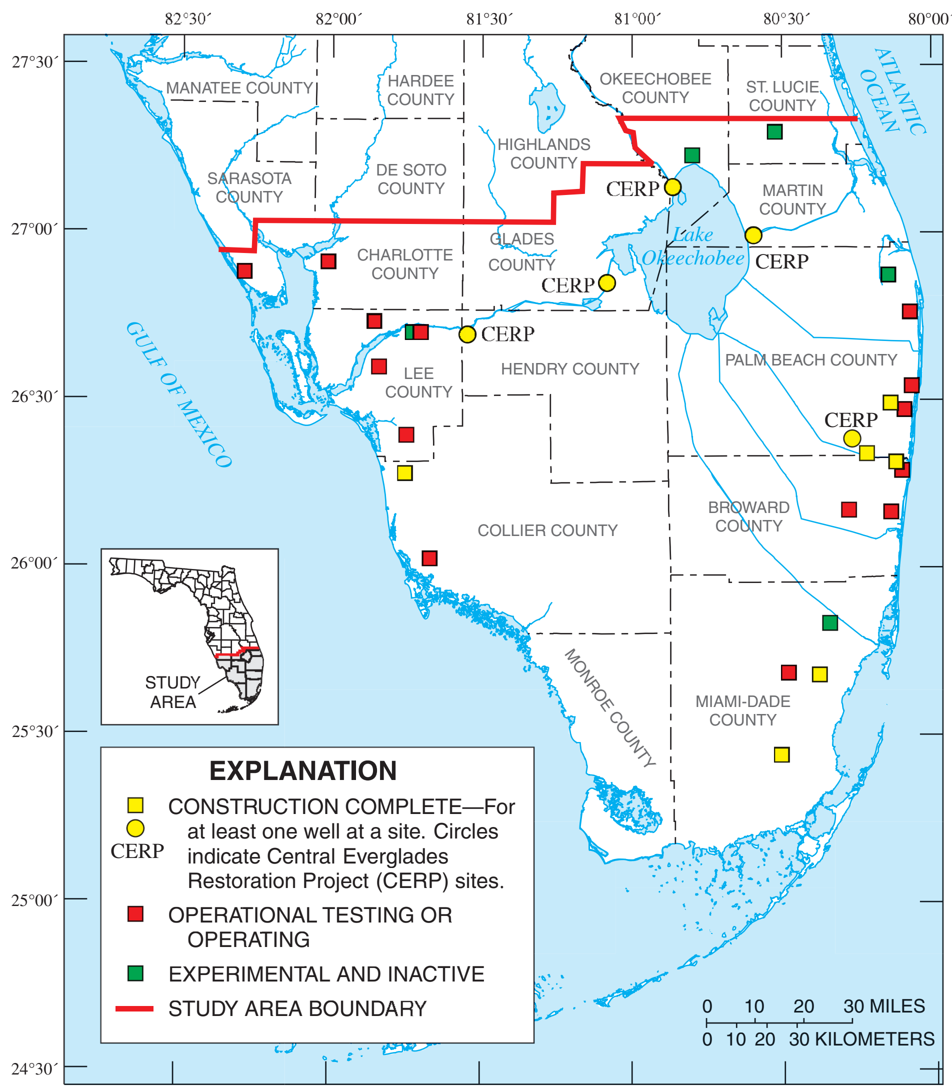

Figure 1. Study area and location and status of aquifer storage and recovery sites in the Floridan aquifer system.

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Scope and Methods

The U.S. Geological Survey is conducting this study to inventory and compile data for existing ASR sites in southern Florida and identify various hydrogeologic, design, and management factors that control the recovery of freshwater recharged into ASR wells. Data for all wells at the 30 Floridan aquifer system sites were compiled into four main categories: (1) well identification, location, and construction data; (2) hydraulic test data; (3) ambient formation water-quality data; and (4) cycle testing data. Each cycle during testing or operation includes periods of recharge of freshwater, storage, and recovery that each last days or months. Cycle testing data include calculations of recovery efficiency.

This study has been divided into two phases, the first of which involves preliminary data inventory, review, and analysis (Reese, 2001). The second phase involves compiling additional ASR data (as the data become available), expanding the hydrogeologic framework, and performing a more complete comparative analysis of ASR sites.

Factors Controlling Recovery Efficiency

Recovery efficiency in this study is defined as the percentage of potable recharged water that is recovered during each cycle. Potable water has a chloride concentration less than or equal to 250 milligrams per liter. The recovered volume in this calculation only includes water recovered prior to reaching the potable limit as the salinity of water increases during recovery. Recovery can continue beyond this limit, depending on operational considerations.

The recovery of freshwater stored in brackish- to saline-water aquifers is controlled by a wide variety of factors involving hydrogeologic conditions, well or well-field design, and operational management. A number of hydrogeologic factors of a storage zone can affect recoverability, including: (1) ambient salinity (defined based on chloride concentration); (2) aquifer permeability and its distribution, which relates to dispersive mixing; (3) aquifer thickness; (4) aquifer confinement; (5) ambient hydraulic gradient; and (6) structural setting. Important design and management factors to consider are: (1) the thickness and location of the storage zone within the aquifer; (2) the volume of injected water for each cycle; (3) the duration and frequency of cycles and cycle storage periods; (4) well performance problems, such as wellbore plugging and pump failure; and (5) multiple recharge well configurations. Generally, recovery efficiency can increase for a cycle as the volume of water recharged increases. Also, recovery efficiency typically improves with repeated cycles because much of the recharged water from a previous cycle is left in the aquifer, and during the next cycle, recharged water mixes with water having a lower salinity. An idealized freshwater-flushed zone (often referred to as a bubble) and zone of mixing at an ASR well are shown in figure 2.

Boynton Beach – An Example of a Successful ASR Site

In late 1992, cycle testing began at the Boynton Beach East Water Treatment Plant site near the eastern coast of Florida in southeastern Palm Beach County. Sixteen recharge-recovery cycles had been conducted by early 2000, for an average of about two cycles per year. Potable recovery efficiency increased rapidly during the first three cycles to about 50 percent per cycle, and recovery efficiencies for cycles 10 to 14 averaged 75 percent. Recovery for most cycles continued past the potable limit until a chloride concentration of about 300 milligrams per liter was reached. Hydrogeologic factors at this site are favorable; the thickness of the storage zone open interval is only 105 feet, reported transmissivity for the storage zone is moderate (about 9,400 square feet per day), and ambient ground-water salinity is also moderate (chloride concentration of 1,900 milligrams per liter). Additionally, the storage zone is located at the top of the Upper Floridan aquifer (fig. 3).

Results of Cycle Testing

Cycle testing has been limited to 20 of the 30 existing ASR, with a total of 85 cycles completed thus far. Of the remaining 10 sites, 7 require additional wells or infrastructure to be constructed and 3 have had testing delayed by regulatory issues, mechanical problems, or for other reasons. Of the 20 sites that have initiated cycle testing, 3 or fewer cycles have been conducted at 10 sites, even though well construction was completed at 9 of these in the 1990s or earlier. Another reason for limited cycle testing at some sites has been the lack of source water during certain years.

Potable water recovery efficiencies for 18 of the 30 sites were calculated, and generally, recovery efficiency improved with the number of cycles completed. Of the 14 sites with 3 or more cycles completed, 10 have had a recovery efficiency of 30 percent or more for at least one cycle. However, of all 18 sites with cycle test data, 5 (about 30 percent) have not exceeded 10 percent recovery per cycle. Low recovery at some of these sites is probably explained by the low number of cycles, low recharge volume per cycle, higher recharge water salinity, or recovery well beyond the potable salinity limit, which can reduce recovery on subsequent cycles. Potable water recovery efficiencies

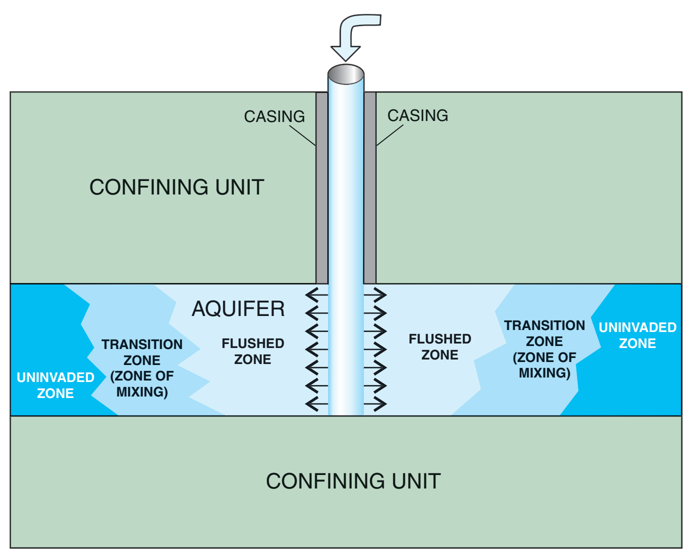

Figure 2. Aquifer storage and recovery well in a confined aquifer depicting idealized flushed and transition zones created by recharge. Flushed zone contains mostly recharged water.

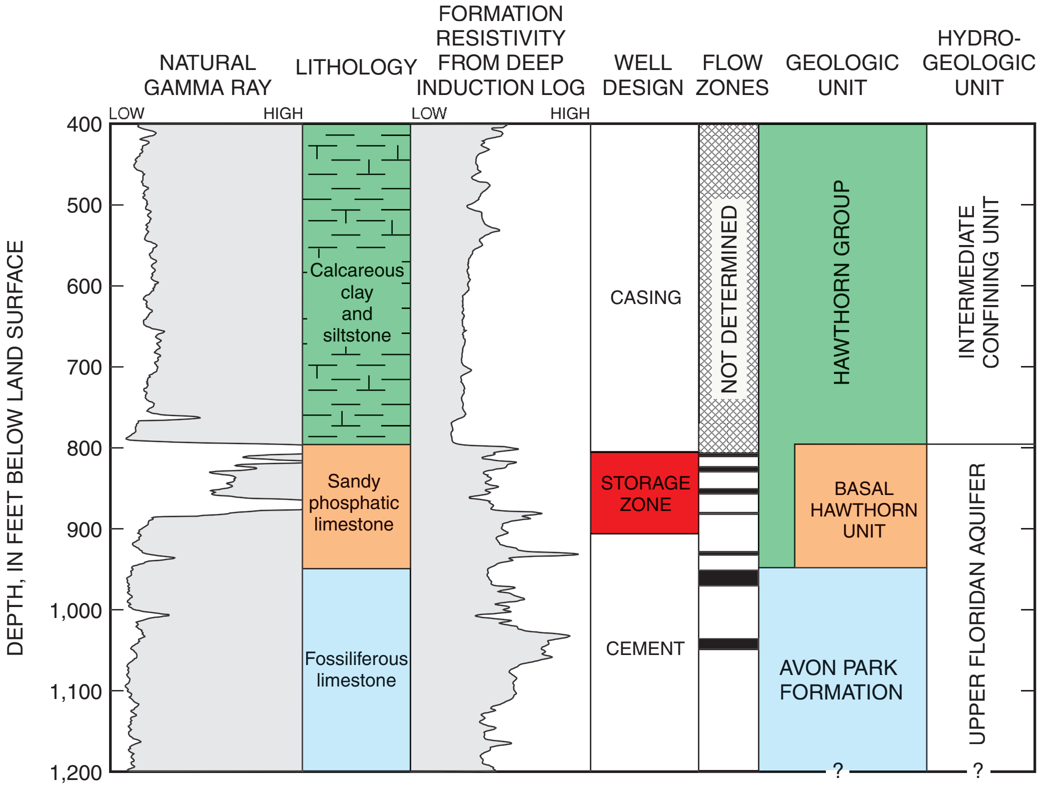

Figure 3. Location of storage zone in relation to geophysical logs, lithology, flow zones, and geologic and hydrogeologic units for the aquifer storage and recovery well at the Boynton Beach East Water Treatment Plant site in Palm Beach County. Flow zones determined by flowmeter, fluid resistivity, and caliper logs. The basal Hawthorn unit could include the Suwannee Limestone in its lower part. Question mark signifies that the base of a unit was not reached.

for the last cycle with data available are shown for 17 sites in figure 4. Recharge volume per cycle averaged 112 million gallons and ranged from 0.6 to 714 million gallons. Except for three sites, all of the sites in figure 4 use a single recharge well; for the other three sites, three recharge wells were used simultaneously for the last cycle, and the recovery efficiency was calculated using the combined volumes. In general, ASR wells located on the east coast appear to achieve greater recovery efficiency than those located on the west coast; three east coast facilities had recovery efficiencies exceeding 60 percent during their most recent cycle. However, more cycles have been conducted at these three east coast sites (six cycles or more) than at most of the west coast sites.

Factors that can affect freshwater recovery vary greatly among sites. The thickness of the open storage zone ranges from 45 to 452 feet over all sites. For Upper Floridan aquifer sites, storage zone transmissivity ranges from 800 to 108,000 square feet

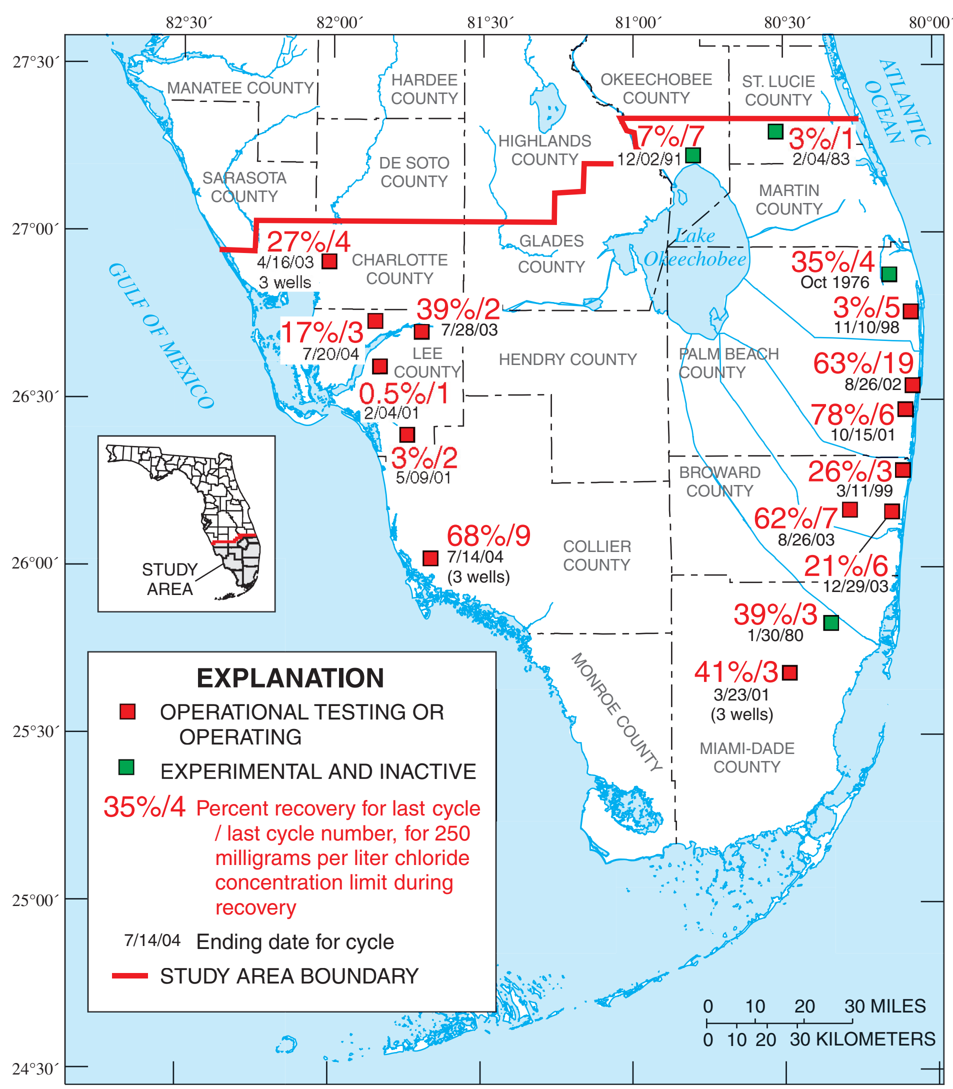

Figure 4. Potable water recovery efficiencies for the most recent cycle for aquifer storage and recovery sites in southern Florida. All sites use one recharge well, except three sites (indicated) that use three wells simultaneously.

per day, chloride concentration of ambient formation water ranges from 500 to 11,000 milligrams per liter, and aquifer test leakance values indicate that confinement separating the storage zone from lower permeable zones may be limited in some areas. High transmissivity (greater than 30,000 to 50,000 square feet per day) may adversely affect recovery because it may equate to high dispersive mixing. Additionally, assuming vertical hydraulic conductivity is not low and depending on the ambient salinity of the storage zone, the probability of buoyancy stratification increases as transmissivity increases. Buoyancy stratification, which results in more mixing during recovery, could begin to occur as chloride concentration increases above 3,000 milligrams per liter. At three sites with storage zone transmissivity of 70,000 square feet per day or greater, recovery efficiency has not exceeded 10 percent for any of the three to seven cycles at each site. Low transmissivity can also be problematic because pressure buildup may restrict the rate of injection, particularly if multiple wells are clustered in a small area. Lower transmissivity (less than 10,000 square feet per day) has been mapped in the Upper Floridan aquifer in the central part of southern Florida around Lake Okeechobee (Ward and others, 2003). The majority of wells planned for the CERP ASR program are proposed for an area around the lake, and their proposed recharge and recovery rate of 5 million gallons per day is two to five times higher than the normal rate for utility-based ASR wells in southern Florida.

Summary

Wells have been drilled to the Floridan aquifer system for the purpose of ASR at 30 sites in southern Florida, and data from these wells provide a basis for the review of their hydrogeologic characteristics and performance. Cycle testing has been limited at a number of sites, but potable water recovery efficiencies for 85 cycles at 18 of the 30 sites were calculated. Based on these efficiency data, several hydrogeologic and design factors appear to most affect the performance of ASR in the Floridan aquifer system. Performance is maximized when the storage zone is thin and located at the top of the Upper Floridan aquifer, and transmissivity and ambient salinity of the storage zone are moderate (less than 30,000 to 50,000 square feet per day and 3,000 milligrams per liter of chloride concentration, respectively). Because of the location and large scale of the proposed CERP ASR program for southern Florida, hydrogeologic factors, such as transmissivity, could also affect performance. Transmissivity may be too low rather than too high in a part of the CERP program area where many of the wells are planned.

References

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