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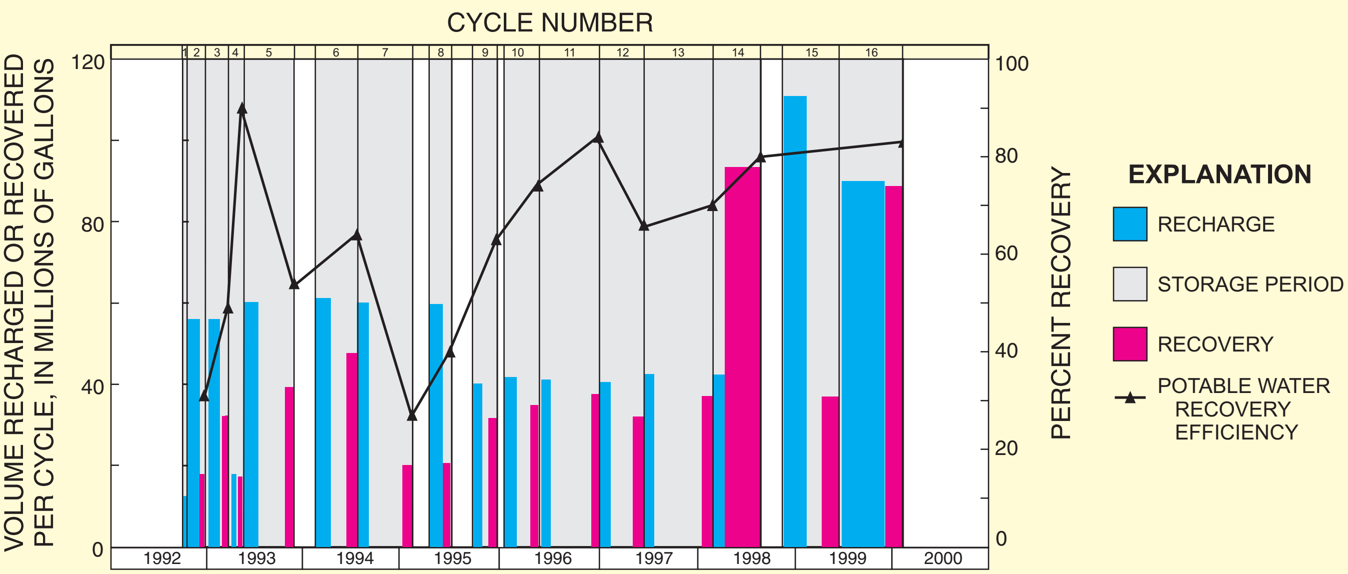
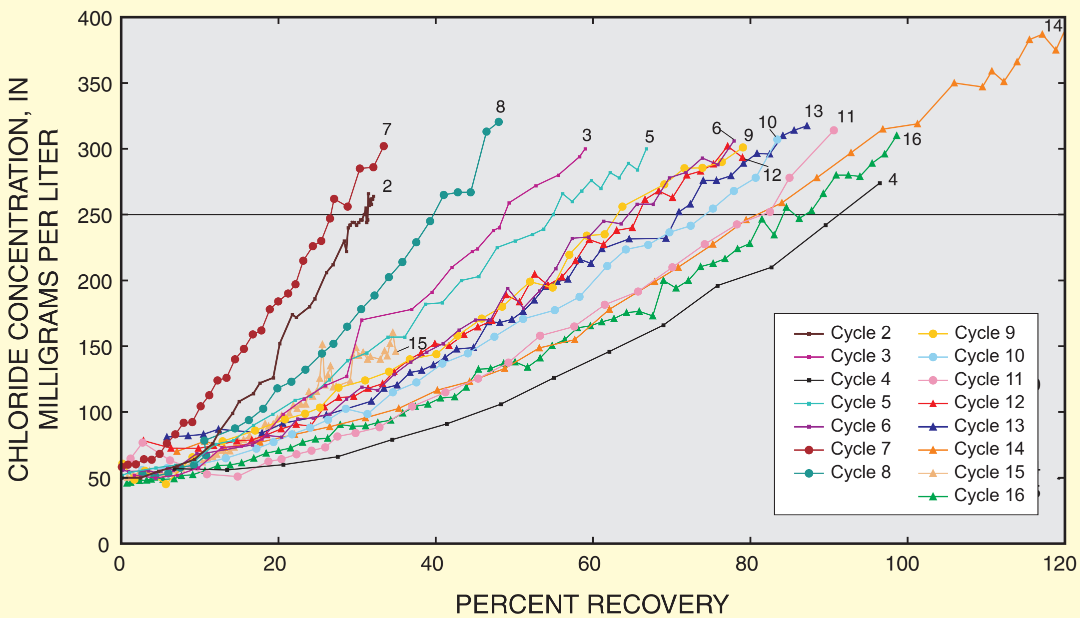
Inventory and Review of Aquifer Storage and Recovery in Southern Florida





Water-Resources Investigations Report 02–4036

Prepared as part of the U.S. Geological Survey Place-Based Studies Program

Inventory and Review of Aquifer Storage and Recovery in Southern Florida

By Ronald S. Reese

U.S. GEOLOGICAL SURVEY
Water-Resources Investigations Report 02-4036

Prepared as part of the
U.S. GEOLOGICAL SURVEY PLACE-BASED STUDIES PROGRAM

Tallahassee, Florida
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Conversion Factors, Vertical Datum, Abbreviations and Acronyms

Multiply	By	To Obtain
inch (in.)	25.4	millimeter
foot (ft)	0.3048	meter
mile (mi)	1.609	kilometer
gallon per minute (gal/min)	3.785	liter per minute
gallon per minute per foot (gal/min/ft)	12.418	liter per minute per meter
million gallons (Mgal)	3,785	cubic meter
million gallons per day (Mgal/d)	3,785	cubic meter per day
square feet per day (ft^2/d)	0.0929	square meter per day
square feet per day (ft^2/d)	7.48	gallon per day per foot
inverse day (1/d)	7.48	gallon per day per cubic foot

Sea level: In this report, “sea level” refers to the National Geodetic Vertical Datum of 1929 (NGVD of 1929)—a geodetic datum derived from a general adjustment of the first-order level nets of both the United States and Canada, formerly called Sea Level Datum of 1929.

ACRONYMS AND ADDITIONAL ABBREVIATIONS USED IN REPORT

ASR	aquifer storage and recovery
CERP	Comprehensive Everglades Restoration Plan
FDEP	Florida Department of Environmental Protection
FKAA	Florida Keys Aqueduct Authority
GPS	global positioning system
GWSI	Ground-Water Site Inventory (U.S. Geological Survey database)
µs/cm	microsiemens per centimeter
mg/L	milligrams per liter
MOR	monthly operating report
SFWMD	South Florida Water Management District
USGS	U.S. Geological Survey
WTP	Water Treatment Plant
WWTP	Wastewater Treatment Plant

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Abstract

Aquifer storage and recovery in southern Florida has been proposed on an unprecedented scale as part of the Comprehensive Everglades Restoration Plan. Aquifer storage and recovery wells were constructed or are under construction at 27 sites in southern Florida, mostly by local municipalities or counties located in coastal areas. The Upper Floridan aquifer, the principal storage zone of interest to the restoration plan, is the aquifer being used at 22 of the sites. The aquifer is brackish to saline in southern Florida, which can greatly affect the recovery of the freshwater recharged and stored.

Well data were inventoried and compiled for all wells at most of the 27 sites. Construction and testing data 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, which is the percentage of the total amount of potable water recharged for each cycle that is recovered.

Calculated cycle test data include potable water recovery efficiencies for 16 of the 27 sites. However, the number of cycles at most sites was limited; except for two sites, the highest number of cycles was five. Only nine sites had a recovery efficiency above 10 percent for the first cycle, and 10 sites achieved a recovery efficiency above 30 percent during at least one cycle. The highest recovery efficiency achieved per cycle was 84 percent for cycle 16 at the Boynton Beach site.

Factors that could affect recovery of freshwater varied widely between sites. The thickness of the open storage zone at all sites ranged from 45 to 452 feet. For sites with the storage zone in the Upper Floridan aquifer, transmissivity based on tests of the storage zones ranged from 800 to 108,000 feet squared per day, leakance values indicated that confinement is not good in some areas, and the chloride concentration of ambient water ranged from 500 to 11,000 milligrams per liter.

Based on review of four case studies and data from other sites, several hydrogeologic and design factors appear to be important to the performance of aquifer storage and recovery 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 salinity of the storage zone are moderate (less than 30,000 feet squared per day and 3,000 milligrams per liter of chloride concentration, respectively). The structural setting at a site could also be important because of the potential for updip migration of a recharged freshwater bubble due to density contrast or loss of overlying confinement due to deformation.

INTRODUCTION

Aquifer storage and recovery (ASR) in southern Florida has been proposed as a cost-effective water-supply alternative that can help meet the needs of agricultural, municipal, and recreational users and can be used for Everglades ecosystem restoration. Plans have been made to utilize ASR on an unprecedented scale in the Central and Southern Florida Comprehensive Review Study as proposed by the U.S. Army Corps of Engineers and the South Florida Water Management District (1999). This review study is also known as the Comprehensive Everglades Restoration Plan (CERP). About 330 ASR wells have been proposed for southern Florida, each with an assumed capacity of 5 Mgal/d during recharge or recovery. Pyne (1995) has described ASR as "the storage of water in a suitable aquifer through a well during times when water is available, and recovery of the water from the same well during times when it is needed."

ASR technology has been tested and implemented in some areas of southern Florida; 26 ASR sites have been constructed and 1 is under construction (fig. 1 and table 1). The status for 10 of the sites is "operational testing," which is a multi-year period of regulatory review during the first phase of operation.

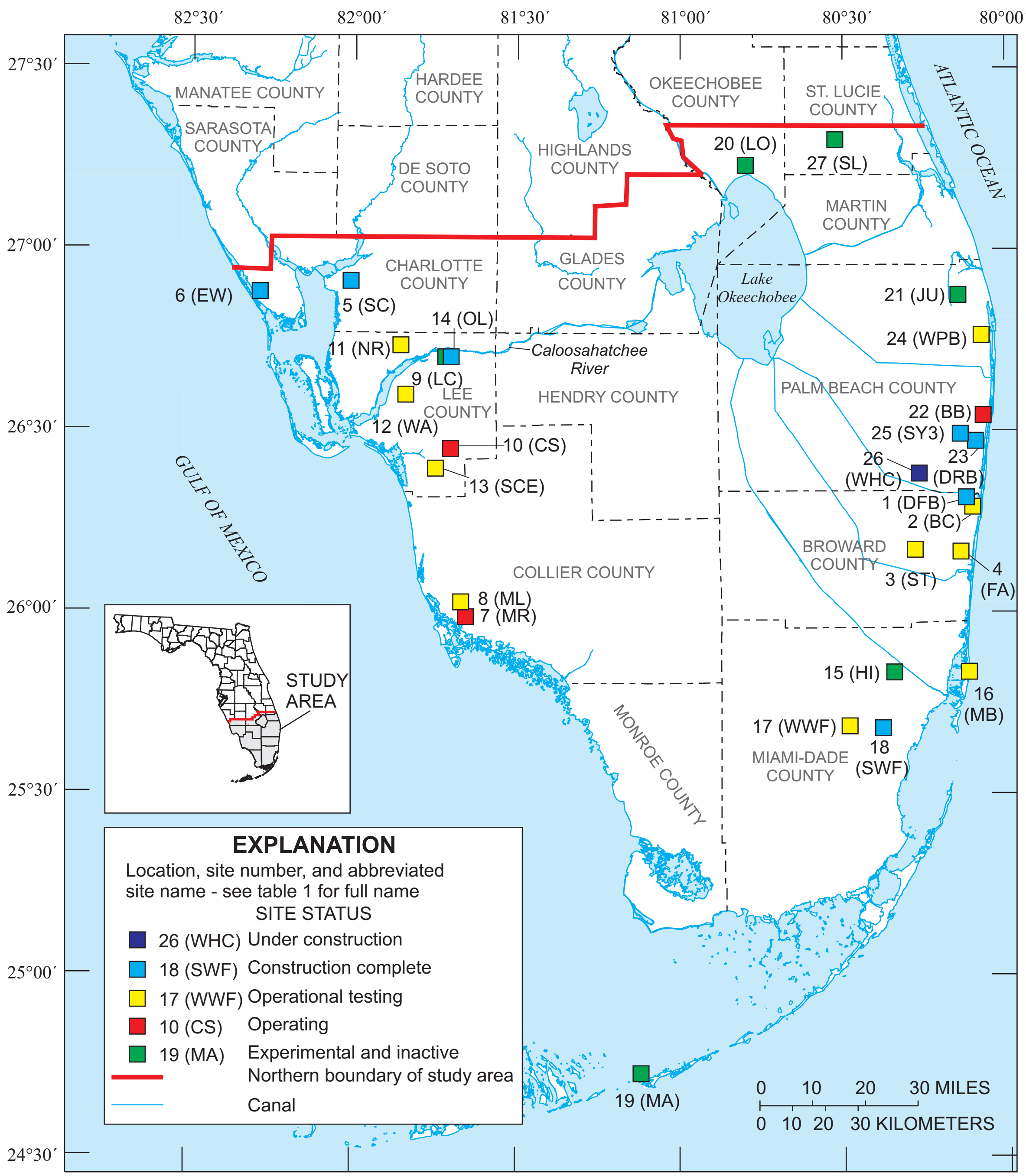

Figure 1. Study area and locations and status of aquifer storage and recovery sites. Status is as of April 2001.

Table 1. Historical and current aquifer storage and recovery sites in southern Florida

[County: B, Broward; CH, Charlotte; CO, Collier; L, Lee; MD, Miami-Dade; MO, Monroe; OK, Okeechobee; PB, Palm Beach; STL. St. Lucie. Utility or operator: BCOES, Broward County Office of Environmental Services; USGS, U.S. Geological Survey; LCRWSA, Lee County Regional Water Supply Authority; MDWSD, Miami-Dade Water and Sewer Department; FKAA, Florida Keys Aqueduct Authority; SFWMD, South Florida Water Management District; FDEP, Florida Department of Environmental Protection; PBCWUD, Palm Beach County Water Utilities Department. Storage zone aquifer: B, Biscayne aquifer; LFA, Lower Floridan Aquifer; MHA, mid-Hawthorn aquifer; SS, sandstone aquifer; UFA, Upper Floridan aquifer. Other abbreviations: WTP, water treatment plant; WWTP, wastewater treatment plant]

Site No.[1]	Site name and abbreviation	County	Utility or operator	Storage zone aquifer	Status	Source water	No. of injection wells	No. of monitoring wells in storage zone
1	Deerfield Beach West WTP (DFB)	B	Deerfield Beach	UFA	Construction complete	Treated drinking water	1	1
2	Broward County WTP 2A (BC)	B	BCOES	UFA	Operational testing	Raw ground water	1	1
3	Springtree WTP (ST)	B	Sunrise	UFA	Operational testing	Treated drinking water	1	0
4	Fiveash WTP (FA)	B	Fort Lauderdale	UFA	Operational testing	Treated drinking water (future raw ground water)	1	1
5	Shell Creek WTP (SC)	CH	Punta Gorda	UFA	Construction complete	Treated drinking water	1	0
6	Englewood South Regional WWTP (EW)	CH	Englewood Water District	UFA	Construction complete	Reclaimed water	1	1
7	Manatee Road (MR)	CO	Collier County	MHA	Operating	Treated drinking water	1	3
8	Marco Lakes (ML)	CO	Florida Water Services	UFA	Operational testing	Partially treated surface water	3	2
9	Lee County WTP (LC)	L	USGS	UFA	Experimental and inactive	Raw and treated surface water	1	2
10	Corkscrew WTP (CS)	L	LCRWSA	MHA	Operating	Treated drinking water	5	5
11	North Reservoir (NR)	L	Lee County	UFA	Operational testing	Treated drinking water	1	1
12	Winkler Avenue (WA)	L	Fort Myers	UFA	Operational testing	Treated drinking water	1	1
13	San Carlos Estates (SCE)	L	Bonita Springs	UFA	Operational testing	Treated drinking water	1	1
14	Olga WTP (OL)	L	Lee County	UFA	Construction complete	Treated drinking water	1	2
15	Hialeah (HI)	MD	USGS	UFA	Experimental and inactive	Raw ground water	1	1

Table 1. Historical and current aquifer storage and recovery sites in southern Florida --(Continued)

[County: B, Broward; CH, Charlotte; CO, Collier; L, Lee; MD, Miami-Dade; MO, Monroe; OK, Okeechobee; PB, Palm Beach; STL. St. Lucie. Utility or operator: BCOES, Broward County Office of Environmental Services; USGS, U.S. Geological Survey; LCRWSA, Lee County Regional Water Supply Authority; MDWSD, Miami-Dade Water and Sewer Department; FKAA, Florida Keys Aqueduct Authority; SFWMD, South Florida Water Management District; FDEP, Florida Department of Environmental Protection; PBCWUD, Palm Beach County Water Utilities Department. Storage zone aquifer: B, Biscayne aquifer; LFA, Lower Floridan Aquifer; MHA, mid-Hawthorn aquifer; SS, sandstone aquifer; UFA, Upper Floridan aquifer. Other abbreviations: WTP, water treatment plant; WWTP, wastewater treatment plant]

Site No.[1]	Site name and abbreviation	County	Utility or operator	Storage zone aquifer	Status	Source water	No. of injection wells	No. of monitoring wells in storage zone
16	Miami Beach (MB)	MD	Miami Beach	B	Operational testing	Treated drinking water	1	Unknown
17	West Well Field (WWF)	MD	MDWSD	MHA, UFA	Operational testing	Raw ground water	3	1
18	Southwest Well Field (SWF)	MD	MDWSD	UFA	Construction complete	Raw ground water	2	0
19	Marathon (MA)	MO	FKAA	SS	Inactive	Treated drinking water	1	1
20	Taylor Creek/Nubbin Slough (Lake Okeechobee) (LO)	OK	SFWMD	LFA	Experimental and inactive	Raw surface water	1	1
21	Jupiter (JU)	PB	FDEP	UFA	Experimental and inactive	Raw surface water	1	1
22	Boynton Beach East WTP (BB)	PB	Boynton Beach	UFA	Operating	Treated drinking water	1	0
23	Delray Beach North Storage Reservoir (DRB)	PB	Delray Beach	UFA	Construction complete	Treated drinking water	1	0
24	West Palm Beach WTP (WPB)	PB	West Palm Beach	UFA	Operational testing	Treated surface water (future raw surface water)	1	1
25	System 3 Palm Beach County (SY3)	PB	PBCWUD	UFA	Construction complete; waiting on permit	Treated drinking water (future raw ground water)	1	1
26	Western Hillsboro Canal, Site 1 (WHC)	PB	SFWMD	UFA	Under construction	Not yet determined	1	1
27	St. Lucie County (SL)	STL	SFWMD	UFA	Experimental and inactive	Raw ground water	1	2

[1] Site numbers refer only to this report. Site locations are shown in figure 1.

During this time, the ASR well system is tested prior to being given a full operating permit by the Florida Department of Environmental Protection (FDEP). Three of the sites have been given an operating permit. Additionally, six sites are no longer active after experimental testing was completed (fig. 1). These sites were operated by government agencies including the U.S. Geological Survey (USGS), South Florida Water Management District (SFWMD), FDEP, and the Florida Keys Aqueduct Authority (FKAA). ASR is a relatively recent development in southern Florida, in terms of its use as a municipal or countywide source of water; 20 active sites in this category were constructed in the 1990's (with 14 of these sites having been constructed since 1996). The strategy for this use of ASR in southern Florida has been to store excess water available during the wet season and recover this water during the dry season when it is needed.

Existing and historical ASR sites in southern Florida are mostly located along the east and west coasts (fig. 1). At most sites, the proposed or planned purpose of the recovered water is to serve as a supplemental supply for municipalities. Under CERP, ASR wells will be constructed in inland areas around Lake Okeechobee, in central Palm Beach County, and along the Caloosahatchee River in Hendry County (U.S. Army Corps of Engineers and South Florida Water Management District, 2001). Recovered water is to be used for additional purposes that include maintaining water levels in Lake Okeechobee and wetland areas and reduction of surface-water flows to tide (estuarine and bay areas) during storm events.

The storage zone being used at most ASR sites is in the Floridan aquifer system (fig. 2). Shallower storage zones are in the mid-Hawthorn and sandstone aquifers of the intermediate aquifer system and the Biscayne aquifer of the surficial aquifer system. The proposed storage zone aquifer in the CERP ASR program is also in the Floridan aquifer system. This aquifer system is continuous throughout southern Florida, and its overlying confinement is generally good.

ASR wells are evaluated and operated through a cyclical process. Each cycle includes periods of injection (recharge) of freshwater into the ASR well, storage, and then withdrawal (recovery) with each period lasting days or months. In southern Florida, the recovery phase may commence immediately after the cessation of recharge with no period of storage, and depending on the source of water supply, municipal supply, or operational problems, the time between cycles may be extensive (months or years). After initial testing and under fully operational conditions, cycles continue but the duration of cycles and storage periods and the volume of water recharged during each cycle usually increase.

In southern Florida, ASR is largely used to store water in an aquifer that contains brackish water. Ambient ground water in the storage zone at most of the ASR sites in the study area is brackish (greater than 1,000 mg/L dissolved-solids concentration) to saline (greater than 10,000 mg/L dissolved-solids concentration); salinity appears to greatly affect the recovery of the recharged freshwater. The salinity of the recharged and recovered water is closely monitored, usually on a daily basis. Because of the high ambient water salinity of the storage zone, much of the recharged freshwater is not recovered largely due to dispersive mixing in the aquifer.

The recovery efficiency for each cycle is the total volume of water recovered, expressed as a percentage of the volume of water recharged. The salinity of water during recovery increases with time, and recovery is terminated at a salinity level that is predetermined by operational considerations. Generally, this limiting salinity level is at the potable water limit of 250 mg/L chloride concentration, or slightly higher if the recovered water is mixed with potable water at a water-treatment plant (WTP).

Few regional investigations of the hydrogeology of the Floridan aquifer system in southern Florida have been conducted, and those studies focused on issues unrelated to ASR. Lacking a regional ASR framework to aid the decision-making process, placement of ASR well sites in southern Florida have primarily been based on factors such as land availability, source-water proximity (preexisting surface-water canal systems or surficial aquifer system well fields), or proximity to a WTP. Little effort has been made to link information collected from each site into a regional hydrogeologic analysis. Additional tools and data are needed to make informed decisions that incorporate constraining hydrogeologic factors in the placement and construction of ASR sites in southern Florida.

This study is part of the USGS South Florida Place-Based Studies Program, which was established for the purpose of providing physical and biological science data and information on which to base ecosystem restoration management decisions. The purpose of

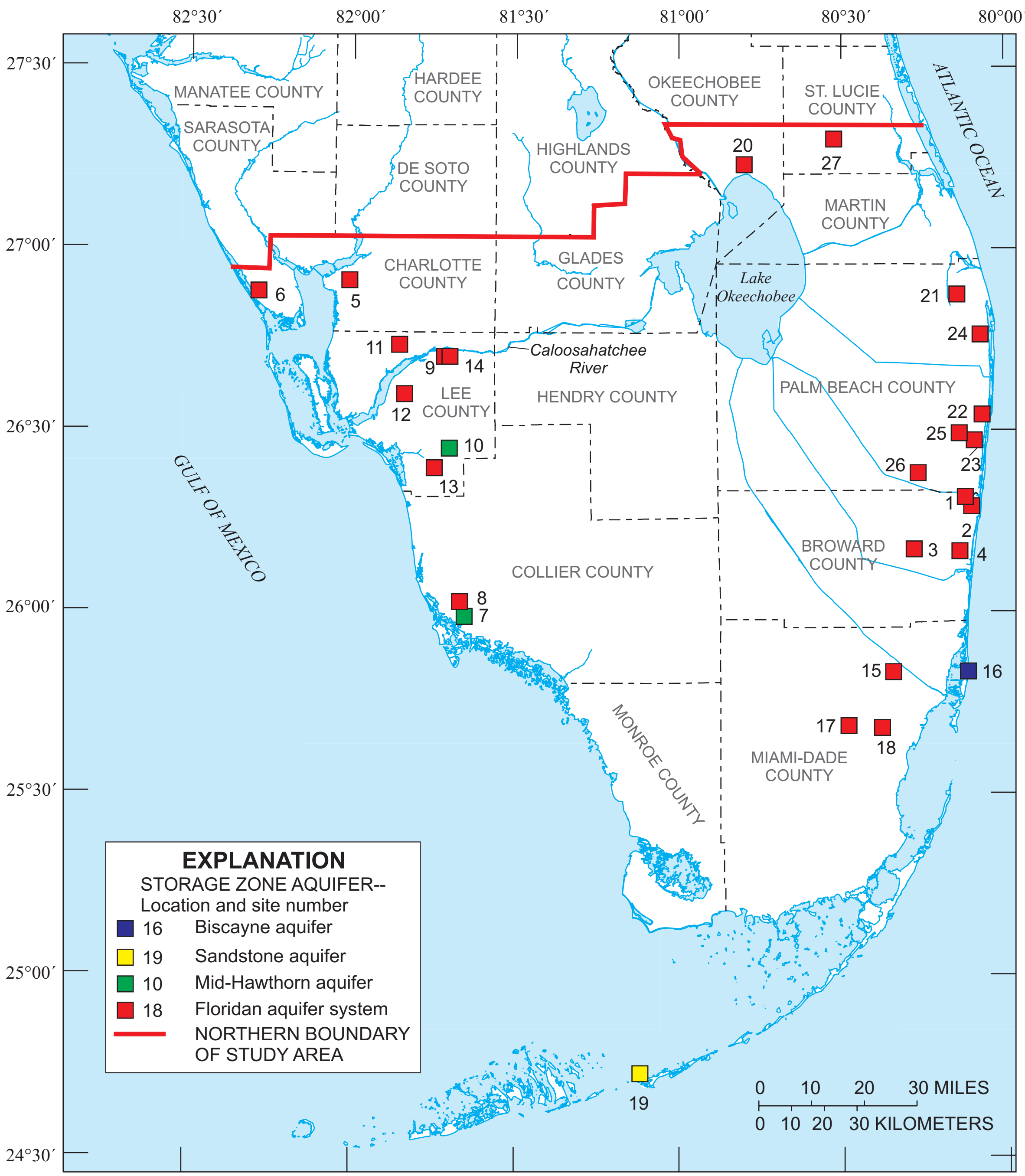

Figure 2. Storage zone aquifers for aquifer storage and recovery sites in southern Florida.

this study was to compile data on existing ASR sites in southern Florida and identify various hydrogeologic, design, and management factors that control the recovery of freshwater recharged into ASR wells.

Purpose and Scope

The purpose of this report is to inventory well construction, hydrogeologic, and operational data on ASR sites in southern Florida and assess site performance. A secondary purpose is to identify hydrogeologic, design, or management factors that influence the success of ASR. Recovery efficiency, defined as the percent of recharged freshwater that is recovered for each cycle, is used to evaluate this performance. Four ASR case studies are described to determine possible technical factors that influence the success of ASR.

The study area includes all of southern Florida and includes Charlotte, Glades, Lee, Hendry, Collier, Monroe, Miami-Dade, Broward, Palm Beach, and Martin Counties, and parts of Okeechobee and St. Lucie Counties (fig. 1). The 27 ASR sites located in the study area represent the source of data for this study. However, this report focuses on the 23 ASR sites in which the Floridan aquifer system serves as the storage zone. Principal hydrogeologic and construction related attributes determined for each ASR site are graphically and spatially illustrated to provide a comparative analysis.

Previous Studies

It has been nearly 20 years since Merritt and others (1983) provided a retrospective overview and status of ASR well development in southern Florida. Merritt and others (1983) presented data from three experimental ASR sites that are also included in this report, and Meyer (1989b) published additional data on experimental ASR sites in southern Florida. Other experimental ASR test data were obtained in reports or written communications for the Jupiter site (fig. 1, map no. 21; J.J. Plappert, Florida Department of Environmental Protection, written commun., 1977), the St. Lucie County site (fig. 1, map no. 27; Wedderburn and Knapp, 1983), the Lee County site (fig. 1, map no. 9; Fitzpatrick, 1986), the Hialeah site (fig. 1, map no. 15; Merritt, 1997), and the Taylor Creek/Nubbin Slough – Lake Okeechobee site (fig. 1, map no. 20; Quiñones-Aponte and others, 1996). Theoretical investigations into the feasibility of cyclic injection of freshwater in southern Florida have been described in reports by Khanal (1980) and Merritt (1985). Merritt (1997) also included numerical simulations of the salinity of recovered water in his study of Hialeah ASR site.

Some regional or local hydrogeologic studies of the Upper Floridan aquifer that encompass or include part of southern Florida are Bush and Johnston (1988), Meyer (1989a), Miller (1986), Reese (1994), Reese (2000), and Reese and Memberg (2000). The reports by Meyer (1989a), Reese (1994; 2000), and Reese and Memberg (2000) are specific to southern Florida.

Factors Affecting Optimal Recovery of Freshwater in Aquifer Storage and Recovery

Recovery of freshwater stored in brackish- to saline-water aquifers is controlled by a wide variety of factors that pertain to hydrogeologic conditions, well or well field design, and operational management. The hydrogeologic factors of a storage zone that are important to recoverability include (1) ambient salinity, (2) aquifer permeability and distribution, (3) aquifer thickness, (4) confinement, (5) ambient hydraulic gradient, and (6) structural setting. Important design and management factors to consider are (1) thickness and location of the storage zone within the aquifer, (2) volume of injected water, (3) duration and frequency of cycles and cycle storage periods, (4) well performance problems such as wellbore plugging, and (5) multiple-well configurations. Most of these factors and their control on recoverability have been numerically simulated (Merritt and others, 1983; Merritt, 1985); however, conclusions on some factors, 95 discussed in the following sections, came from consulting reports and other literature.

Hydrogeologic Factors

During recharge of water by an ASR well, a radial zone of mixing forms around the well in the aquifer. This zone, referred to as the transition zone (Merritt, 1985), separates native water from an inner flushed zone containing mostly injected water, and this inner zone can be described as a freshwater bubble

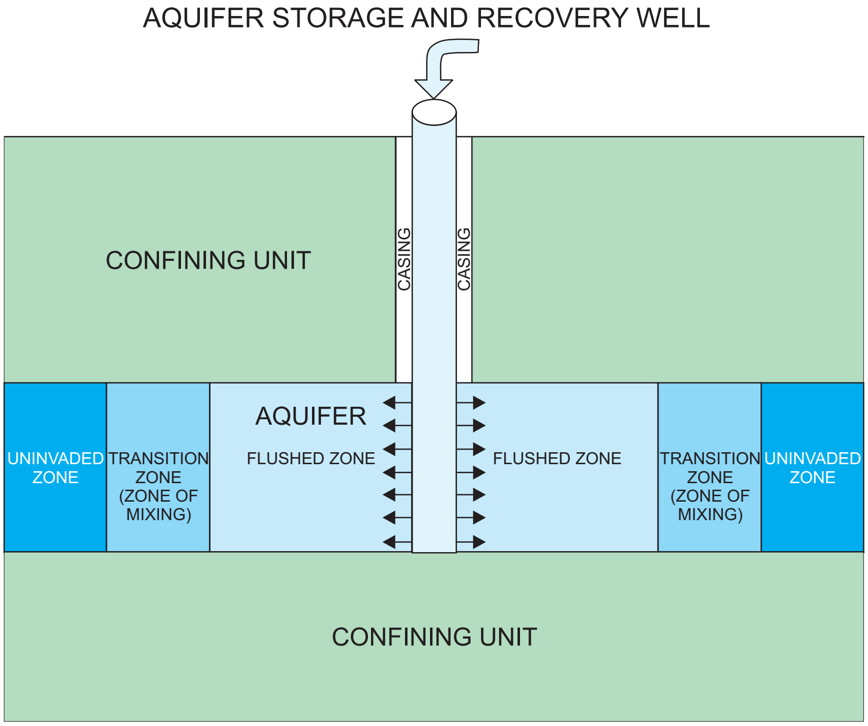

Figure 3. Aquifer storage and recovery well in a confined aquifer depicting idealized flushed and transition zones created by recharge. Flushed zone contains mostly recharged water.

(fig. 3). The degree of mixing between the injected and native water and the width of the transition zone is primarily controlled by hydrodynamic dispersion. Hydrodynamic dispersion or dispersive mixing refers to the effects of molecular diffusion and mechanical dispersion. Mechanical dispersion results from the unevenness of flow through porous media, and at flow velocities occurring during ASR recharge and recovery, this dispersion will dominate over diffusion.

The ambient salinity of water in the storage zone is of primary importance in controlling recovery of freshwater because of mixing with this water and potential buoyancy stratification. Buoyancy stratification occurs where the ambient salinity is high, provided permeability in the aquifer is also high (Merritt, 1985); the injected freshwater moves upward and flows out over the native ground water. During the recovery phase, such stratification increases mixing. Buoyancy stratification should be considered possible when the ambient ground water has a dissolved-solids concentration greater than 5,000 mg/L (Pyne, 1995); in the Floridan aquifer system of southern Florida this equates to about 2,500 mg/L chloride concentration (Reese, 1994). On the basis of numerical simulation, recovery efficiency has been shown to decrease with increasing salinity in saline aquifers only because of dispersive mixing in the transition zone – no buoyancy stratification (Merritt, 1985). Ambient water salinities modeled in Merritt's study, as defined by chloride concentration, were 2,000, 7,000 to 8,000, and 19,000 mg/L (seawater-like salinity).

The permeability or hydraulic conductivity of the storage zone may greatly affect recoverability. The probability of buoyancy stratification increases as permeability increases (Merritt, 1985). Additionally, mechanical dispersion is related to the distribution of permeability within the storage zone. Higher permeability can equate to higher dispersive mixing, and an increase in this dispersion lowers recovery efficiency (fig. 3). Thus, recovery could be better in a sand aquifer of uniform permeability where dispersion results primarily from flow through intergranular pore spaces, as opposed to a limestone aquifer having diffuse and conduit flow components, particularly if thin zones of high permeability occur within the limestone aquifer.

Loss of injected freshwater could occur if a storage zone is not well confined. Injected water may move upward or downward out of the storage zone, or saline water may move up into the storage zone during recovery.

Recovery efficiency is greater in a thin aquifer than in a thick aquifer because of the lower vertical extent of the transition zone along which mixing occurs. However, this effect can be partially offset by increasing the volume of water recharged during a cycle. Minimizing the thickness of the storage zone within a thick aquifer can also be beneficial depending on the aquifer's distribution of vertical hydraulic conductivity.

Downgradient movement of a bubble of recharged water due to the background hydraulic gradient could reduce recovery efficiency. Based on an estimated gradient at the Hialeah ASR site in the Upper Floridan aquifer, reduction in recovery due to this effect was simulated to be minor for a storage period of 6 months, but not for 5 years (Merritt and others, 1983). The average velocity of ambient flow, referred to as the average linear velocity, is a function of both hydraulic conductivity and porosity as well as the background hydraulic gradient (Freeze and Cherry, 1979).

The structural setting of the storage zone at an ASR site could be important to recovery (Water Resources Solutions, Inc., 1999a). Freshwater recovery at a site located in an area that is structurally high or where the dip is low could be more favorable than in an area that is in a structural depression or where the dip is relatively high due to the tendency of the bubble of recharged water to move updip because of buoyancy forces. This factor is likely to be more important as the contrast in salinity and fluid density increases. Structural deformation may influence storage zone confinement due to fracturing, faulting, or vertical dissolution features.

Design and Management Factors

The location of the storage zone relative to the aquifer may be important. If a storage zone extends over only a portion of an aquifer's thickness, this could negatively affect recovery. Merritt (1985) simulated recovery in a case where the ASR storage zone extended only over the lower part of the important flow zone (zone with high permeability) near the top of the Upper Floridan aquifer. Results indicated that recovery efficiency was virtually unaffected compared to the case with the well open to the full thickness of the zone. However, the low ambient salinity (1,200 to 1,300 mg/L chloride concentration) and the moderate hydraulic conductivity values that were used in the simulation prevented any appreciable buoyancy effects from occurring (effects that could cause vertical flow and mixing to increase).

The volume of injected water affects the recovery efficiency. On a per cycle basis, recovery efficiency generally increases as the total volume of injected water increases (Merritt, 1985). However, the effect is much less beneficial when interlayer dispersion (the transverse dispersion between layers of differing hydraulic conductivity in the aquifer) increases. Interlayer dispersion causes mixing between injected and ambient waters in addition to the mixing in the transition zone.

Recovery efficiency increases with repeated cycles. Twelve successive cycles of injection and recovery, with recovery of up to only 250 mg/L chloride concentration for each cycle, were simulated for a variety of longitudinal and transverse dispersivity coefficients. Recovery efficiency improved substantially for all cases with repeated cycles, but the rate of improvement diminished with increasing cycles (fig. 4). Recovery efficiency 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 of a lower salinity.

Well plugging can occur during recharge in the Upper Floridan aquifer, reducing the recharge rate and freshwater recovery. This plugging is usually caused by deposition of particulate matter in the injected water or by the formation of a precipitate or sludge caused by reactions that occur at the wellbore face or in the aquifer. One method used to restore formation injectivity is periodic backflushing of the well during the recharge phase. At the Hialeah site, well backflushing produced very fine particles of calcite and an iron compound that had precipitated (Merritt, 1997). Plugging at the Lee County site is attributed to suspended material in the injected water and bacteriological growth at the open borehole face (Fitzpatrick, 1986). Well plugging may affect one flow zone in an open-hole interval more than another, reducing overall recovery. During recovery, the less affected zone contributes most of the flow, and the salinity of water from this zone exceeds the limiting salinity level before all the recoverable freshwater from the plugged zone is obtained.

Various numbers and configurations of multiple storage wells at a site were modeled by Merritt (1985). In that study, the number of wells were varied from one to nine, and the well patterns were varied from a linear array to eight wells in an octagonal pattern with an additional well in the center. Greatest recovery efficiencies were attained in arrays consisting of a central well surrounded by perimeter wells. Though in all cases, the recovery efficiencies for the multiple-well configurations were no better than the single-well case injecting the same total volume as the array of wells. Recovery efficiency could improve, however, when the total volume injected increases as the number of wells injecting at a site increases.

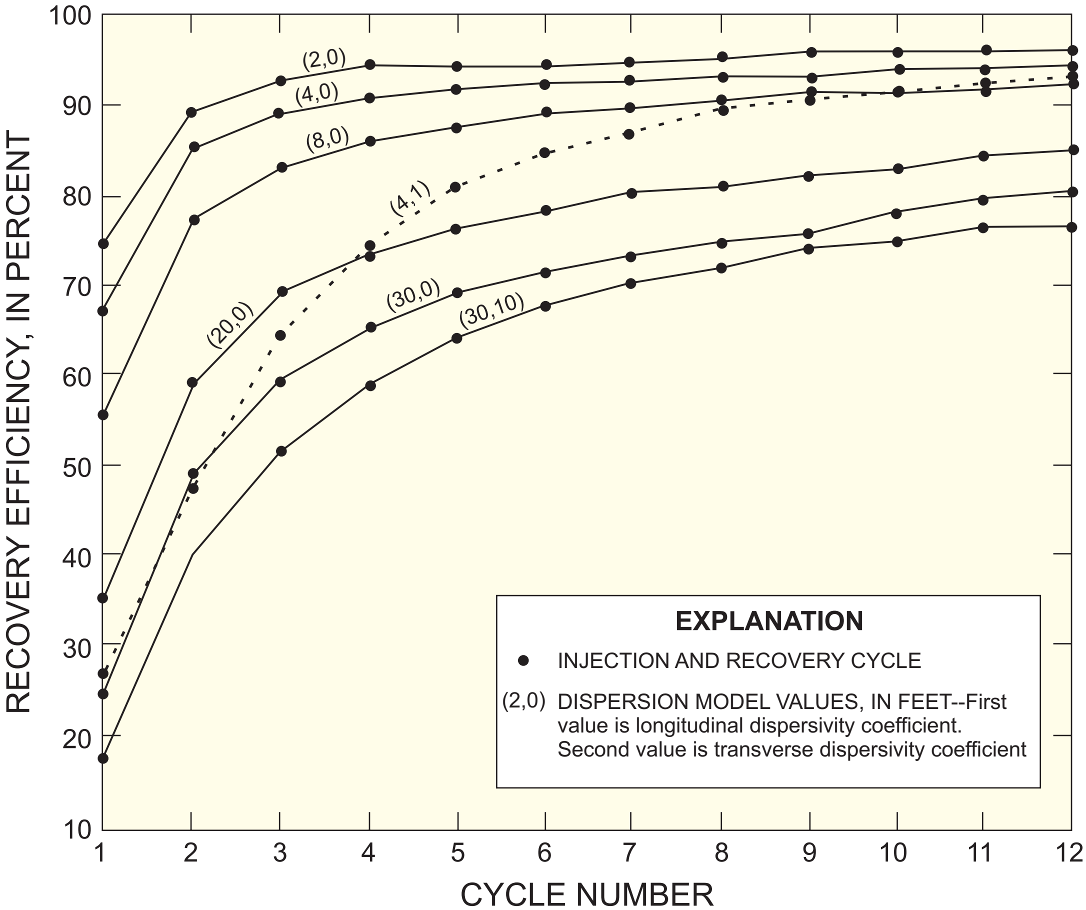

Figure 4. Simulated improvement of potable water recovery efficiency with successive injection and recovery cycles for a variety of dispersion models. The Upper Floridan aquifer at the Hialeah aquifer storage and recovery site was used in the design of the model (modified from Merritt, 1985).

Hydrogeology

The three principal hydrogeologic units in southern Florida are the surficial, intermediate, and Floridan aquifer systems. These aquifer systems in the western part of the study area (Lee, Hendry, and Collier Counties) are described in figure 5. Water-bearing rocks in the intermediate aquifer system grade or pinch out to the east, and in southeastern Florida the intermediate aquifer system becomes the intermediate confining unit. The Floridan aquifer system consists of the Upper Floridan aquifer, middle confining unit, and Lower Floridan aquifer. Three of the aquifers used for ASR in southern Florida are shown in figure 5; namely, the sandstone and mid-Hawthorn aquifers of the intermediate aquifer system and the Upper Floridan aquifer.

The Upper Floridan aquifer is 500 to 1,200 ft thick in southern Florida (fig. 5; Reese, 1994 and Reese and Memberg, 2000). This aquifer is well confined above by thick units in the Hawthorn Group consisting of clay, marl, silt, or clayey sand; hydraulic head in the aquifer is above land surface. The middle confining unit of the Floridan aquifer system underlies the Upper Floridan aquifer and provides good to leaky confinement. This confining unit consists of micritic limestone (wackstone to mudstone), dense dolomite, and in some areas, beds of gypsum (fig. 5). The upper and lower boundaries of the middle confining unit are difficult to define, but its thickness has been estimated to range from 500 to 800 ft in southwestern Florida.

In southwestern Florida, the Upper Floridan aquifer includes the lower part of the Hawthorn Group, Suwannee Limestone, Ocala Limestone, and in some areas, the upper part of the Avon Park Formation (fig. 5). In southeastern Florida, the Suwannee Limestone and Ocala Limestone are commonly absent (Reese, 2000; Reese and Memberg, 2000). In both eastern and western areas, the top of the Upper Floridan aquifer usually is contained within a basal

Series		Geologic Unit		Approximate thickness (feet)	Lithology
HOLOCENE TO PLIOCENE		UNDIFFERENTIATED		0-70	Quartz sand, silt, clay, and shell
HOLOCENE TO PLIOCENE		TAMIAMI FORMATION		0-175	Silt, sandy clay, micritic limestone, sandy, shelly limestone, calcereous sandstone, and quartz sand
MIOCENE AND LATE OLIGOCENE		HAWTHORN GROUP	PEACE RIVER FORMATION	50-400	Interbedded sand, silt, gravel, clay, carbonate, and phosphatic sand
MIOCENE AND LATE OLIGOCENE		HAWTHORN GROUP	ARCADIA FORMATION	400-550	Sandy limestone, shell beds, dolomite, phosphatic sand and carbonate, sand, silt, and clay
EARLY OLIGOCENE		SUWANNEE LIMESTONE		0-600	Fossiliferous, calcarenitic limestone
EOCENE	LATE	OCALA LIMESTONE		0-400	Chalky to fossiliferous, calcarenitic limestone
EOCENE	MIDDLE	AVON PARK FORMATION		900-1,200	Fine-grained, micritic to fossiliferous limestone, dolomitic limestone, dense dolomite, and gypsum
		?		?	
EOCENE	EARLY	OLDSMAR FORMATION		800-1,400	Fine-grained, micritic to fossiliferous limestone, dolomitic limestone, dense dolomite, and gypsum
PALEOCENE		CEDAR KEYS FORMATION		500-700	Dolomite and dolomitic limestone
PALEOCENE		CEDAR KEYS FORMATION		1,200?	Massive anhydrite beds

Hydrogeologic unit			Approximate thickness (feet)	
SURFICIAL AQUIFER SYSTEM	WATER-TABLE AQUIFER		20-100	
SURFICIAL AQUIFER SYSTEM	CONFINING BEDS		0-60	
SURFICIAL AQUIFER SYSTEM	LOWER TAMIAMI AQUIFER		25-160	
INTERMEDIATE AQUIFER SYSTEM	CONFINING UNIT		20-100	
INTERMEDIATE AQUIFER SYSTEM	SANDSTONE AQUIFER		0-100	
INTERMEDIATE AQUIFER SYSTEM	CONFINING UNIT		10-250	
INTERMEDIATE AQUIFER SYSTEM	MID-HAWTHORN AQUIFER		0-130	
INTERMEDIATE AQUIFER SYSTEM	CONFINING UNIT		100-400	
FLORIDAN AQUIFER SYSTEM	UPPER FLORIDAN AQUIFER	LOWER HAWTHORN PRODUCING ZONE	700-1,200	0-300
FLORIDAN AQUIFER SYSTEM	MIDDLE CONFINING UNIT		500-800	
FLORIDAN AQUIFER SYSTEM	LOWER FLORIDAN AQUIFER	BOULDER ZONE	1,400-1,800	400
	SUB-FLORIDAN CONFINING UNIT		1,200?	

Figure 5. Generalized geology and hydrogeology of Lee, Hendry, and Collier Counties (modified from Reese, 2000).

Hawthorn unit, which is defined by an overlying marker unit composed of micritic limestone or marl (fig. 5; Reese and Memberg, 2000). In some areas along the east coast, the Suwannee Limestone is either interpreted as being absent (Miller, 1986; Reese and Memberg, 2000) or present in the lower part of this basal Hawthorn unit.

The Upper Floridan aquifer generally consists of several thin water-bearing zones of high permeability (flow zones) interlayered with thick zones of much lower permeability. Commonly, only one or two major flow zones provide the bulk of the productive capacity. These flow zones are often less than 20 ft thick each and tend to be in the upper part of the Upper Floridan aquifer, typically at or near the top of the Suwannee Limestone, Ocala Limestone, and Avon Park Formation. Unconformities that formed at the end of the Oligocene and Eocene Epochs are present at these contacts (Miller, 1986), and zones of dissolution occur in association with these unconformities in southern Florida (Meyer, 1989a). In southwestern Florida, the most important flow zone tends to be associated with the top of the Suwannee Limestone, whereas in southeastern Florida it is the top of the Avon Park Formation or, if present, the top of the Ocala Limestone. In both of these areas, the basal Hawthorn unit lies above this contact.

The basal Hawthorn unit is shown in an east-west hydrogeologic section that extends across Palm Beach County near the southern end of Lake Okeechobee (figs. 6 and 7). This unit is thickest along

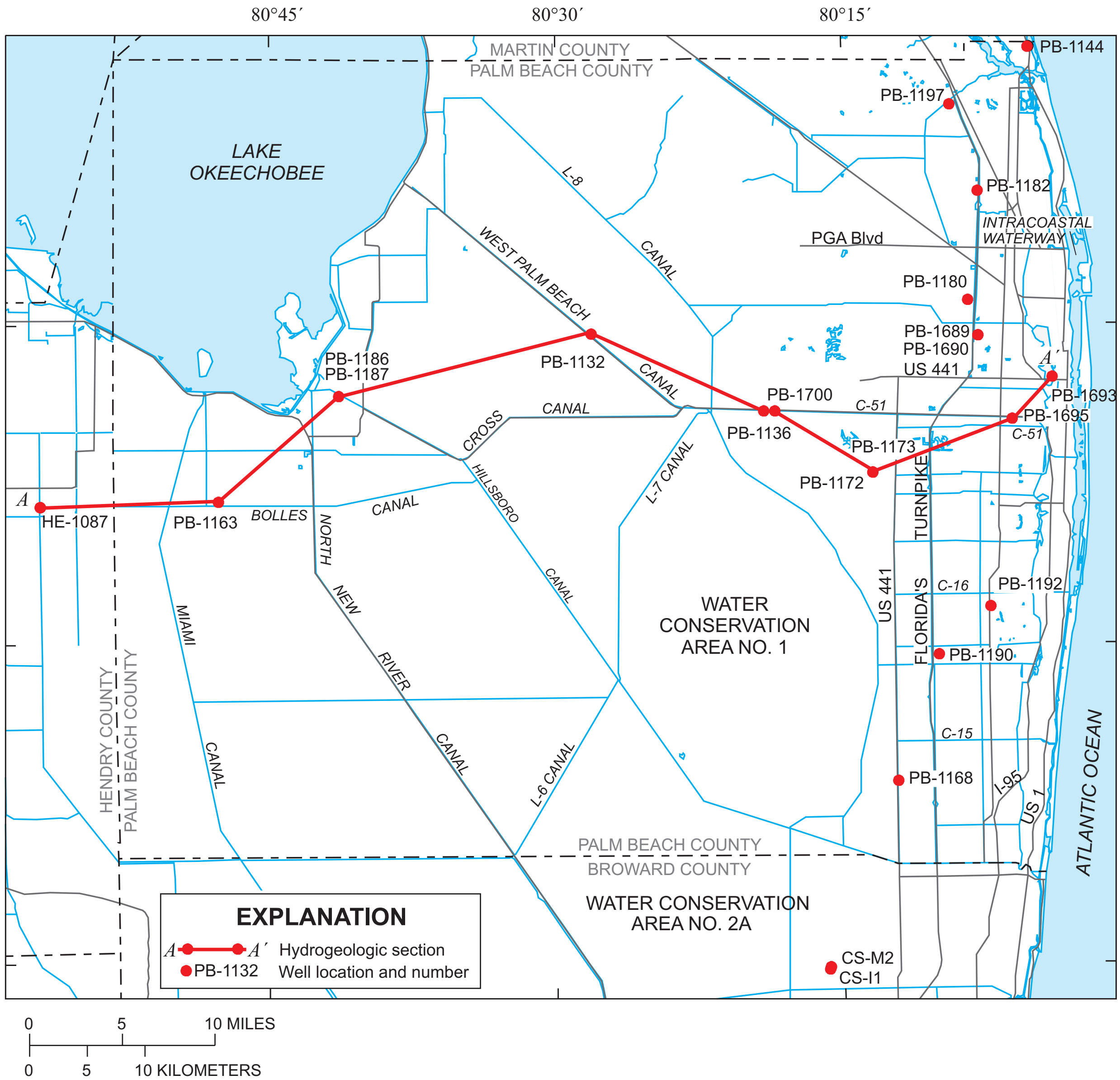

Figure 6. Trace of hydrogeologic section in Palm Beach County (modified from Reese and Memberg, 2000).

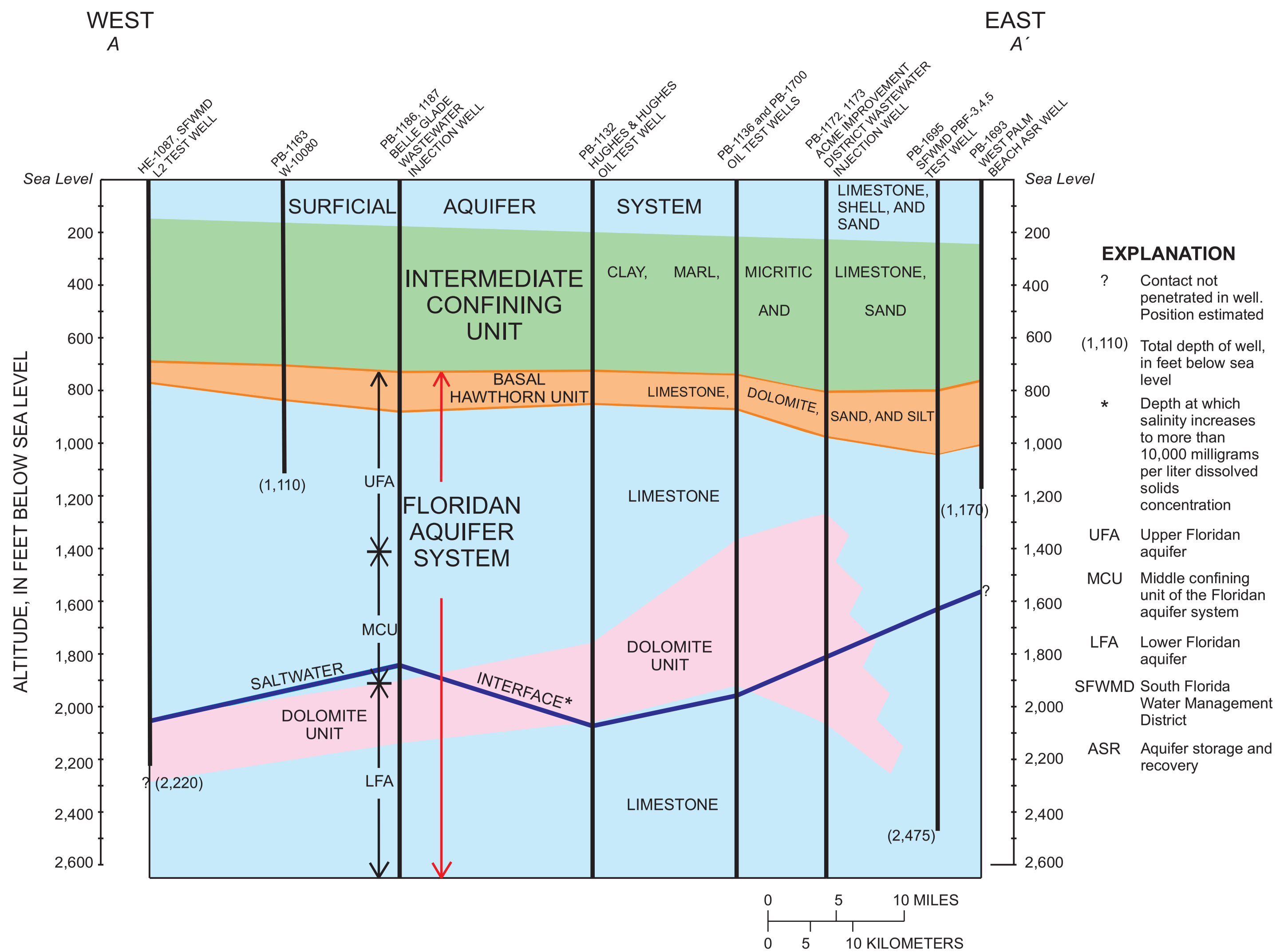

Figure 7. Hydrogeologic section extending east-west across Palm Beach County (modified from Reese and Memberg, 2000).

the coast and thins toward the center of the peninsula. Also shown on the section (fig. 7) are the depths of the saltwater interface in the Floridan aquifer system and a unit composed mostly of dolomite and dolomitic limestone referred to as the dolomite unit (Reese and Memberg, 2000). The saltwater interface (fig. 7) is defined as the depth below which total dissolved solids concentration is greater than 10,000 mg/L.

The dolomite unit of the Floridan aquifer system generally is considered to be within the uppermost permeable unit of the Lower Floridan aquifer in southern Florida (fig. 7; Meyer, 1989a). In some areas of Palm Beach County, however, the top of this unit is as high as 1,200 to 1,300 ft below sea level, as shown (for example) by wells PB-1172 and PB-1173 in figure 7. In these areas, it is uncertain whether all of the dolomite unit would be included in the Lower Floridan aquifer.

The altitude of the basal contact of the Hawthorn Group (same as the base of the basal Hawthorn unit) was mapped for most of southern Florida in three previous studies (Reese, 1994, fig. 6; Reese, 2000, fig. 7; and Reese and Memberg, 2000, fig. 6). Determination of the depth of this contact was primarily based on lithology and gamma-ray geophysical log patterns. As described above, this contact does not necessarily correspond with the top of the Upper Floridan aquifer, but the most important flow zone(s) in the Upper Floridan aquifer is typically associated with the contact. The altitude of this contact varies considerably in southern Florida, ranging from less than 600 ft to greater than 1,200 ft below sea level. Local relief can be as much as several hundred feet, particularly in southwestern Florida.

Complex structure in the Hawthorn Group has been identified in Lee and Hendry Counties along the Caloosahatchee River (Cunningham and others, 2001). The wavy configuration patterns of seismic reflection data show this structure, and these patterns are probably related to karstic collapse of deeper limestone that could be in the Floridan aquifer system.

Acknowledgments

A number of individuals, private consulting firms, water utilities, and regulatory agencies assisted in this study by providing data and technical input. Maintenance supervisor John Reynolds of the Boynton Beach East WTP and lead operators Guy Bartolotta (Broward County WTP 2A), John Cargill (Fiveash WTP), and Howard Erlick (Springtree WTP) were very helpful in providing information and conducting tours of their sites. Steve Evans, Water Quality Supervisor at the Boynton Beach East WTP, was especially helpful in providing detailed water-quality records of all cycles for the ASR well. Offices of the Underground Injection Control Program of FDEP in West Palm Beach, Ft. Myers, and Tallahassee graciously provided additional ASR technical information and data. Mark Pearce of Water Resource Solutions, Inc., Cape Coral, Fla., provided helpful technical input.

INVENTORY OF WELL AND TEST DATA

Well data were inventoried and compiled for all wells at existing and historical ASR sites in southern Florida, and cycle test data (also available for many sites) were synthesized. Consulting reports on the construction and testing of wells and on cycle testing provided much of these data. The consulting reports used to compile these data are listed in the selected references section at the back of this report.

Historical and current ASR sites are listed in table 1 along with the utility or operator of the site, the aquifer being used for the storage zone, site status, type of source water used for injection, and number of wells drilled at each site. The locations of these sites are shown in figure 1. The number of injection (storage) wells at each site ranges from one to five, and most sites have at least one monitoring well in the storage zone.

The type of source water used for injection in southern Florida has included treated drinking water, raw ground or surface water, and reclaimed water (table 1). Treated drinking water is the most common source water type, but raw ground water also is used, or has been proposed for use, at a number of sites on the east coast. The source water planned for the CERP ASR program is raw or partially treated ground water or surface water (table 1, Western Hillsboro Canal, site 1). Special permits, obtained through the FDEP Underground Injection Control program and the U.S. Environmental Protection Agency, are required to inject raw surface or ground water because these waters sometimes exceed maximum contaminant levels for primary or secondary drinking water standards for some constituents.

Construction and Testing Data

Construction and testing data were compiled into three main categories. These categories are well identification, location, and construction data; hydraulic well-test data; and ambient formation water-quality data.

Well Identification and Construction Data

For the purpose of this study, all ASR storage and associated monitoring wells were assigned a USGS number, and data from these wells have been stored as part of the USGS Ground-Water Site Inventory (GWSI) database. Well identification, location, and construction data are given in table 2 (at end of report). The construction information includes total hole depth, ending date of construction, casing depth and diameter, type of each casing string set in the well, and the completed (constructed) open interval and its diameter. In most cases, the completed interval is open hole, but a gravel-packed screen was installed in a few wells. At many sites, the first well drilled was plugged back to the selected storage zone after being drilled deeper to test other potential zones or to determine water-quality changes with depth. In many instances, the latitude and longitude provided herein were obtained from the construction permit, and this location is representative of the storage well only; however, in some instances, the latitude and longitude were more precisely determined for all wells at a site by the use of a hand-held global positioning system (GPS) (see footnote 1 in table 2 at end of report).

The thickness of the open interval ranges from 45 ft at the Marco Lakes (well C-1206) and Marathon (well MO-189) sites to 452 ft at the West Well Field site (well G-3706) (fig. 8; table 2 at end of reort). Open intervals for ASR wells in the Floridan aquifer system average 172 ft thick. The diameter of the open interval ranges from 5.125 in. at the St. Lucie County site to 29 in. at the West Well Field site in Miami-Dade County. Large diameter open intervals are constructed for the purpose of obtaining a high rate of flow. Each of the storage wells at the West Well Field site is designed for a pumping rate of up to 5 Mgal/d.

Hydraulic Well-Test Data

Reported data describing hydraulic tests were compiled for ASR well systems. The data include the reported results of packer tests conducted during drilling, step drawdown tests, single-well constant rate recovery tests, and multiwell constant rate tests (table 3 at end of report). Tests of other permeable intervals at a site that are shallower or deeper than the interval selected to be the storage zone are also included (table 3 at end of report). Water-level data were not analyzed as part of this study; rather, all of the analytical results given in table 3 (at end of report) came from consulting reports in the selected references listed at the back of this report.

Some tests reported in table 3 (at end of report) are single-well step drawdown tests run to determine the specific capacity of a well. These tests provide insight into the productive capacity of a well and are used to determine the size and depth of a pump to be used in the well for a multiwell test or for long-term operation. At some sites, the transmissivity of the tested interval was estimated from a step drawdown test using the specific capacity at each step. At the Marco Lakes ASR site, transmissivity was determined during a step drawdown test of ASR-3 by analyzing the resulting drawdown data from nearby wells using the Cooper and Jacob (1946) solution. Transmissivity was estimated at the Boynton Beach East WTP site from a step drawdown test of ASR-1 using the Cooper and Jacob (1946) solution, but without any monitoring wells. Specific capacity determined from step drawdown tests of storage zones range from 2.7 gal/min/ft at the Marathon site to 390 gal/min/ft at the West Palm Beach site, well ASR-1 (table 3 at end of report). Specific capacity was reported to be 1,600 gal/min/ft on the basis of a multiwell test at the Taylor Creek/Nubbin Slough (Lake Okeechobee) site.

Packer tests are tests of open-hole intervals conducted during drilling using inflatable packers set on a string of drill pipe for the purpose of isolating the interval to be tested. Often, only specific capacity data are reported for packer tests (table 3 at end of report). However, transmissivity can be estimated either from the specific capacity results, or from analysis of the recovery of water level after a period of constant rate pumping during a packer test. This latter method, known as the Theis (1935) residual drawdown or recovery analysis, gives a more reliable estimate than the specific capacity method. Packer test results can be unreliable because of partial penetration, a low pumping rate, a short pumping period, or incomplete isolation of the interval tested (leaky packers).

Hydraulic properties determined from a multiwell, constant rate, drawdown test include transmissivity, storage coefficient, and leakance. Solutions commonly used to analyze water-level data from this type of test include Theis (1935) and Cooper and Jacob (1946) for confined aquifers and Hantush and Jacob (1955) and Walton (1962) for semiconfined, leaky aquifers. Depending on the amount of drawdown (pumping rate) and the degree of background variations in water level, such as tidal fluctuations,

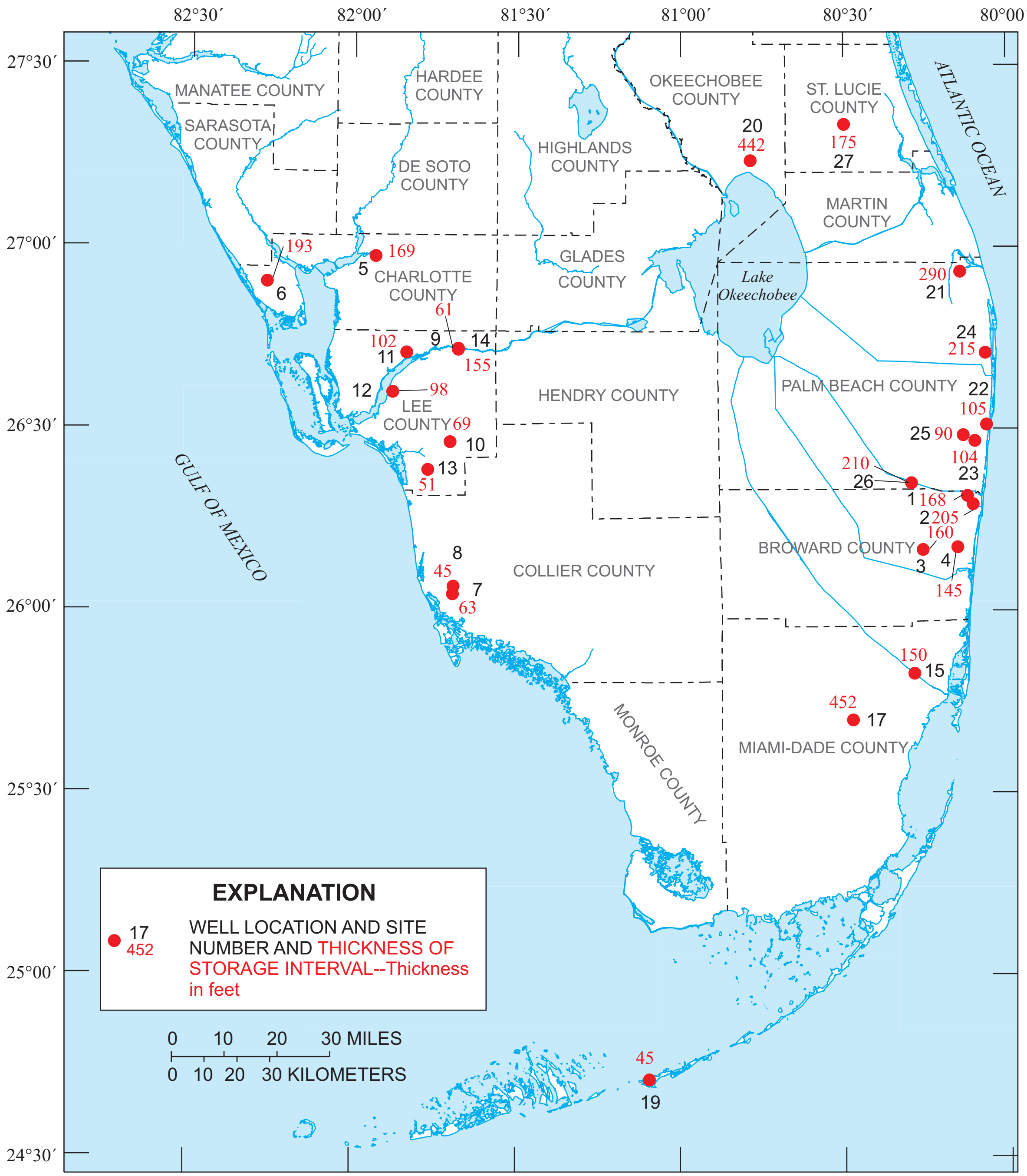

Figure 8. Thickness of open interval in storage wells at aquifer storage and recovery sites in southern Florida. All wells represent first storage well at each site (see table 2).

background water-level measurements should be made for at least 1 day prior to the beginning of the pumping test, and these measurements should be subtracted from the drawdown water-level data collected during the test. Single-well constant rate tests usually provide only an estimate of transmissivity, and solutions used to analyze the recovery water-level data from these tests include the Theis (1935) solution for residual drawdown and the Cooper and Jacob (1946) solution.

Multiwell constant rate tests of the storage zone were performed at 16 of the ASR sites (table 3 at end of report), and not including packer tests, single-well constant rate recovery tests of the storage zone were run at 4 sites, 2 of which also had a multiwell-test run. Constant rate test results could be affected by pretest well treatment designed to increase specific capacity. Acidization of the ASR well prior to the multiwell test was done at the Springtree WTP and West Well Field sites. The Western Hillsboro site planned recharge well (EXW-1) also was acidized after the reported step drawdown test (table 3 at end of report).

Hydraulic properties determined from tests of storage zones may apply only to the storage zone or to a thicker interval if the aquifer containing the storage zone is thicker than the storage zone. In the case where the aquifer is thicker than the storage zone, the hydraulic conductivity of a storage zone will be less than that obtained by dividing the transmissivity determined from a test by the thickness of the storage zone. However, in the Upper Floridan aquifer where thick zones of relatively low permeability separate flow zones, tests of part of the aquifer are typically not influenced by the entire thickness of the aquifer. Thus, the value of transmissivity obtained is less than the total transmissivity of the aquifer (Wedderburn and Knapp, 1983).

For 18 sites where the storage zone is in the Floridan aquifer system, the most reliable or representative values for transmissivity from storage zone tests were selected and then plotted on a map of southern Florida (fig. 9). In most cases, these values came from drawdown analysis of constant rate multiwell tests; if performed, the leaky aquifer solution was used. The storage zone is in the Upper Floridan aquifer in all cases, except at the Taylor Creek/Nubbin Slough (Lake Okeechobee) and the West Well Field sites. At the Lake Okeechobee site, this zone is in the Lower Floridan aquifer (Quiñones-Aponte and others, 1996), and at the West Well Field site, some of the mid-Hawthorn aquifer in addition to the upper part of the Upper Floridan aquifer is included in the storage zone. Transmissivity values range from 800 ft^2/d at the Lee County site to nearly 590,000 ft^2/d at the Lake Okeechobee site. The highest value in the Upper Floridan aquifer is 108,000 ft^2/d at the West Palm Beach WTP site. The average value for sites in the Upper Floridan aquifer is 21,100 ft^2/d, and values greater than 30,000 ft^2/d are considered to be high in this study.

The high transmissivity estimate at the Lake Okeechobee site (fig. 9) is a function of the large thickness of the open interval and the dominant lithology in this interval, which is dolomite. The storage zone contains several highly permeable flow zones that may have secondary fracture permeability. The open interval in the ASR well for the Lee County WTP site is confined to the lower Hawthorn producing zone of the basal Hawthorn unit (Reese, 2000). A second ASR site was later constructed at the same location (Olga WTP site). The Olga WTP site storage zone is deeper in the Upper Floridan aquifer and is contained within the Suwannee Limestone, about 150 ft below the top of this formation (Water Resources Solutions, Inc., 2000a). The estimated transmissivity for the Olga storage zone is 9,400 ft^2/d (fig. 9; table 3 at end of report).

Leakance of the tested aquifer was determined at eight sites in the Floridan aquifer system by multiwell aquifer tests, and values are higher than expected (table 3 at end of report). Leakance is a measure of the degree of aquifer confinement and is defined as the vertical hydraulic conductivity of a confining unit, *divided* by the thickness of the confining unit. However, leakance determined from an aquifer test applies to both the upper and lower confining units of the aquifer, unless it is known that one of the confining units is nonleaky. Leakance estimates ranged from 3.9×10^{-5} 1/d at the West Well Field site to 6.3×10^{-2} 1/d at the Deerfield Beach West WTP site. Leakance estimates less than 1×10^{-3} 1/d have been used to indicate confining conditions in the surficial aquifer system in southern Florida (Reese and Cunningham, 2000). Of the eight values determined for leakance (table 3 at end of report), five exceed this limiting value. Leakance was greater than 4.0×10^{-2} 1/d at the Deerfield Beach West WTP, Olga WTP, and the St. Lucie County sites. Leakance may also be high at the West Palm Beach WTP site. The confined aquifer Theis (1935) solution was used to analyze the multiwell-test data collected at this site, despite a large observed departure below the type curve during the latter part of the test indicating a leaky aquifer.

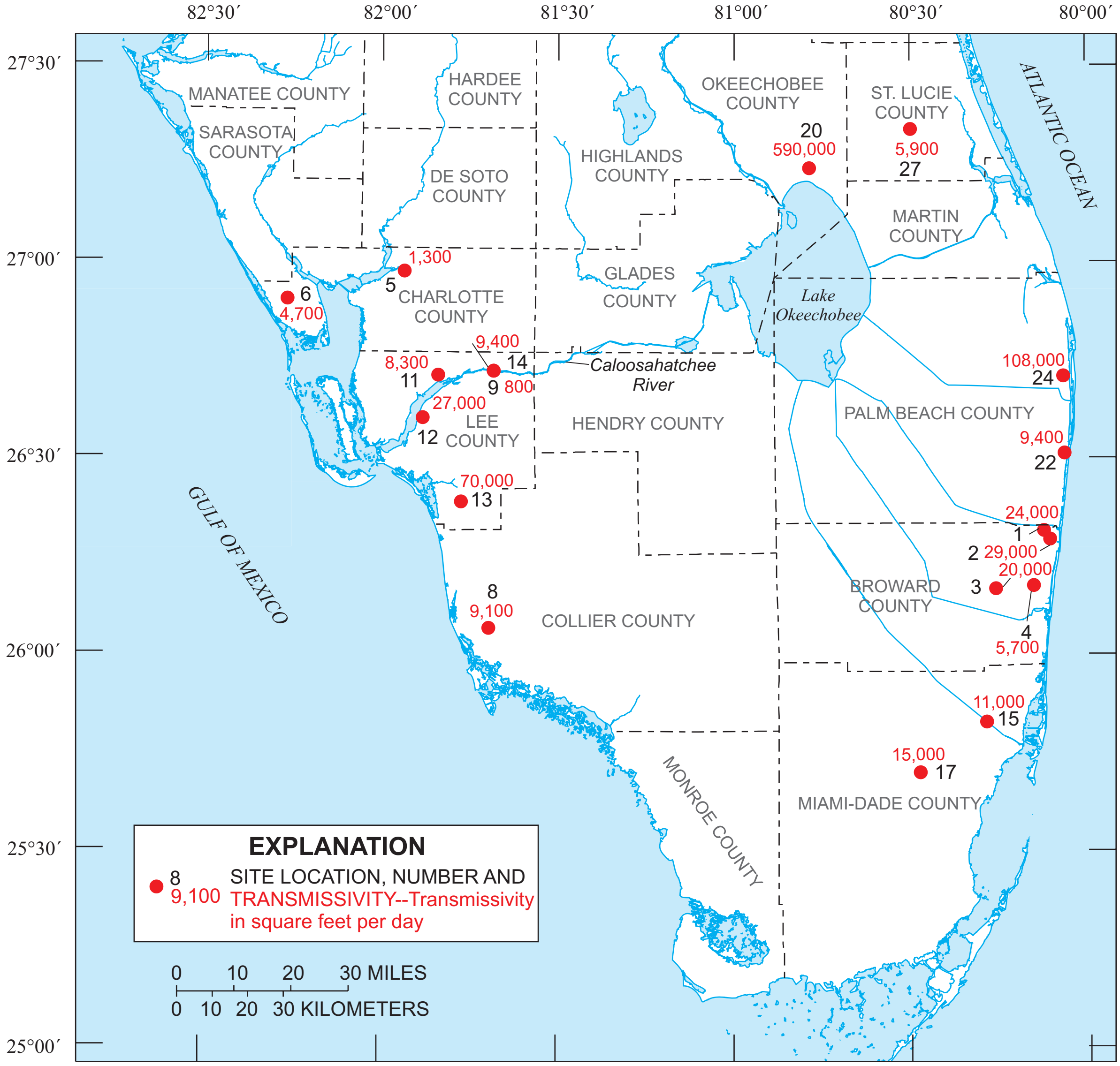

Figure 9. Transmissivity determined for storage zones in the Floridan aquifer system at aquifer storage and recovery sites in southern Florida. The production well used for the test at all sites was ASR-1, except for sites 15 and 27 where MW-1 was used.

The high leakance estimates from the Upper Floridan aquifer are probably best attributed to leakage from below the tested interval rather than from above because of the good confinement generally accepted as being present above the aquifer in southern Florida (Bush and Johnston, 1988). This leakage either originated from intervals lower in the Upper Floridan aquifer or from the middle confining unit of the Floridan aquifer system.

Ambient Water-Quality Data

Ambient water-quality data were collected from storage and monitoring wells at ASR sites (table 4). The inventoried data describe formation water salinity and include the sampled interval, sample date, specific conductance, dissolved chloride concentration, dissolved solids concentration, temperature, and dissolved sulfate concentration. The sampling methods, listed in order of increasing reliability, include (1) collected during drilling by the reverse-air rotary method, (2) collected from packer tests, (3) collected from a pump out test of an open interval below casing before final construction of the well, and (4) collected from a completed open interval. Intervals sampled include the storage zone, intervals deeper and shallower than the storage zone, and intervals that include more than the

Table 4. Ambient water-quality data collected from aquifer storage and recovery well systems in southern Florida

[USGS, U.S. Geological Survey; WTP, water treatment plant; WWTP, wastewater treatment plant; PD, post development; --, not determined or not reported. Type of interval: C, constructed (completed) open interval; O, pump out test of open interval below casing during drilling; P, packer test interval; R, sample collected during reverse-air rotary drilling with top of interval being the base of casing]

Site name	Other identifier	USGS local number	Interval sampled (feet below land surface)	Type of interval	Date sampled	Specific conductance (microsiemens per centimeter)	Dissolved chloride (milligrams per liter)	Dissolved solids (milligrams per liter)	Temperature (degrees Celsius)	Dissolved sulfate (milligrams per liter)
Broward County										
Deerfield Beach West WTP	ASR-1	G-2887	960-1,128[1]	C	09-30-92	5,400	2,000	3,800	25.0	400
			960-1,120[1]	C	09-03-92	5,430	1,850	3,800	22.7	--
			960-1,128[1]	C	09-09-92	6,000	1,600	3,400	--	400
			960-1,128[1]	C	09-30-92	5,400	2,000	3,800	25.0	400
			960-1,128[1]	C	12-11-92	--	1,800	3,700	--	--
Broward County WTP 2A	ASR-1	G-2889	995-1,200[1]	C	12-03-96	--	1,900	3,200	--	380
	MW-1	G-2916	990-1,200[1]	C	03-12-97	--	1,900	2,600	--	250
Springtree WTP	ASR-1	G-2914	1,110-1,340	R	--	4,300	2,200	--	--	--
			1,110-1,270[1]	C	07-31-97	7,310	2,449	4,520	31.0	644
			1,110-1,270[1]	C	01-13-98	9,300	3,600	6,030	28.0	774
Fiveash WTP	ASR-1	G-2917	1,055-1,300	R	--	7,800	4,000	--	--	--
	FMW-1	G-2918	1,055-1,175[1]	C	03-17-98	9,345	3,524	7,880	--	725
	SMW-1	G-2919	180-200	C	01-15-98	--	24	279	--	21
Charlotte County										
Shell Creek WTP	ASR-1	CH-315	700-1,040	R	--	3,540	--	2,020	--	--
			700-755	P	11-05-97	--	837	2,090	--	--
			700-764	C	11-18-97	--	850	1,918	--	--
			764-933[1]	C	08-07-99	--	900	1,900	--	380
Englewood South Regional WWTP	TPW	CH-318	295-808	O	03-02-00	16,800	5,200	10,267	--	664
			563-583	P	02-26-00	31,600	12,000	21,100	--	881
			630-808	P	03-06-00	50,100	17,500	31,133	--	--
			507-700[1]	C	03-31-00	27,000	11,595	19,350	24.2	1,279
	SZMW-1	CH-319	510-700[1]	C	04-20-00	21,600	10,997	22,100	21.0	1,106
	IMW-1	CH-320	280-320	C	04-18-00	11,780	4,458	8,040	21.0	535
	SMW-1	CH-321	170-205	C	04-18-00	8,410	2,875	6,000	21.0	204
Collier County										
Manatee Road	ASR-1	C-1202	465-528[1]	C	10-15-91	8,030	2,754	5,032	--	--
			320-398	P	12-18-90	--	2,450	5,287	--	723
	MW-A	C-1102	970-1,110	P	11-90	--	10,000	--	--	--
			1,220-1,270	P	11-90	--	17,000	--	--	--
			1,330-1,610	P	11-90	--	18,000	--	--	--
			360-500	C	11-90	--	--	--	--	--
			650-770	C	11-90	--	4,000	--	--	--

Table 4. Ambient water-quality data collected from aquifer storage and recovery well systems in southern Florida --(Continued)

[USGS, U.S. Geological Survey; WTP, water treatment plant; WWTP, wastewater treatment plant; PD, post development; --, not determined or not reported. Type of interval: C, constructed (completed) open interval; O, pump out test of open interval below casing during drilling; P, packer test interval; R, sample collected during reverse-air rotary drilling with top of interval being the base of casing]

Site name	Other identifier	USGS local number	Interval sampled (feet below land surface)	Type of interval	Date sampled	Specific conductance (microsiemens per centimeter)	Dissolved chloride (milligrams per liter)	Dissolved solids (milligrams per liter)	Temperature (degrees Celsius)	Dissolved sulfate (milligrams per liter)
Collier County--Continued										
Marco Lakes	ASR-1	C-1206	745-790[1]	C	--	6,000	2,520	6,620	--	--
			745-790[1]	C	06-24-97	--	3,740	5,500	--	744
	DZMW	C-1207	293-352	C	07-01-97	--	3,260	6,180	--	800
			745-817[1]	C	07-01-97	--	2,590	5,620	--	718
	ASR-2	C-1208	735-780[1]	C	PD	8,500	2,480	--	--	--
			735-780[1]	C	09-20-99	6,860	2,449	4,280	--	663
	MHZ2MW	C-1209	440-470	C	09-20-99	8,700	2,999	5,665	25.8	758
	ASRZMW	C-1210	725-774[1]	C	10-01-99	9,120	2,958	5,816	29.8	699
	ASR-3	C-1211	735-780[1]	C	PD	9,120	2,680	--	--	--
			735-780[1]	C	11-24-99	8,860	2,774	3,920	26.3	686
Lee County										
Lee County WTP	MW-1	L-2530	475-615[1]	C	09-25-79	2,500	500	1,520	26.5	270
Corkscrew WTP	ASR-1 LM3982	L-5855	328-397[1]	C	09-09-95	--	39	336	27.0	18
	MW-A	L-5856	524-578	P	08-17-94	640	100	--	--	--
			744-778	P	08-24-94	1,930	600	--	--	--
			340-402[1]	C	04-04-97	-	42	348	--	34
North Reservoir	ASR-1 LM-6210	L-5810	540-642[1]	C	03-02-99	2,400	700	--	--	--
			540-642[1]	C	03-04-99	2,450	740	--	--	--
			540-642[1]	C	03-10-99	2,450	750	--	--	--
	MW-1 LM-6208	L-5811	480-518	P	12-07-98	3,230	890	--	--	--
			529-619[1]	P	12-09-98	2,640	700	--	--	--
			640-703	P	12-11-98	2,710	740	--	--	--
			808-890	P	12-16-98	2,450	720	--	--	--
			904-977	P	12-18-98	3,244	1,000	--	--	--
Winkler Avenue	ASR-1		455-574[1]	P	06-16-99	3,860	972	--	28.5	--
			455-575[1]	P	06-17-99	3,240	770	--	28.5	--
			455-553[1]	C	11-01-99	--	1,240	1,770	--	354
	SZMW-1		455-553[1]	C	09-16-99	--	1,282	2,998	--	414
	MHMW-1		150-200	C	11-01-99	--	1,540	2,410	--	323

Table 4. Ambient water-quality data collected from aquifer storage and recovery well systems in southern Florida --(Continued)

[USGS, U.S. Geological Survey; WTP, water treatment plant; WWTP, wastewater treatment plant; PD, post development; --, not determined or not reported. Type of interval: C, constructed (completed) open interval; O, pump out test of open interval below casing during drilling; P, packer test interval; R, sample collected during reverse-air rotary drilling with top of interval being the base of casing]

Site name	Other identifier	USGS local number	Interval sampled (feet below land surface)	Type of interval	Date sampled	Specific conductance (microsiemens per centimeter)	Dissolved chloride (milligrams per liter)	Dissolved solids (milligrams per liter)	Temperature (degrees Celsius)	Dissolved sulfate (milligrams per liter)
Lee County--Continued										
San Carlos Estates	ASR-1	L-5812	650-687[1]	R	--	4,660	1,100	2,800	31.5	560
			650-718[1]	R	--	4,680	1,110	2,900	32.2	560
			650-701[1]	C	06-07-99	4,700	1,100	3,000	--	520
	SZMW-1R	L-5814	659-721[1]	R	--	4,590	1,100	3,000	31.2	520
			659-721[1]	C	07-29-99	4,570	1,100	2,800	--	580
	SMW-1	L-5815	234-321	R	--	1,681	370	920	28.5	83
			234-321	C	08-02-99	1,694	340	950	--	77
Olga WTP	ASR-1 LM-6086	L-5816	859-920[1]	C	10-21-99	2,677	1,000	--	--	--
			859-920[1]	C	11-09-99	2,690	1,000	--	--	--
	MW-1 LM-6209	L-5817	520-610	P	01-05-99	1,988	540	--	--	--
			617-694	P	01-06-99	1,427	260	--	--	--
			840-940[1]	P	02-30-99	3,420	1,000	--	--	--
			840-940[1]	P	02-04-99	3,461	1,140	--	--	--
			715-940	P	02-04-99	2,928	900	--	--	--
			950-1,106	P	02-08-99	2,793	850	--	--	--
	MW-3 LM-6615	L-5818	826-945	P	03-25-99	2,350	790	--	--	--
			857-945[1]	P	03-25-99	2,948	970	--	--	--
Miami-Dade County										
Hialeah	ASR-1	G-3061	955-1,105[1]	C	12-04-74	4,750	1,200	2,920	--	500
	MW-1	G-3062	840-844	C	07-24-75	6,600	1,900	--	--	--
		G-3062	953-1,060[1]	C	11-20-74	4,200	1,200	2,830	--	480
West Well Field	ASR-1	G-3706	850-1,302[1]	C	01-26-97	8,980	2,000	5,980	25.0	238
	ASR-2	G-3707	845-1,250[1]	C	02-25-97	6,650	2,449	4,390	23.0	615
	ASR-3	G-3708	835-1,210[1]	C	04-09-97	6,750	2,349	4,040	--	595
	MW-1	G-3709	855-1,010	C	02-06-97	6,520	2,499	4,300	25.0	662
			1,370-1,390	C	02-06-97	10,590	4,649	7,220	25.0	466
Monroe County										
Marathon	ASR-1	MO-189	387-432[1]	C	05-04-90	49,000	20,800	37,200	--	2,910

Table 4. Ambient water-quality data collected from aquifer storage and recovery well systems in southern Florida --(Continued)

[USGS, U.S. Geological Survey; WTP, water treatment plant; WWTP, wastewater treatment plant; PD, post development; --, not determined or not reported. Type of interval: C, constructed (completed) open interval; O, pump out test of open interval below casing during drilling; P, packer test interval; R, sample collected during reverse-air rotary drilling with top of interval being the base of casing]

Site name	Other identifier	USGS local number	Interval sampled (feet below land surface)	Type of interval	Date sampled	Specific conductance (microsiemens per centimeter)	Dissolved chloride (milligrams per liter)	Dissolved solids (milligrams per liter)	Temper-ature (degrees Celsius)	Dissolved sulfate (milligrams per liter)
Okeechobee County										
Taylor Creek/Nubbin Slough (Lake Okeechobee)	ASR-1	OK -9000	1,268-1,710[1]	C	11-04-89	9,270	2,910	5,730	--	--
			1,268-1,710[1]	C	04-17-91	--	3,100	7,180	35.0	--
	MW-1	OK -9001	1,175-1,227	P	04-20-88	800	131	656	28.5	210
			1,288-1,354	P	04-25-88	4,800	1,680	4,000	28.0	570
			1,347-1,370	P	04-25-88	4,800	1,900	4,230	30.0	630
			1,358-1,508	P	04-24-88	7,500	2,510	5,740	29.0	760
			1,540-1,662	P	04-23-88	7,500	2,920	6,710	28.0	930
			990-1,075	C	04-17-91	--	210	820	27.5	--
	MW-1	OK -9002	1,275-1,700[1]	C	04-17-91	--	2,200	5,230	27.0	--
Palm Beach County										
Jupiter	ASR-1	PB-747	990-1,280[1]	C	06-19-74	6,400	1,800	4,060	--	400
Boynton Beach East WTP	ASR-1	PB-1194	804-909[1]	C	05-21-92	6,670	1,920	3,910	25.0	436
	MW-1	PB-1195	300-320	C	05-21-92	33,100	12,100	21,900	--	617
Delray Beach North Storage Reservoir	ASR-1	PB-1702	849-899	P	06-05-96	9,160	2,630	5,670	--	--
			900-952	P	06-11-96	8,480	2,669	5,529	--	--
			974-1,020	P	06-14-96	7,440	2,143	4,363	--	--
			1,020-1,100	P	06-18-96	6,800	2,057	4,255	--	--
			1,020-1,120	O	07-26-96	6,930	2,069	4,752	--	--
			1,020-1,200[1]	O	09-06-96	6,810	2,556	4,234	--	--
			1,016-1,200[1]	C	09-20-96	--	2,300	8,000	--	430
West Palm Beach WTP	ASR-1	PB-1692	985-1,200[1]	C	07-17-97	7,600	2,800	5,056	--	--
	MW-1	PB-1693	975-1,091	P	08-22-96	7,700	2,600	3,800	--	--
			975-1,090	O	08-29-96	7,700	2,600	3,800	--	--
			975-1,190[1]	O	09-01-96	8,290	2,750	4,150	--	--
			975-1,290	O	09-04-96	7,970	2,300	4,270	--	--
			975-1,384	O	09-06-96	7,120	2,520	3,830	--	--
			1,304-1,384	P	09-14-96	6,860	2,060	3,650	--	--
			975-1,191[1]	C	11-16-96	7,350	2,381	3,550	--	--
System 3 Palm Beach County	ASR-1	PB-1763	1,065-1,155[1]	C	01-28-99	7,820	2,100	4,080	23.7	467

Table 4. Ambient water-quality data collected from aquifer storage and recovery well systems in southern Florida --(Continued)

[USGS, U.S. Geological Survey; WTP, water treatment plant; WWTP, wastewater treatment plant; PD, post development; --, not determined or not reported. Type of interval: C, constructed (completed) open interval; O, pump out test of open interval below casing during drilling; P, packer test interval; R, sample collected during reverse-air rotary drilling with top of interval being the base of casing]

Site name	Other identifier	USGS local number	Interval sampled (feet below land surface)	Type of interval	Date sampled	Specific conductance (microsiemens per centimeter)	Dissolved chloride (milligrams per liter)	Dissolved solids (milligrams per liter)	Temper-ature (degrees Celsius)	Dissolved sulfate (milligrams per liter)
Palm Beach County--Continued										
Western Hillsboro Canal, Site 1	EXW-1	PB-1765	1,160-1,225	P	04-05-00	3,898	1,390	--	23.9	--
			1,015-1,150	P	04-07-00	8,223	2,706	--	23.8	--
			1,015-1,225[1]	C	11-18-00	6,900	--	--	--	--
	PBF-10R	PB-1767	1,015-1,225[1]	C	01-24-01	9,440	--	--	--	--
St. Lucie County										
St. Lucie County	ASR-1	STL-356	600-766[1]	P	03-11-82	3,400	888	2,058	27.8	--
			770-1,000	P	03-12-82	3,200	1,015	1,888	27.8	--
			600-775[1]	C	03-12-82	3,325	955	2,379	27.8	--
	MW-1	STL-357	600-775[1]	C	03-12-82	3,500	1,022	2,143	27.8	--

[1]Interval tested is the same (or about the same) as the storage zone.

selected storage zone (table 4). Upper Floridan aquifer ASR sites in southwestern Florida were usually sampled from shallower permeable zones of the intermediate aquifer system.

The chloride concentration of ambient water in ASR storage zones in the Floridan aquifer system is shown on a map of southern Florida (fig. 10). Samples used for this map were selected from table 4 based on the most reliable sampling method as described above. Chloride concentrations ranged from 500 mg/L at the Lee County WTP site to 11,000 mg/L at the Englewood South Regional WWTP site. At most sites, the chloride concentration ranged from about 1,000 to 3,000 mg/L, and the average concentration was about 2,300 mg/L. Storage zones containing water with 3,000 mg/L or greater were considered to have high chloride concentration in this study. The highest value found in the east coast area was 3,600 mg/L at the Springtree WTP site. The highest chloride concentration found in the upper part of the Upper Floridan aquifer in southern Florida based on three previous studies was 8,000 mg/L in northeastern Palm Beach County; the lowest concentration found was 400 mg/L in Lee County (Reese, 1994; Reese, 2000; and Reese and Memberg, 2000).

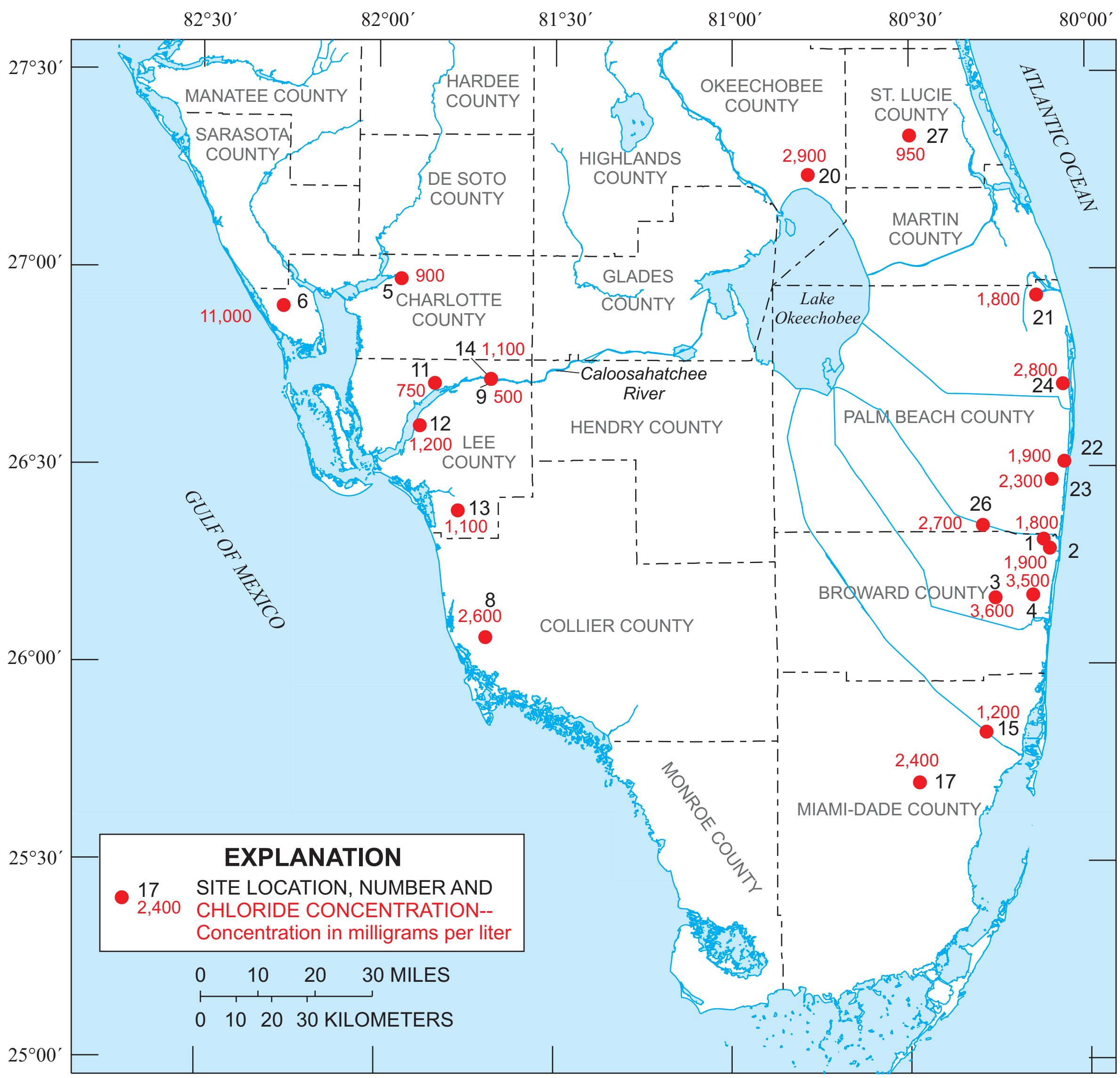

Figure 10. Ambient water salinity of storage zones in the Floridan aquifer system at aquifer storage and recovery sites in southern Florida.

Cycle Test Data

Cycle test information was obtained from consulting reports, other published reports, monthly operating reports (MOR) required by the FDEP as part of the permitting process during operational testing, and in several cases, from daily records provided by a WTP. These data were compiled and are given in table 5. All of the test data given are only for the first storage well (ASR-1) at a site, except for the West Well Field site. Only 18 of the 27 ASR sites listed in table 1 are included in table 5; other ASR sites have not initiated operational testing or test data were not available. Cycle testing at the Olga WTP and North Reservoir sites was postponed due to inadequate treated drinking water supplies that will be used for recharge. The number of days of storage in table 5 includes only the time between the recharge and recovery periods; it does not include days during the recharge period in which injection ceased due to a lack of source water or other operational problems. The MOR provided insufficient data to calculate recovery efficiencies at some ASR sites because the water quality of recharged and recovered water was not reported; these data are not required by the FDEP in the report.

Two recovery efficiency numbers were determined for each cycle (table 5). The first is total recovery efficiency, and it is the percent recovery at the end of the cycle. The chloride concentration of the recovered water at this point is also given in table 5. The chloride concentration at the end of the cycle is usually in the range of 250 to 400 mg/L. The second recovery efficiency number is the potable water recovery efficiency. It is the percent recovery when the chloride concentration of the recovered water reaches only 250 mg/L. Potable water recovery efficiency numbers (potable recovery efficiencies) are used in this report for performance comparisons between sites.

Chloride concentrations of recharged and recovered water for the West Palm Beach WTP site were not reported or made available, and only the total recovery efficiencies are given in table 5. At the West Well Field site, two storage wells were active during the second cycle and all three storage wells were active during the third cycle. However, water was not recovered from well ASR-3 during the cycle 3 recovery period. For cycle 3, recovery efficiencies were determined for individual storage wells and also for all three wells combined (table 5).

The Boynton Beach East WTP site underwent 16 recharge-recovery cycles (table 5). The Marathon site had 11 cycles, and the Marco Lakes and Springtree WTP sites had 5 cycles each; the number of cycles was 4 or less at all other sites. Additional cycles were conducted at the Manatee Road site, but were not reported. Recharge volume per cycle ranged from as low as 0.6 Mgal for cycle 1 at the Lee County WTP site, to as high as 714.33 Mgal during cycle 3 at the West Well Field site. The longest storage period was 181 days for cycle 3 at the Hialeah site.

The highest reported first cycle potable recovery efficiency was 47 percent for the Boynton Beach ASR site. The first cycle recovery efficiency of the Corkscrew WTP site is greater but is not considered here due to the potable nature of water in its storage zone. Except for the Jupiter site where no potable water was reported to be recovered on the first cycle, the lowest potable recovery efficiency was 2 percent at the San Carlos Estates site. Of the 16 sites in table 5 with potable recovery efficiencies calculated, 9 sites had a potable recovery efficiency of well over 10 percent during the first cycle. The seven exceptions include Fiveash WTP, Manatee Road, North Reservoir, San Carlos Estates, Lake Okeechobee, Jupiter, and St. Lucie County sites. Two of these, the Manatee Road and Jupiter sites, showed improvement to a level substantially higher than 10 percent in succeeding cycles. The Fiveash, San Carlos Estates, and Lake Okeechobee sites did not; however, few cycles were conducted at these three sites (two, two and four, respectively). Only one cycle was run at the North Reservoir and St. Lucie County sites.

Ten sites achieved a potable recovery efficiency exceeding 30 percent during at least one cycle; however, at the Shell Creek WTP site, the recovery efficiency diminished to 9 percent during the third cycle when the recharge volume was greatly increased. The highest potable recovery efficiency of 90 percent was during cycle 4 at the Boynton Beach East WTP site, but the recharge volume reported for this cycle could be too low. This recharge volume is based on flow totalizer equipment readings, but calculation of the recharge volume based on reported daily flow rates gives a higher number. The second highest recovery efficiency was 84 percent for cycle 16 at the Boynton Beach site. Recovery efficiency was 72 percent for cycle 4 at the Marathon site; however, the storage zone at this site is within a siliciclastic sandstone aquifer. Because of lower dispersive mixing, recovery from a siliciclastic aquifer may be larger, having only intergranular porosity as compared to carbonate rock storage zones that probably also have secondary, conduit type porosity (Merritt, 1985).

Table 5. Cycle test data from aquifer storage and recovery wells in southern Florida

[Test data at all sites, excluding the West Well Field site, are only for the first storage well at the site (ASR-1). *Data extracted from monthly operating reports and daily records provided by the water treatment plant. All other cycle test data are from consulting reports or other published reports. DS, dissolved solids concentration in mg/L (milligrams per liter); Mgal, million gallons; NA, not applicable; NR, not reported; WTP, Water Treatment Plant; >, greater than]

Site name	Ambient chloride concentration (mg/L)	Cycle			Recharge, storage, recovery periods (days)	Recharge volume (Mgal)	Recovery volume (Mgal)	Chloride concentration of recharge water (mg/L)	Chloride concentration of recovered water at end of cycle (mg/L)	Recovery efficiency at end of cycle (percent)	Recovery efficiency at recovered water chloride concentration of 250 mg/L (percent)
		No.	Beginning date	End date							
Broward County											
Broward County WTP 2A	2,000	Test	07-09-98	07-21-98	10, 1, 2	20	4	30	225	20	>20
		1	07-27-98	11-12-98	91, 0, 17	171	36	35	225	21.1	>21.1
		2	11-13-98	03-11-99	87, 9, 22	196	52	35	225	26	>26
Springtree WTP	3,600	1	07-29-09	08-17-99	20, 0, 4	20	4	70	61	20	>20
		2	08-22-99	10-12-99	40, 1, 10	40	11	65	213	28	>28
		3	10-13-99	12-09-99	42, 1, 14	40	15	60	225	38	>38
		4*	12-10-99	03-27-00	62, 32, 14	40	15	60	222	37.5	>37.5
		5*	03-28-00	11-23-00	[1]178, 31, 31	120	33	NR	225	27.5	>27.5
Fiveash WTP	3,520	1*	10-12-99	10-23-99	10, 0, 1	11.04	1.2	60	225	10.9	>10.9
		2*	10-25-99	12-06-99	39, 1, 2	70.3	4.38	59	225	6.23	>6.23
Charlotte County											
Shell Creek WTP	830	1	07-01-99	08-07-99	21, 0, 9	4.9	1.47	100	250	30	30
		2	08-16-99	09-08-99	17, 0, 8	1.6	.59	75	250	37	37
		3	01-10-00	02-08-00	24, 1, 3	20.3	1.8	180-230	250	9	9
		3	01-10-00	02-08-00	24, 1, 3	20.3	NA	[2]80	250	[2]15	[2]15
Collier County											
Manatee Road	2,750	1	10-16-91	11-06-91	14, 6, 2	6.98	.33	60	300	5	NR
		2	11-11-91	01-14-92	46, 19, 6	30.38	2.57	60	300	8	6.8
		3	07-28-92	09-06-92	20, 20, 6	10	3.02	60	300	30	24
		4	09-15-92	10-25-92	20, 20, 8	10	3.94	60	300	39	32

Table 5. Cycle test data from aquifer storage and recovery wells in southern Florida --(Continued)

[Test data at all sites, excluding the West Well Field site, are only for the first storage well at the site (ASR-1). *Data extracted from monthly operating reports and daily records provided by the water treatment plant. All other cycle test data are from consulting reports or other published reports. DS, dissolved solids concentration in mg/L (milligrams per liter); Mgal, million gallons; NA, not applicable; NR, not reported; WTP, Water Treatment Plant; >, greater than]

Site name	Ambient chloride concentration (mg/L)	Cycle No.	Cycle Beginning date	Cycle End date	Recharge, storage, recovery periods (days)	Recharge volume (Mgal)	Recovery volume (Mgal)	Chloride concentration of recharge water (mg/L)	Chloride concentration of recovered water at end of cycle (mg/L)	Recovery efficiency at end of cycle (percent)	Recovery efficiency at recovered water chloride concentration of 250 mg/L (percent)
Collier County--Continued											
Marco Lakes	2,600	1	06-26-97	08-19-97	39, 3, 12	19.763	6.04	NR	350	31	22
		1*	06-26-97	08-19-97	39, 3, 12	19.763	6.045	110	384	30.6	22.26
		2	08-21-97	02-25-98	88, 63, 37	86.686	25.7	NR	350	30	5.0
		2*	08-21-97	02-25-98	88, 63, 37	86.686	30.222	115	398	34.9	4
		3	03-05-98	04-29-98	26, 2, 27	21.054	15.8	NR	350	75	38
		3*	03-05-98	04-29-98	26, 2, 27	21.054	17.242	130	370	81.9	33.2
		4	09-01-98	06-10-99	134, 83, 68	110	55	NR	350	50.0	34.5
		4*	09-01-98	06-20-99	121, 98, 73	111	64.391	130	420	58.0	NR
		5	08-19-99	07-03-00	140, 102, 77	132	67	110	350	50.8	35.6
		5*	08-19-99	07-02-00	132, 109, 77	132.303	74	110	395	55.9	NR
Lee County											
Lee County WTP	550	1	10-14-80	NR	1.7, 0, 1.4	0.6	0.22	60	250	38.7	38.7
		2	03-26-81	NR	16, 47, 2.8	6.83	.66	150-350	250	9.7	9.7
		3	08-18-81	NR	79, 98, 40.8	29.03	8.82	60-100	250	30.4	30.4
Corkscrew WTP	39	1	10-25-95	11-14-95	7, 1, 12	2.001	2.963	NR	DS=330	150	NA
		2	02-14-96	10-04-96	76, 35, 122	31.3	22.8	NR	DS=300	73	NA
		3	10-07-96	02-12-97	63, 31, 34	26.1	19.8	NR	DS=225	76	NA
North Reservoir	670	1*	02-26-00	03-18-00	13, 7, 1	6.179	.607	155	250	9.8	9.8
San Carlos Estates	1,150	Test	10-25-99	11-15-99	10, 6, 5	28	7	90	600	25	2
		1	11-30-99	06-28-00	175, 0, 36	138	13	90	466	9.4	3.3
Miami-Dade County											
Hialeah	1,200	1	07-17-75	12-17-75	53, 2, 98	41.9	[3]13.8	65	NR	NR	32.9
		2	01-05-76	07-21-76	65, 54, 79	85	[3]40.7	65	NR	NR	47.8
		3	07-23-76	01-30-80	179, 181, 926	208	[3]80.1	65	NR	NR	38.5

Table 5. Cycle test data from aquifer storage and recovery wells in southern Florida --(Continued)

[Test data at all sites, excluding the West Well Field site, are only for the first storage well at the site (ASR-1). *Data extracted from monthly operating reports and daily records provided by the water treatment plant. All other cycle test data are from consulting reports or other published reports. DS, dissolved solids concentration in mg/L (milligrams per liter); Mgal, million gallons; NA, not applicable; NR, not reported; WTP, Water Treatment Plant; >, greater than]

Site name	Ambient chloride concentration (mg/L)	Cycle No.	Cycle Beginning date	Cycle End date	Recharge, storage, recovery periods (days)	Recharge volume (Mgal)	Recovery volume (Mgal)	Chloride concentration of recharge water (mg/L)	Chloride concentration of recovered water at end of cycle (mg/L)	Recovery efficiency at end of cycle (percent)	Recovery efficiency at recovered water chloride concentration of 250 mg/L (percent)
Miami-Dade County--Continued											
West Well Field	2,400	1* (ASR-1)	02-18-99	07-21-99	146, 0, 7	359.7	27.8	48	164	7.7	>7.7
		2* (ASR-1)	07-31-99	02-15-00	187, 0, 12	212.2	53.3	43	80	25.1	>25.1
		2* (ASR-2)	09-03-99	02-15-00	153, 0, 12	276.1	61.7	43	212	22.3	>22.3
		3* (ASR-1)	02-15-00	03-23-01	299, 18, 85	338.56	359.37	41	500	106.1	57.4
		3* (ASR-2)	03-27-00	03-23-01	153, 123, 85	175.3	446.563	41	1,150	254.7	54.2
		3* (ASR-3)	02-15-00	03-23-01	Recharge = 299	200.47	No recovery	41	No recovery	NA	NA
		3* (ASR-1, ASR2, ASR-3 combined)	See dates above	See dates above	See values above	714.33	805.933	41	See values above	112.8	40.5
Monroe County											
Marathon	20,800	1	08-12-90	09-17-90	17, 0, 19	4.528	5.132	42	16,200	113	33
		2	09-17-90	12-13-90	43, 34, 11	9.698	3.458	NR	290	35	28
		3	12-13-90	01-25-91	27, 0, 16	5.322	4.181	NR	NR	79	68
		4	01-28-91	02-20-91	14, 0, 10	3.623	2.752	NR	NR	76	72
		5	NR	NR	51, 39, 26	15	6.5	NR	NR	NR	43
		6	NR	NR	56, 36, 43	15.1	7.7	NR	NR	NR	51
		7	NR	NR	56, 35, 30	15..8	8.9	NR	NR	NR	55
		8	NR	NR	76, 21, 34	15.4	10.1	NR	NR	NR	65
		9	NR	NR	54, 0, 44	15	10.1	NR	NR	NR	65
		10	NR	NR	56, 35, 31	15.3	8.6	NR	NR	NR	56
		11	NR	NR	63, 81, 25	[4]14	10.4	NR	NR	NR	71

Table 5. Cycle test data from aquifer storage and recovery wells in southern Florida --(Continued)

[Test data at all sites, excluding the West Well Field site, are only for the first storage well at the site (ASR-1). *Data extracted from monthly operating reports and daily records provided by the water treatment plant. All other cycle test data are from consulting reports or other published reports. DS, dissolved solids concentration in mg/L (milligrams per liter); Mgal, million gallons; NA, not applicable; NR, not reported; WTP, Water Treatment Plant; >, greater than]

Site name	Ambient chloride concen-tration (mg/L)	Cycle No.	Cycle Begin-ning date	Cycle End date	Recharge, storage, recovery periods (days)	Recharge volume (Mgal)	Recovery volume (Mgal)	Chloride concen-tration of recharge water (mg/L)	Chloride concen-tration of recovered water at end of cycle (mg/L)	Recov-ery effi-ciency at end of cycle (per-cent)	Recovery efficiency at recovered water chloride concen-tration of 250 mg/L (percent)
Okeechobee County											
Taylor Creek/Nubbin Slough (Lake Okeechobee)	3,100	[5]4	09-05-89	11-04-89	20, 0, 40	90.94	NR	NR	[6]1,385	24	NR
		[7]1	04-17-91	05-29-91	35, 0, 7	181.35	28.06	150	[6]1,385	15	3.1
		[7]2	06-24-91	09-20-91	63, 8, 17	342.1	75.9	100 or less	[6]1,385	22	2.7
		[7]3	09-23-91	12-02-91	65, 5, 0	355	128	70 or less	[6]1,385	36	7.2
Palm Beach County											
Jupiter	1,980	1	NR	NR	Storage=15	[8]20.5	[8]0	65	250	0	0
		2	NR	NR	Storage=30	[8]100	[8]4.7	65	250	4.7	4.7
		3	NR	NR	Storage=30	[8]306	[8]55.5	65	250	18	18
		4	NR	NR	Storage=120	[8]102	[8]36.1	65	250	35.2	35.2
Boynton Beach East WTP	1,920	1	10-21-92	11-10-92	14, 0, 8	12.52	9.58	60	760	76.5	47
		2	11-10-92	01-22-93	44, 0, 31	57.32	26.1	50	420	45.5	30
		3	01-25-93	04-06-93	43, 5, 25	58.34	32.24	50	NR	55.3	47
		3*	01-25-93	04-06-93	41, 8, 22	54.31	32.04	47	300	59	49
		4*	04-20-93	05-28-93	16, 8, 14	[9]17.87	17.237	51	274	96.5	90
		5*	06-02-93	12-06-93	55, 98, 34	60.16	39.302	46	300	65.3	53.7
		6*	02-24-94	07-25-94	55, 57, 39	61.24	47.713	47	306.5	77.9	64
		7*	07-25-94	02-13-95	44, 124, 35	60.058	20.052	48	302	33.4	26.7
		8*	04-20-95	07-03-95	46, 2, 26	42.906	20.598	52	320.5	48	40
		9*	09-27-95	12-20-95	33, 22, 29	40.091	31.701	52	301	79.1	63
		10*	01-18-96	05-22-96	46, 52, 27	41.764	34.841	48	307	83.4	75
		11*	06-04-96	12-31-96	34, 149, 27	41.218	37.347	41	314	90.6	82
		12*	01-03-97	06-16-97	42, 81, 41	40.586	32.062	49	302	79	66
		13*	06-19-97	02-23-98	35, 174, 40	42.496	37.061	48	317.5	87.2	70
		14*	02-24-98	08-20-98	45, 1, 131	33.36	95.84	62	1,004	287	81
		15*	11-13-98	06-03-99	83, 57, 62	110.83	37.56	46	146	33.9	>33.9
		16*	06-15-99	01-28-00	156, 4, 67	89.98	88.724	NR	310	98.6	84

Table 5. Cycle test data from aquifer storage and recovery wells in southern Florida --(Continued)

[Test data at all sites, excluding the West Well Field site, are only for the first storage well at the site (ASR-1). *Data extracted from monthly operating reports and daily records provided by the water treatment plant. All other cycle test data are from consulting reports or other published reports. DS, dissolved solids concentration in mg/L (milligrams per liter); Mgal, million gallons; NA, not applicable; NR, not reported; WTP, Water Treatment Plant; >, greater than]

Site name	Ambient chloride concentration (mg/L)	Cycle			Recharge, storage, recovery periods (days)	Recharge volume (Mgal)	Recovery volume (Mgal)	Chloride concentration of recharge water (mg/L)	Chloride concentration of recovered water at end of cycle (mg/L)	Recovery efficiency at end of cycle (percent)	Recovery efficiency at recovered water chloride concentration of 250 mg/L (percent)
		No.	Beginning date	End date							
Palm Beach County--Continued											
West Palm Beach WTP	2,800	1*	10-04-97	01-22-98	93, 0, 17	270.7	40	NR	NR	14.8	NR
		2*	01-23-98	03-27-98	40, 1, 22	110.7	46	NR	NR	41.5	NR
		3*	04-01-98	06-08-98	37, 3, 28	102.6	58	NR	NR	56.5	NR
		4*	08-10-98	11-10-98	53, 3, 36	143.1	73.32	NR	NR	51.2	NR
St. Lucie County											
St. Lucie County	955	1	10-19-82	02-04-83	3, 38, 67	1.5	3.41	200	NR	NR	3
		1	10-19-82	02-04-83	3, 38, 67	1.5	NA	[2]50	NR	NR	[2]33

[1]Cycle 5 had 52 days of down time during the recharge period.

[2]Recovery efficiency estimated using a fictitious value for recharge chloride concentration.

[3]Recovery continued past the reported recovery volume, which had an ending chloride concentration of 250 mg/L.

[4]An additional 5.2 million gallons were recharged during the last 57 days of the storage period by trickle flow (50 gallons per minute).

[5]Conducted by CH_2M Hill.

[6]A specific conductance of 5,000 microsiemens per centimeter was used to terminate recovery for all cycles, which equals 1,385 milligrams per liter chloride concentration.

[7]Conducted by the U.S. Geological Survey.

[8]Injection rate for all cycles was 2,000 gallons per minute, and recovery rate was 1,000 gallons per minute.

[9]The recharge volume for cycle 4 could be too low, which would make the recovery efficiencies too high.

CASE STUDIES OF SELECTED AQUIFER STORAGE AND RECOVERY SITES

Detailed information regarding four sites is presented in this section. For the most part, the sites were selected on the basis of the number of cycles that were conducted. Two sites are located in southeastern Florida, and two are in southwestern Florida. The selected sites illustrate the contrast in hydrogeology between the coastal areas. Each case study includes a graphical representation of the hydrogeology at the site and well construction information.

Boynton Beach East Water Treatment Plant

The Boynton Beach East WTP ASR site located on the east coast in Palm Beach County is operated by Boynton Beach Utilities. The source of water for recharge is treated drinking water from the WTP. The location of the storage zone in relation to lithology, geophysical log signatures, and hydrogeologic units at the Boynton Beach site is shown in figure 11. Also shown are the location of flow zones as determined by flowmeter, fluid resistivity, and caliper logs for the interval extending from a depth of 804 to 1,200 ft below land surface. The flow zones in this interval primarily occur in the basal Hawthorn unit (Reese and Memberg, 2000) or near its base. The flow zones are thin, they tend to coincide with formation resistivity peaks possibly indicating cementation and secondary porosity, and they occur just below intervals of higher gamma-ray response. These intervals of higher gamma-ray response indicate beds high in phosphate sand content. The base of the Upper Floridan aquifer was not penetrated in the ASR well but is estimated to be at a depth of at least 1,500 ft below land surface.

The thickness of the storage zone open interval at the Boynton Beach site is 105 ft (fig. 9); transmissivity is reported to be about 9,400 ft^2/d (fig. 9; CH_2M Hill 1993), and ambient water had a chloride concentration of 1,900 mg/L (fig. 10). The site is located in a structurally high area along the east coast where the altitude of the Hawthorn Group basal contact is 930 ft below sea level (Reese and Memberg, 2000).

Cycle testing at the Boynton Beach site began in late 1992, and by early 2000, 16 recharge-recovery cycles had been conducted for an average of about 2 cycles per year (fig. 12). Potable recovery efficiency increased rapidly during the first four cycles to 90 percent per cycle; however, as noted previously, the 90 percent recovery for cycle 4 is questionable. During the next three cycles, recovery efficiency decreased to less than 30 percent, possibly because of longer storage periods. Recovery efficiency for cycles 8 to 16 generally increased to greater than 80 percent.

Percent recovery is plotted against the chloride concentration of recovered water during each cycle in figure 13. For most cycles, water was recovered until the chloride concentration in the recovered water slightly exceeded 300 mg/L (also see table 5). During cycle 14, however, recovery continued until chloride concentration increased to about 1,000 mg/L, contributing to a lower recovery rate for cycle 15. The data points for cycle 15 are shifted to substantially lower recovery percentages than for cycle 14 (fig. 13). The recovery efficiency for cycle 16 is the best obtained, with the exception of cycle 4, which has a recharge volume that could be higher than reported. However, the storage period for cycle 16 was only 4 days, and the recovery efficiency for this cycle could have benefited from the large recharge volume (111 Mgal) and incomplete recovery (recovery up to a chloride concentration of only 146 mg/L) for cycle 15.

Potable water recovery efficiencies for test and operational cycles at the Boynton Beach site appear to be greater than for all other Floridan aquifer system ASR sites in southern Florida. However, the number of cycles conducted at most other sites are limited, and the chloride concentration of the recharge water used at the Boynton Beach site is only about 50 mg/L (table 5). Several hydrogeologic, and design and management factors are favorable at this site that may explain the higher recovery efficiencies. The storage zone is located at the top of the Upper Floridan aquifer and is thin in comparison to the average storage zone thickness (about 180 ft) for wells in the Floridan aquifer system (fig. 8). Transmissivity and ambient salinity of the storage zone are moderate, being less than 30,000 ft^2/d and 3,000 mg/L of chloride concentration, respectively, and the site is located in a structurally high area.

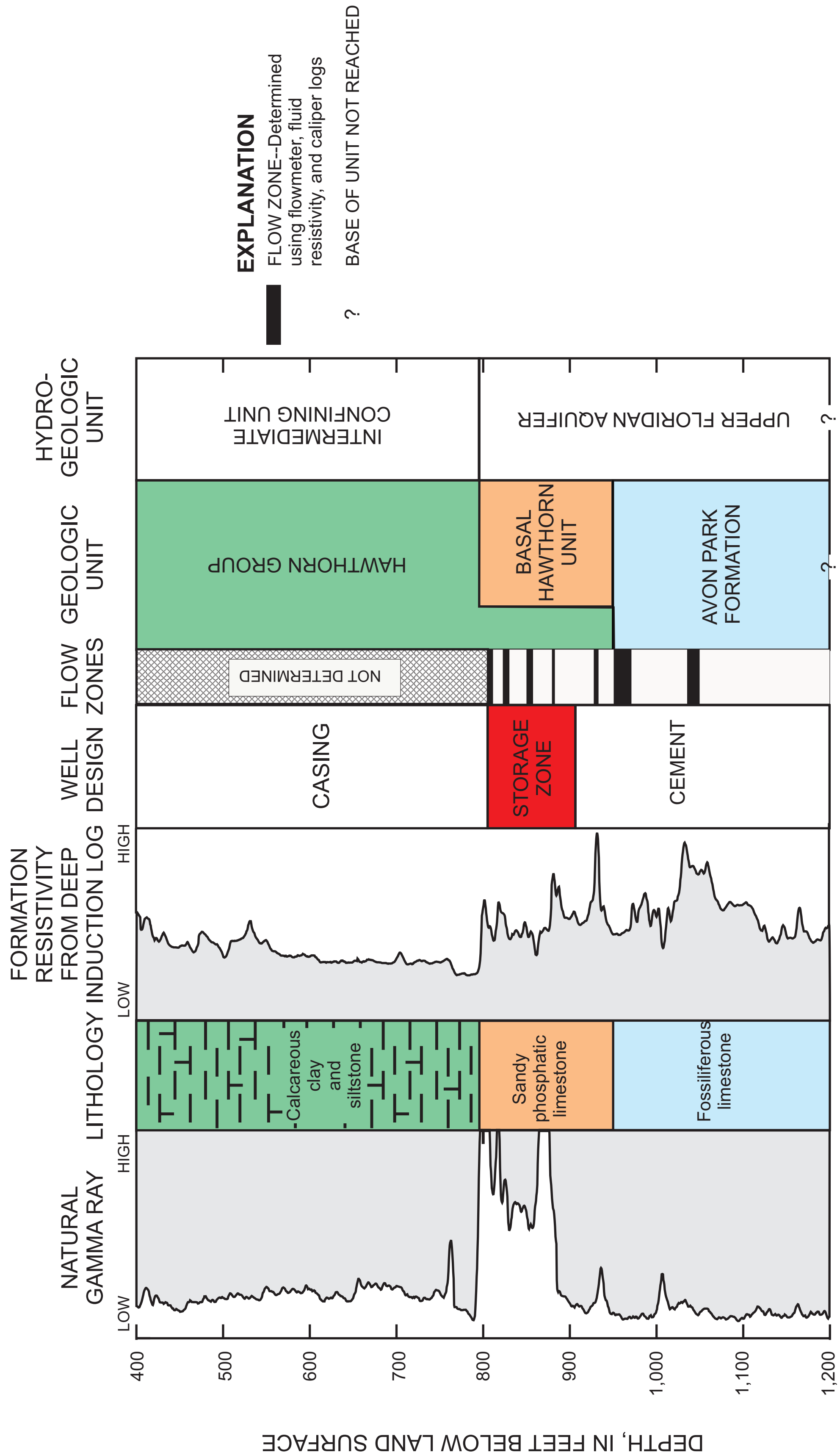

Figure 11. Location of the storage zone in relation to geophysical logs, lithology, flow zones, and geologic and hydrogeologic units for aquifer storage and recovery well PB-1194 at the Boynton Beach East Water Treatment Plant site in Palm Beach County.

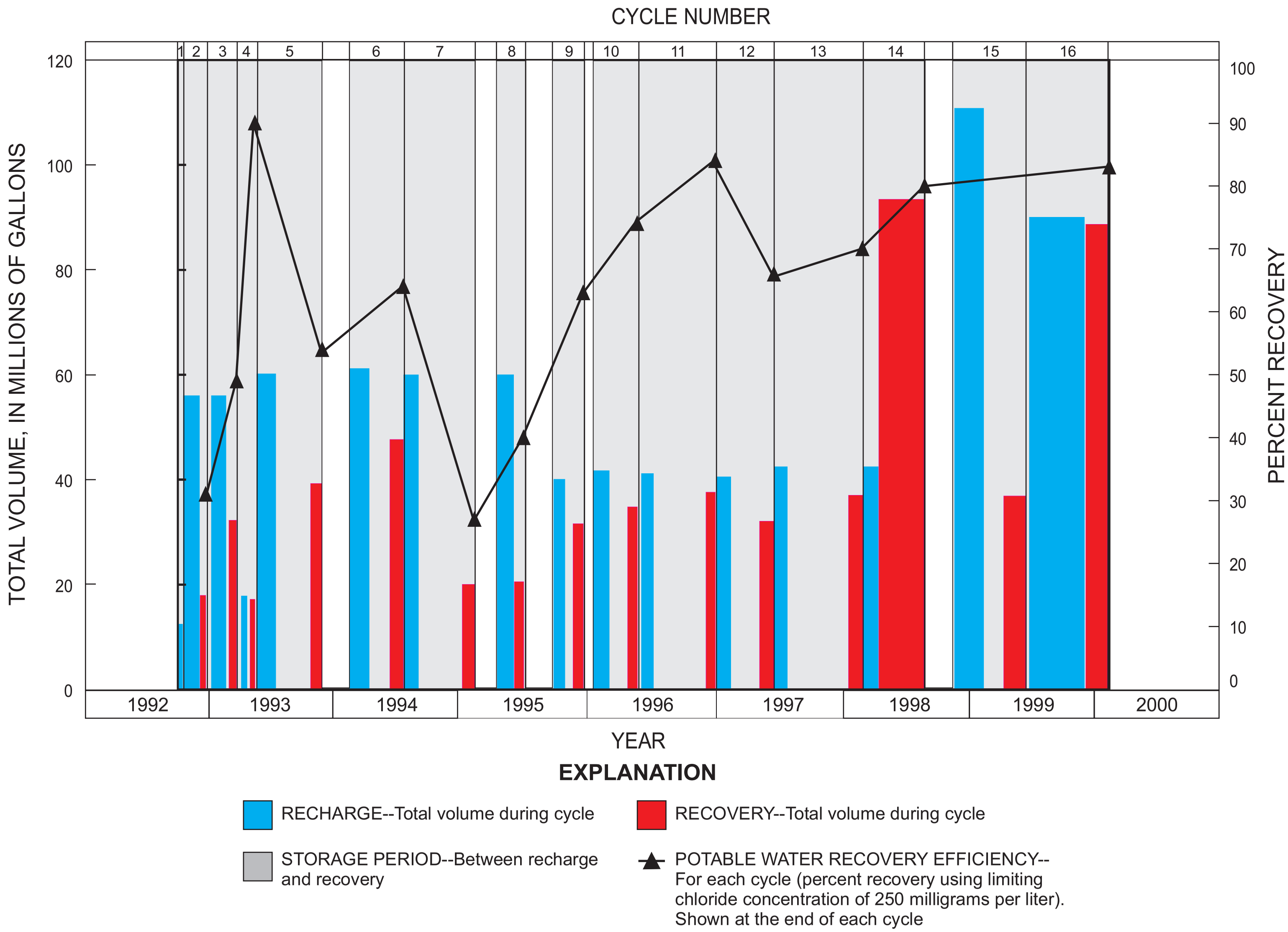

Figure 12. Operational cycles at the Boynton Beach East Water Treatment Plant site in Palm Beach County and relations of volumes recharged and recovered, time, and percent recovery for each cycle. Recovery for cycle 15 was 34 percent for an ending chloride concentration of 146 milligrams per liter.

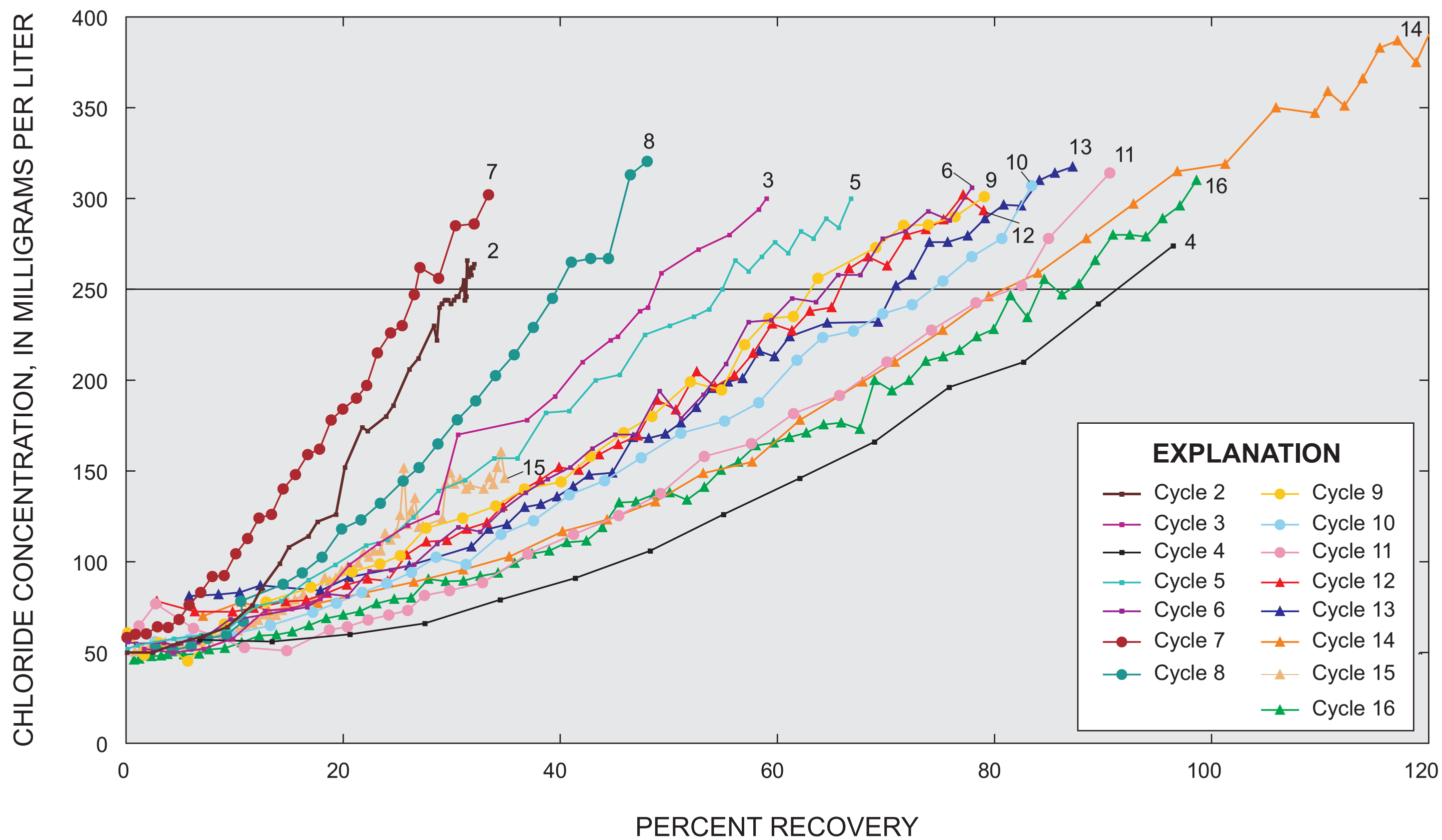

Figure 13. Percent recovery of recharged water during operational cycles in relation to chloride concentration of recovered water at the Boynton Beach East Water Treatment Plant site in Palm Beach County. Recovery for cycle 14 was continued until reaching a chloride concentration of about 1,000 milligrams per liter.

Springtree Water Treatment Plant

The Springtree WTP ASR site located in Broward County is operated by the City of Sunrise. Treated drinking water is used for recharge. The location of the storage zone in relation to lithology, geophysical log signatures, and hydrogeologic units at the Springtree site is shown in figure 14. Geophysical logs, such as the flowmeter, used to identify flow zones in the well were not run. Unlike the Boynton Beach site, the storage zone is not located at the top of the Upper Floridan aquifer. Casing was set through virtually all of the basal Hawthorn unit. The thickness of the storage zone open interval at the Springtree site is 160 ft (fig. 8). A photograph of the Springtree site wellhead site is shown in figure 15.

Storage zone transmissivity at the Springtree site is reported to be about 5,700 ft^2/d (table 3 at end

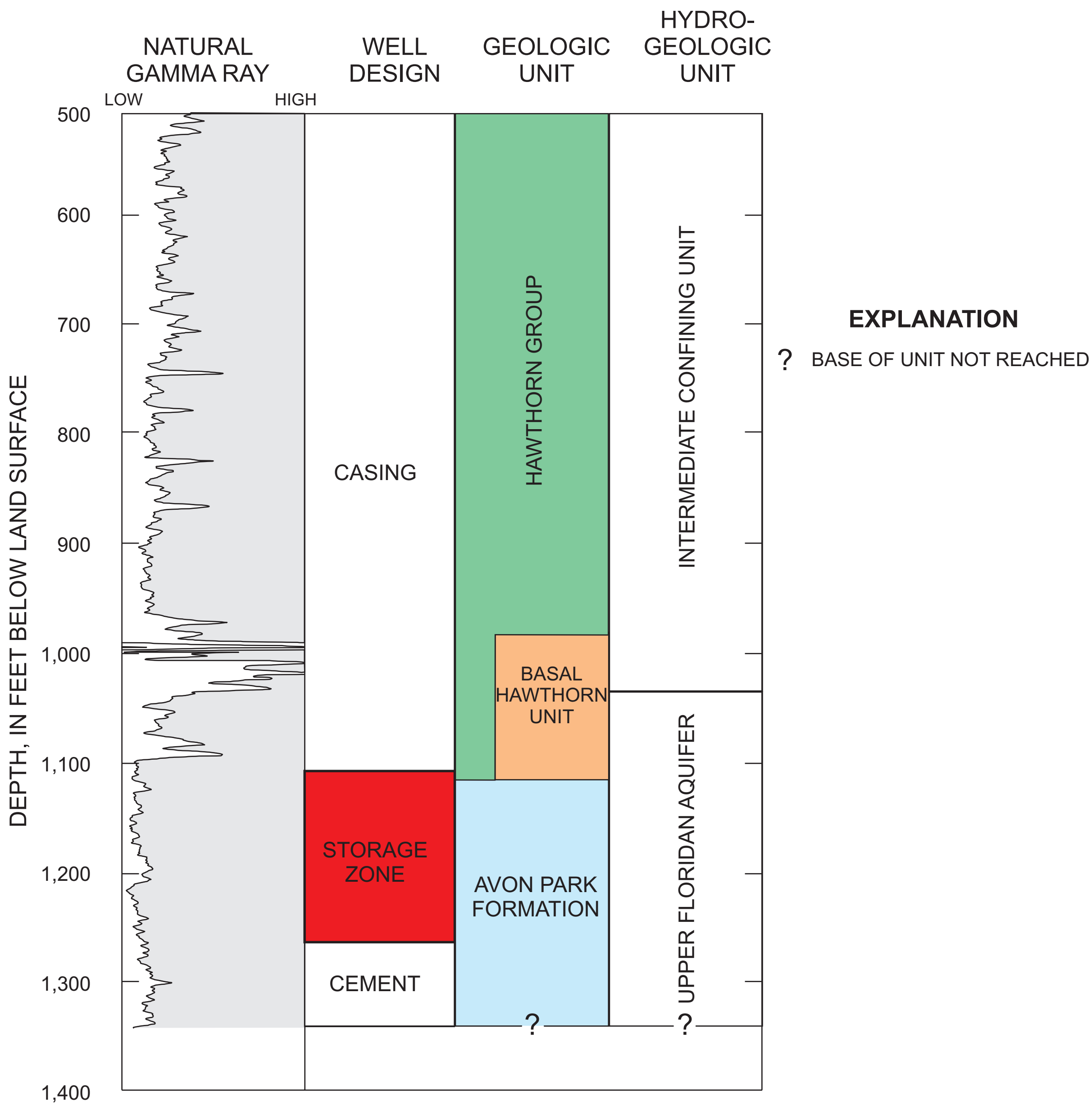

Figure 14. Location of the storage zone in relation to gamma-ray geophysical log and geologic and hydrogeologic units for aquifer storage and recovery well G-2914 at the Springtree Water Treatment Plant site in Broward County.

Figure 15. Wellhead piping, valves, and control system for the aquifer storage and recovery well at the Springtree Water Treatment Plant site in Broward County. Storage well on left side of concrete pad as shown by arrow.

of report; Montgomery Watson, 1998a). This value is lower than at surrounding sites (fig. 9), perhaps because only a small part of the basal Hawthorn unit is included in the open interval. The chloride concentration of ambient water in the storage zone is 3,600 mg/L (fig. 10). The altitude of the Hawthorn Group basal contact is 1,105 ft below sea level, and the site is located at the edge of a structurally low area (Reese, 1994).

Cycle testing at the Springtree site began at the end of July 1999, and five recharge-recovery cycles had been completed by the end of November 2000 (table 5). The ending chloride concentration for all cycles was 225 mg/L or less. The increase in recovery efficiency during the first four cycles was not as great as the Boynton Beach East WTP site, increasing from 20 percent for the first cycle to 37.5 for the fourth cycle. Although the volume recharged for the fifth cycle (120 Mgal) was at least three times that recharged in each of the first four cycles, recovery efficiency diminished to 27.5 percent. The lower recovery efficiencies at the Springtree site relative to the Boynton Beach East WTP site could be explained by high storage zone ambient water salinity and the storage zone position relative to the top of the aquifer.

Marco Lakes

The Marco Lakes ASR site located on the west coast in Collier County is operated by Florida Water Services for the City of Marco Island. The source of recharge water is partially treated surface water. The storage zone at the site straddles the contact between the basal Hawthorn unit and the Suwannee Limestone (fig. 16). The Suwannee Limestone is thick and well developed in the area, unlike southeastern Florida where the formation is thin or absent. The thickness and diameter of the open interval for the storage zone in well ASR-1 at the Marco Lakes site are 45 ft and 10 in., respectively (fig. 8; table 2 at end of report). By comparison, these dimensions are 44 ft and 12.25 in., respectively, for well ASR-2 (fig. 16; table 2 at end of report).

Transmissivity of the storage zone is reported to be about 9,100 ft^2/d (fig. 9; ViroGroup, Inc., 1998b). Storage zone ambient water is brackish; the reported chloride concentration is about 2,600 mg/L (fig. 10; well DZMW, table 4). Chloride concentration ranged from about 2,500 to about 3,700 mg/L in other wells completed in the storage zone at the Marco Lakes site (table 4). The site is located in a structurally high area where the altitude of the Hawthorn Group basal contact is 742 ft below sea level (Reese, 2000).

Five recharge-recovery cycles were conducted at the Marco Lakes site in ASR-1 between June 1997 and July 2000 (table 5). The ending chloride concentration for the recovery period used for comparison of cycles was 350 mg/L (Water Resources Solutions, Inc., 2000d), and the recovery efficiencies at this chloride concentration level increased from 31 percent for the first cycle to about 51 percent for the fifth cycle. The total volume of water recharged per cycle

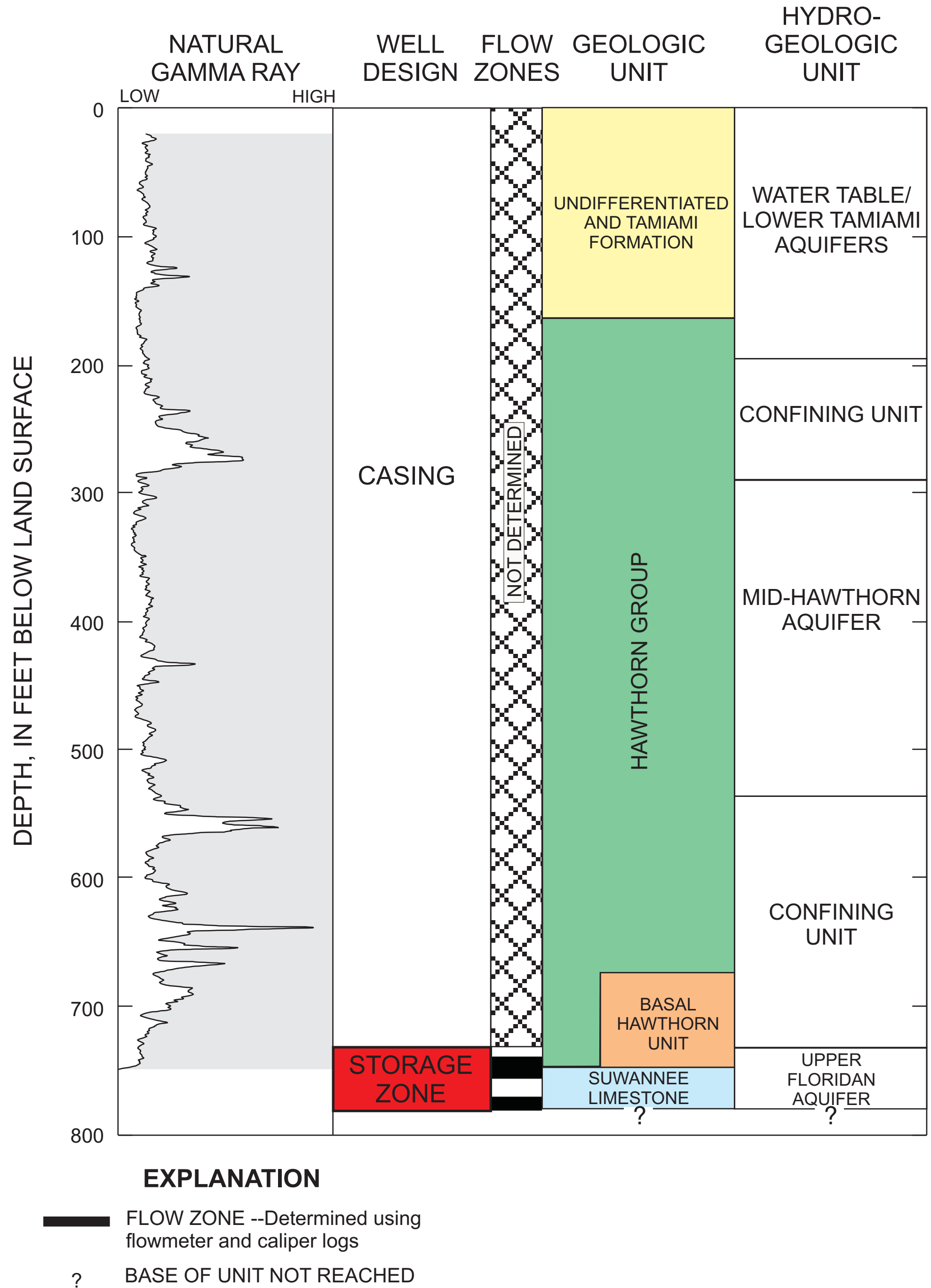

Figure 16. Location of storage zone in relation to gamma-ray geophysical log, flow zones, and geologic and hydrogeologic units for aquifer storage and recovery well C-1208 (ASR-2) at the Marco Lakes site in Collier County

increased from about 20 to 132 Mgal, respectively. The potable water recovery efficiency increased from 22 to almost 36 percent for the same two cycles.

Percent recovery was compared with the chloride concentration of recovered water during each cycle at the Marco Lakes site (fig. 17). On the basis of numerical simulation, the erratic recovery curve and poor recovery efficiency for cycle 2 is attributed to preferential well plugging during recharge of one of two receiving intervals (flow zones) in the storage zone (Water Resources Solutions, Inc., 1999c). Calcium carbonate is the likely precipitate causing plugging, and acidification of the recharge water prior to injection has reduced or eliminated the problem in later cycles.

The Marco Lakes recovery efficiencies at an ending chloride concentration of 350 mg/L rather than those at 250 mg/L concentration could serve as a better comparison with the Boynton Beach East WTP site potable recovery efficiencies. The chloride concentration of the recharge water at Marco Lakes averages

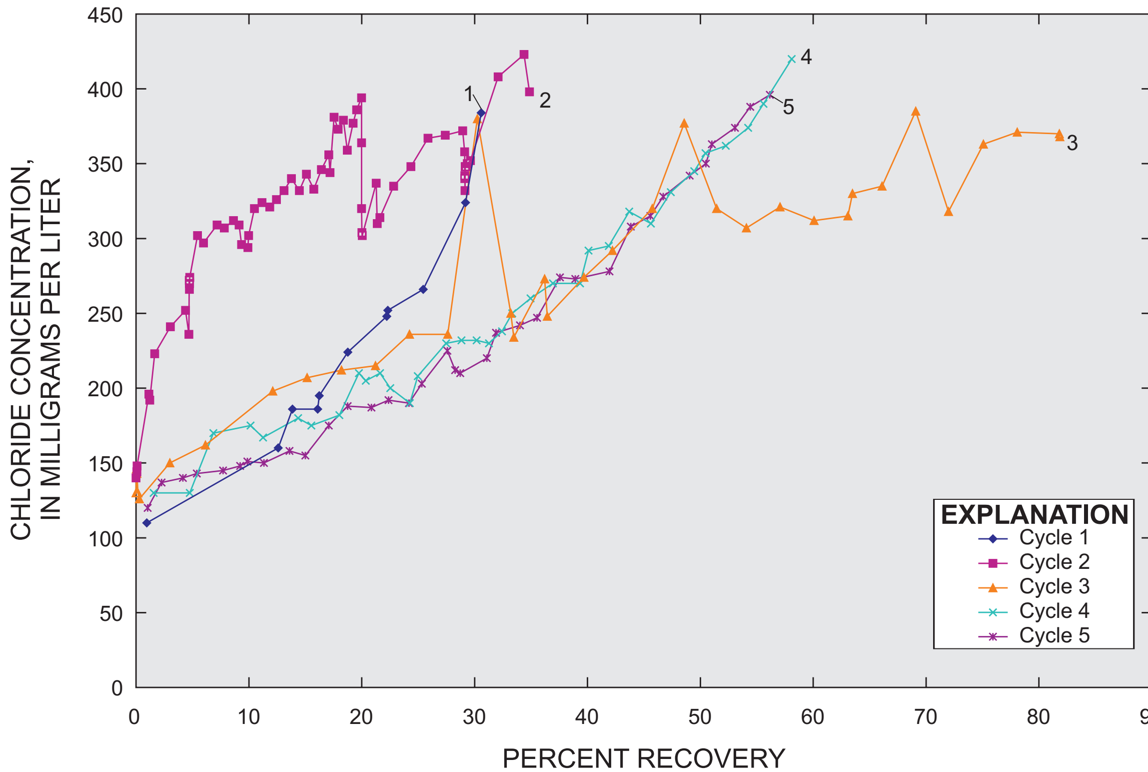

Figure 17. Percent recovery of recharged water during operational cycles in relation to chloride concentration of recovered water at the Marco Lakes site in Collier County.

120 mg/L (table 5), whereas the concentration at Boynton Beach averages about 50 mg/L. Perhaps calculations of recovery efficiencies based on a mass-balance approach would provide a better means of comparison between these two sites. These calculations would include the chloride concentrations of both the ambient and recharged water. Although the Marco Lakes site is in early phases of testing and operation, several factors could explain the moderate to good recovery efficiencies. The storage zone is thin and located near the top of the Upper Floridan aquifer (fig. 16). The storage zone has moderate transmissivity, and the site is located on a structural geologic high.

San Carlos Estates

The San Carlos Estates ASR site located near the west coast in Lee County is operated by Bonita Springs Utilities. Treated drinking water is used as the recharge water source. The storage zone at the site is located within the basal Hawthorn unit (fig. 18). The top of the Suwannee Limestone was not reached in any of the wells at the site. The thickness of the ASR well storage zone is only 51 ft (fig. 8).

Compared to the Marco Lakes site, transmissivity of the storage zone at the San Carlos Estates site is high; it is reported to be about 70,000 ft^2/d (fig. 9; CH_2M Hill, 1999b). The chloride concentration of ambient water in the storage zone is only 1,100 mg/L (fig. 10). The site may be located in a slightly low area structurally (Reese, 2000); however, additional wells that intersect the basal contact of the Hawthorn Group are required to confirm this setting.

Two cycles, one a short test cycle, were conducted at the San Carlos Estates ASR site (table 5). Despite a second cycle recharge volume of 138 Mgal, potable recovery efficiency has been no greater than about 3 percent. High transmissivity of the storage zone and the distribution of permeability within it may explain the poor recovery efficiency obtained thus far. Flowmeter log data indicate that most flow in the storage zone occurs within a 4-ft-thick interval between 698 and 702 ft below land surface (fig. 18). The high permeability of this thin flow zone may cause high dispersive mixing within the storage zone resulting in the poor recovery.

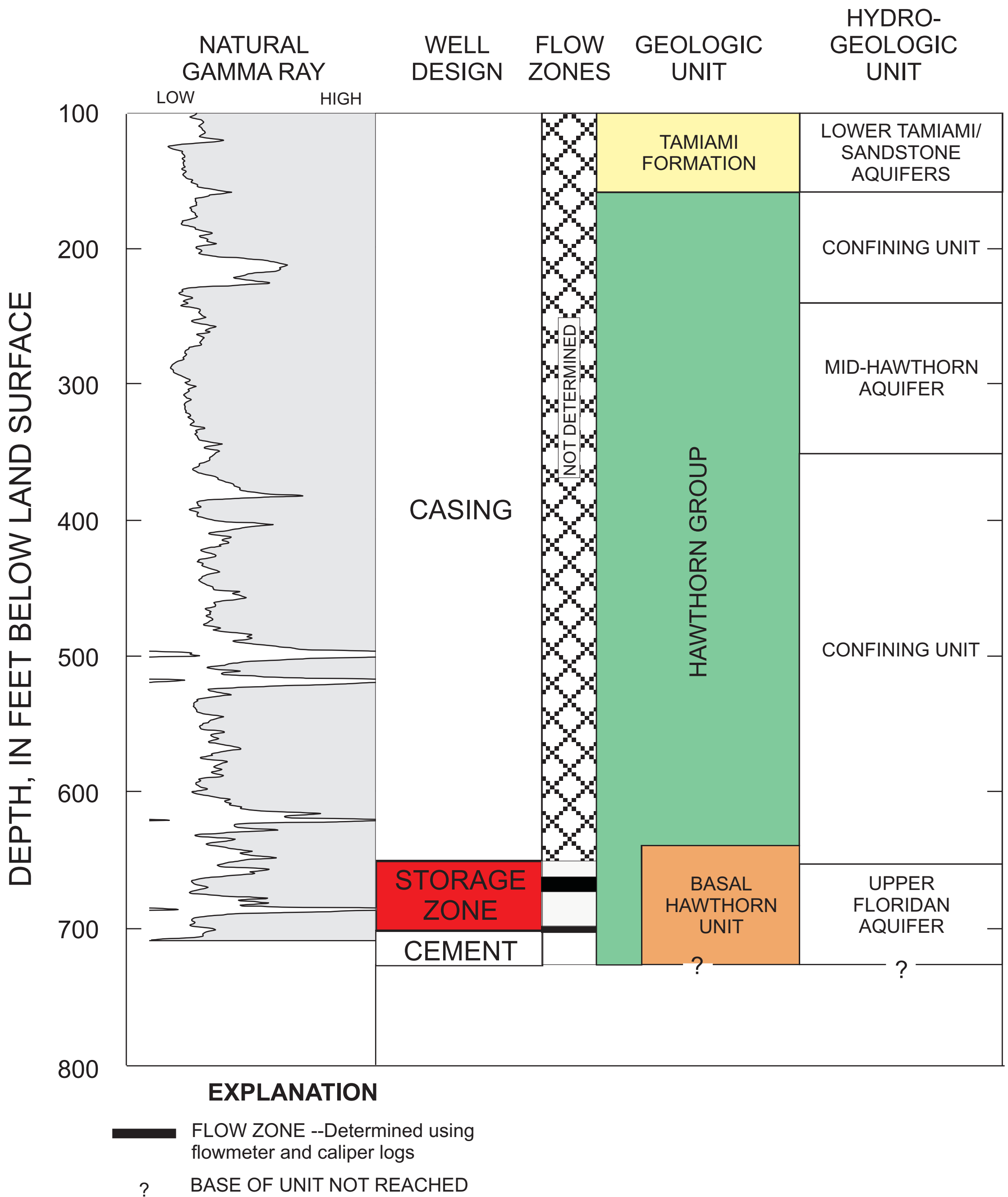

Figure 18. Location of storage zone in relation to gamma-ray geophysical log, flow zones, and geologic and hydrogeologic units for aquifer storage and recovery well L-5812 at the San Carlos Estates site in Lee County.

SUMMARY AND CONCLUSIONS

Aquifer storage and recovery (ASR) wells were constructed at 27 sites in southern Florida with most sites located in coastal areas. Twenty ASR were constructed by local municipalities or counties in southern Florida in the 1990's and 14 since 1996. Six of the 27 sites were experimental in nature and are no longer active. The storage zone at 23 of the 27 sites is contained within the Floridan aquifer system; of these 23 sites, 22 are in the Upper Floridan aquifer and 1 is in the Lower Floridan aquifer

Regional ASR in southern Florida has been proposed in the Comprehensive Everglades Restoration Plan (CERP) as a cost-effective water-supply alternative that can help meet needs of agricultural, municipal, and recreational users and help provide ecological benefits. About 330 high capacity wells have been proposed for southern Florida, with most to be sited inland, such as around Lake Okeechobee. Water salinity in the Upper Floridan aquifer, the hydrogeologic unit of interest in the CERP, is brackish to saline at all current ASR sites in southern Florida. The ambient salinity of water contained in the storage zone can substantially affect recovery of water recharged and stored.

This study was performed to inventory construction, hydrogeologic, and operational data on ASR sites in southern Florida and to compare site performance to hydrogeologic, design, or management factors that may influence their degree of success. Each ASR cycle includes periods of injection of freshwater, storage, and recovery, with each period lasting days or months. Potable water recovery efficiency of individual cycles at a site is the primary measure used to evaluate the performance of sites, and this efficiency is the volume of water recovered when chloride concentration reaches 250 as a percent of the volume recharged.

The basal contact of the Hawthorn Group lies close to the top of the Upper Floridan aquifer, and the most important flow zones in this aquifer commonly occur at or near this contact. The altitude of this contact varies considerably in southern Florida, ranging from less than 600 ft to greater than 1,200 ft below sea level. Local relief on this contact can be as much as several hundred feet.

Well data were inventoried and complied for all wells at existing and historical ASR sites in southern Florida. Construction and testing data were compiled into four categories: (1) well identification, location, and construction data; (2) hydraulic well-test data; (3) ambient formation water-quality data; and (4) cycle testing data. Intervals for which data were inventoried and compiled include the ASR storage zone interval and deeper and shallower intervals.

Factors important to efficient ASR operation vary widely between the sites. The thickness of the open storage zone ranged from 45 to 452 ft. Open intervals in the 150 to 200 ft range are most common. Transmissivity of the Upper Floridan aquifer storage zone for 17 sites ranged from 800 to 108,000 ft^2/d. Transmissivity at the Taylor Creek/Nubbin Slough (Lake Okeechobee) site, completed in the Lower Floridan aquifer, was reported to be 590,000 ft^2/d. Storage zone transmissivity for most sites ranged from 5,000 to 30,000 ft^2/d; greater than 30,000 ft^2/d is considered high. Leakance of storage zone confining units, determined from multiwell aquifer tests at seven sites in the Upper Floridan aquifer, ranged from 3.9×10^{-5} to 6.3×10^{-2} 1/d; of these, five had leakance greater than 1×10^{-3} 1/d, indicating that confinement is poor in some areas. These high leakance estimates are probably best attributed to leakage from below the storage zone rather than from above. Chloride concentration of ambient water from storage zones in the Upper Floridan aquifer ranged from 500 to 11,000 mg/L. At most sites, the chloride concentration ranged from about 1,000 to 3,000 mg/L; greater than 3,000 mg/L is considered to be high.

Cycle test data were compiled for 18 ASR sites, and potable water recovery efficiencies were calculated at 16 of these sites. To date, the Boynton Beach East WTP site has experienced the highest number of recharge-recovery cycles (16 cycles). Recharge volume per cycle ranged from as low as 0.6 to as high as 714 Mgal. Cycle 3 at the Hialeah site had the longest storage time (181 days). The highest potable water recovery efficiency for the first cycle was 47 percent at the Boynton Beach East WTP site, and except for one site with incomplete information, the lowest was 2 percent at the San Carlos Estates site. Nine of the 16 sites had a recovery efficiency above 10 percent for the first cycle, and 10 sites achieved a recovery efficiency above 30 percent during at least one cycle. The highest recovery efficiency achieved was 84 percent for cycle 16 at the Boynton Beach East WTP site. Recovery efficiencies for test and operational cycles at Boynton Beach appeared to be better than all other Floridan aquifer system sites. However, the number of cycles conducted at most other sites was limited, and the chloride concentration of the recharge water used at Boynton Beach was low (about 50 mg/L).

The increase in potable water recovery efficiency during the first five cycles at the Springtree WTP site was not as favorable as at the Boynton Beach East WTP site. Recovery started at 20 percent for the first cycle and ended at 27.5 percent for the fifth cycle, despite a recharge volume for the fifth cycle (120 Mgal) that was three or more times greater than in all previous cycles. Recovery efficiencies at the Marco Lakes site for the first five cycles increased from 22 to 36 percent, with 132 Mgal recharged during cycle 5. However, these numbers may not be comparable to those from the Boynton Beach and Springtree sites because the chloride concentration of the recharged water at the Marco Lakes site was two or more times higher than at the other two sites, lowering the potable water recovery efficiencies.

Based on review of four case studies and review of data from other sites, several hydrogeologic and design factors appear to play a substantial role in the performance of ASR in the Floridan aquifer system in southern Florida. Recovery efficiency appears to be maximized if the storage zone is thin and located within the uppermost part of the Upper Floridan aquifer, and transmissivity (less than about 30,000 ft^2/d) and ambient salinity (less than 3,000 mg/L chloride concentration) of the ASR storage zone are moderate. The structural setting of a site could also be important because of the potential for updip migration of recharged freshwater or the lessening of overlying confinement due to deformation. Avoiding areas that lie within a structural low or which are structurally complex or have higher dip could improve recovery efficiency.

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Table 2. Well Identification, location, and construction data for aquifer storage and recovery system wells in southern Florida

[Depths are in feet below land surface. Completed open intervals are open hole unless noted otherwise. Diameter of open interval for open-hole completions is size of bit used to drill or ream out hole. Abbreviations and annotations: USGS, U.S. Geological Survey; WTP, water treatment plant; WWTP, wastewater treatment plant; PVC, polyvinyl chlorinated; ?, unknown; NR, not reported]

Site name	USGS local well no.	Other well identifier	Land-net location	Latitude and longitude	Altitude of land surface (feet)	Total hole depth (feet)	Date at end of construction	Depth to top and bottom of casing (feet)	Casing diameter (inches)	Type of casing	Completed open interval (feet)	Diameter of open interval (inches)
Broward County												
Deerfield Beach West WTP	G-2887	ASR-1	Same as for MW-1	261857 800726	13.17	1,128	10-92	0-400 0-960	26.00 12.00	Steel PVC	960-1,128	10.63
	G-2888	MW-1	SENE S2, 48S,42E; 370 feet north of ASR-1	261901 800726	12	1,128	12-10-92	0-42 0-402 0-960	24.00 16.00 6.00	Steel Steel Steel	960-1,128	5.875
Broward County WTP 2A	G-2889	ASR-1	SE S12, 48S, 42E	261735 800625	16.6	1,200	12-03-96	0-40 0-397 0-995	36.00 26.00 16.00	Steel Steel Steel	995-1,200	16
	G-2916	MW-1			17	1,200	09-25-96	0-40 0-400 0-990	24.00 14.00 6.63	Steel Steel Steel	990-1,200	6
Springtree WTP	G-2914	ASR-1	NW S21,49S,41E	261033 [1]801540	10	1,345	07-97	0-170 0-1,110	26.00 16.00	Steel Steel	1,110-1,270	16
Fiveash WTP	G-2917	ASR-1		261030 800915	NR	1,300	12-30-97	0-198 0-1,055	26.00 16.00	Steel Steel	1,055-1,200	16
	G-2918	FMW-1			NR	1,175	03-15-98	0-370 0-1,055	14.00 6.63	Steel Steel	1,055-1,175	13
	G-2919	SMW-1			NR	210	01-11-98	0-20 0-180 [2]180-200	12.00 2.00 2.00	Steel PVC PVC	[3]180-200	2
Charlotte County												
Shell Creek WTP	CH-315	ASR-1	S29, 40S, 24E	265831 815607	19.4	1,043	04-99	0-34 0-700 650-764	24.00 16.00 12.00	Steel	764-933	12.25
Englewood South Regional WWTP	CH-318	TPW-1 (ASR-1)	S16, 41S, 20E	265415 821604	6	807	03-30-00	0-37 0-295 0-507	30.00 24.00 16.00	Steel Steel Steel	507-700	15
	CH-319	SZMW-1	400 feet west of TPW-1		NR	700	04-17-00	0-42 0-290 0-510	20.00 14.00 6.00	Steel Steel PVC	510-700	6
	CH-320	IMW-1	2,200 feet northwest of TPW-1		NR	320	04-06-00	0-40 0-280	14.00 4.00	Steel PVC	280-320	4
	CH-321	SMW-1	150 feet east of TPW-1		NR	205	03-23-00	0-40 0-170	14.00 6.00	Steel PVC	170-205	6

Table 2. Well Identification, location, and construction data for aquifer storage and recovery system wells in southern Florida --(Continued)

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Site name	USGS local well no.	Other well identifier	Land-net location	Latitude and longitude	Altitude of land surface (feet)	Total hole depth (feet)	Date at end of construction	Depth to top and bottom of casing (feet)	Casing diameter (inches)	Type of casing	Completed open interval (feet)	Diameter of open interval (inches)
Collier County												
Manatee Road	C-1202	ASR-1	400 feet southeast of MW-A	260247 814141	NR	528	1991	0-40 0-100 100-465	24.00 16.00 12.00	Steel ? ?	465-528	12
	C-1102	MW-A CO-2080	SWNE S10, 51S, 26 E	260249 814145	5	1,608	11-90	0-360 0-650	12.00 4.00	NR NR	360-500 650-770	8 8
	C-1203	MW-B		260247 814141	NR	520	1991	0-465	4.00	PVC	465-520	
	C-1204	MW-C		260247 814141	NR	520	1991	0-465	4.00	PVC	465-520	
	C-1205	MW-D		260247 814141	NR	150	1991	0-110	4.00	PVC	110-150	
Marco Lakes	C-1206	ASR-1	NE S3, 51S, 26E	260356 [1]814136	NR	790	7-8-96	0-40 0-152 152-745	24.00 16.00 12.00	Steel PVC PVC	745-790	10
	C-1207	DZMW	375 feet southeast of ASR-1	260353 814133	NR	817	04-26-96	0-293 0-745	10.00 6.00	PVC Steel	293-352 745-817	9.625 9.625
	C-1208	ASR-2	SE S34, 50S, 26E		7.5	780	08-26-99	0-27 0-736	26.00 16.00	Steel PVC	736-780	12.25
	C-1209	MHZ2MW	S34, 50S, 26E		7.5	470	09-10-99	0-31 0-440	16.00 6.90	PVC	440-470	12.25
	C-1210	ASRZMW	1,750 feet northeast of ASR-2		9.25	774	10-01-99	0-38 0-725	16.00 6.90	PVC	725-774	12.25
	C-1211	ASR-3	S34, 50S, 26E		7.5	780	11-08-99	0-30 0-736	26.00 16.00	Steel PVC	736-780	12.25
Lee County												
Lee County WTP	L-2530	MW-1	NESE S23, 43S, 26E	264308 814049	7.2	614	1977	0-475	4.00	NR	475-615	2
	L-2901	Deep test	SE S23, 43S, 26E	264309 814051	8	705	12-05-78	0-60	6.00	NR	60-705	4
	L-3224	MW-2	NESE S23, 43S, 26E	264309 814057	9.99	622	04-79	0-460	4.00	NR	460-620	4
	L-3225	ASR-1	NESE S23, 43S, 26E	264309 814052	10.72	602	1980	0-445	10.00	PVC	445-600	9

Table 2. Well Identification, location, and construction data for aquifer storage and recovery system wells in southern Florida --(Continued)

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Site name	USGS local well no.	Other well identifier	Land-net location	Latitude and longitude	Altitude of land surface (feet)	Total hole depth (feet)	Date at end of construc-tion	Depth to top and bottom of casing (feet)	Casing diam-eter (inches)	Type of casing	Completed open interval (feet)	Diameter of open interval (inches)
Lee County--Continued												
Corkscrew WTP	L-5855	ASR-1 LM-4627	NENW S22, 46S, 26E	262752 814216	23.31	397	06-23-95	0-30 0-328	18.00 12.00	Steel PVC	328-397	12
	L-5856	MW-A LM-3982	NENW S22, 46S, 26E	262752 814211	24.37	780	09-06-94	0-340	8.00	PVC	340-402	8
	L-5857	MW-B	NENW S22, 46S, 26E	262749 814218	25.29	504	02-27-95	0-452	4.00	PVC	452-504	4
	L-5858	MW-C	NENW S22, 46S, 26E	262752 814220	24.55	400	03-03-95	0-330	4.00	PVC	330-400	4
	L-5859	ASR-2	NENW S22, 46S, 26E	262744 814216	27.18	397	06-23-99	0-33 0-337	20.00 12.00	Steel PVC	337-397	10.63
	L-5860	ASR-3	SW S15, 46S, 26E	262818 814232	27.32	347	02-11-99	0-41 0-285	20.00 12.00	Steel PVC	285-347	10.63
	L-5861	ASR-4	SW S15, 46S, 26E	262805 814226	27.03	368	06-10-99	0-40 0-310	20.00 12.00	Steel PVC	310-368	10.63
	L-5862	ASR-5	NE S16, 46S, 26E	262831 814238	29.14	329	05-25-99	0-21 0-253	20.00 12.00	Steel PVC	253-291	10.63
	L-5863	MW-1	SW S22, 46S, 26E	262720 814215	23.44	410	02-01-99	0-41 0-358	16.00 6.00	Steel PVC	358-410	5.5
	L-5864	MW-2	SW S15, 46S, 26E	262821 814233	28.64	354	01-20-99	0-39 0-283	16.00 6.00	Steel PVC	283-354	5.5
	L-5865	MW-3	NENW S22, 46S, 26E	262735 814217	25.15	411	02-23-99	0-41 0-355	16.00 6.00	Steel PVC	355-411	5.5
North Reservoir	L-5810	ASR-1 LM-6210	SWSW S20, 43S, 25E	264238 815019	12	642	03-02-99	0-40 0-499 0-540	30.00 24.00 16.00	Steel Steel PVC	540-642	12
	L-5811	MW-1 LM-6208	260 feet south of ASR-1		12	980	01-27-99	0-42 0-495 0-537	18.00 12.00 6.00	Steel Steel PVC	537-615	8
Winkler Avenue	L-5871	ASR-1	S35, 44S, 24E	263608 815253	NR	647	06-23-99	0-91 0-455	20.00 12.00	Steel PVC	455-553	9.625
	L-5872	SZMW-1	~220 feet southwest of ASR-1		NR	553	08-05-99	0-16 0-455	16.00 6.00	Steel PVC	455-553	5.5
	L-5873	MHMW-1	~80 feet south of ASR-1		NR	200	08-06-99	0-150	6.00	PVC	150-200	5.5

Table 2. Well Identification, location, and construction data for aquifer storage and recovery system wells in southern Florida --(Continued)

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Site name	USGS local well no.	Other well identifier	Land-net location	Latitude and longitude	Altitude of land surface (feet)	Total hole depth (feet)	Date at end of construction	Depth to top and bottom of casing (feet)	Casing diameter (inches)	Type of casing	Completed open interval (feet)	Diameter of open interval (inches)
Lee County--Continued												
San Carlos Estates	L-5812	TPW-1 (ASR-1)	S14, 47S, 25E	262321 [1]814625	NR	718	08-03-99	0-93 0-650	20.00 12.00	Steel PVC	650-701	11
	L-5813	SZMW-1	~200 feet south of ASR-1, abandoned		NR	657	07-26-99	0-19 0-655	16.00 6.00	Steel PVC	Abandoned	12
	L-5814	SZMW-1R	~200 feet south of ASR-1, replacement well	262319 814625	NR	721	07-29-99	0-19 0-659	16.00 6.00	Steel PVC	659-721	5.5
	L-5815	SMW-1	~100 feet east of ASR-1		NR	321	08-02-99	0-19 0-234	16.00 6.00	Steel PVC	234-321	5.5
Olga WTP	L-5816	ASR-1 LM-6068	NESE S23, 43S, 26E	264312 [1]814056	6	920	10-22-99	0-35 0-737 0-859	34.00 24.00 16.00	Steel Steel PVC	859-920	13
	L-5817	MW-1 LM-6209	470 feet southwest of ASR-1	264309 [1]814100	6	1,200	09-08-99	0-30 0-525.5 0-674.5 0-850	18.00 12.00 8.00 4.00	Steel Steel PVC PVC	850-895	8
	L-5818	MW-3 LM-6615	370 feet west-northwest of ASR-1	264313 [1]814100	6	945	05-13-99	0-35 0-742 0-864	18.00 12.00 6.00	Steel Steel PVC	864-945	8
Miami-Dade County												
Hialeah	G-3061	ASR-1	NWSW S18, 53S, 41E	254941 801717	8.4	1,105	12-09-74	0-201 0-955	24.00 14.00	Steel Steel	955-1,105	12
	G-3062	MW-1	289 feet north-northwest of ASR-1	254944 801718	5.43	1,064	11-19-74 06-04-80	0-198 0-953 0-862	14.00 6.63 2.38	Steel Steel Steel	840-844 953-1,060	
West Well Field	G-3706	ASR-1		254200 802830	NR	1,302	12-23-96	0-170 0-850	40.00 30.00	Steel Steel	850-1,302	29
	G-3707	ASR-2	975 feet north of ASR-1		NR	1,350	02-14-97	0-170 0-845	40.00 30.00	Steel Steel	845-1,250	29
	G-3708	ASR-3	1,955 feet north of ASR-1		NR	1,300	03-11-97	0-170 0-835	40.00 30.00	Steel Steel	835-1,210	29
	G-3709	MW-1 Test 711	270 feet north-northwest of ASR-1		NR	1,643	01-03-97	0-170 0-855 0-1,370 [2]1,370-1,390	24.00 12.00 12.00 2.00	Steel Steel PVC PVC	855-1,010 [3]1,370-1,390	12 2

Table 2. Well Identification, location, and construction data for aquifer storage and recovery system wells in southern Florida --(Continued)

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Site name	USGS local well no.	Other well identifier	Land-net location	Latitude and longitude	Altitude of land surface (feet)	Total hole depth (feet)	Date at end of construction	Depth to top and bottom of casing (feet)	Casing diameter (inches)	Type of casing	Completed open interval (feet)	Diameter of open interval (inches)
Monroe County												
Marathon	MO-189	ASR-1	S8, 66S, 32E	244239 810538	NR	450	05-01-90	0-36 0-387 362-387 [2]387-427	30.00 16.00 10.00 10.00	Steel PVC Steel Steel	[3]387-432	12
	MO-190	OW-1	126 feet south of ASR-1		NR	428	03-17-90	0-19 0-388 [2]388-428	12.00 4.00 4.00	Steel PVC PVC	[3]356-428	8
	MO-191	OW-2 Test well	258 feet southeast of ASR-1		NR	550	1989	0-22 0-400 375-413 [2]413-435	16.00 10.00 4.00 4.00	Steel Steel Steel Steel	[3]400-450	10
Okeechobee County												
Taylor Creek/Nubbin Slough (Lake Okeechobee)	OK-9000	ASR-1	S24, 37S, 35E	271420 804709	16	1,710	06-19-88	0-65 0-200 0-1,268	42.00 34.00 24.00	Steel Steel Steel	1,268-1,710	22
	OK-9001	MW-1	560 feet north of ASR-1		16	1,800	07-22-88	0-82 0-200 0-990 0-1,270	24.00 12.00 6.00 1.50	Steel Steel Steel ?	990-1,075 1,275-1,700	8 6
	OK-9002	Deep monitoring tube in MW-1			16						1,275-1,700	
Palm Beach County												
Jupiter	PB-747	ASR-1	S3, 41S, 42E	265604 800826	13	1,280	06-74	0-400 0-990	20.00 12.00	Steel Steel	990-1,280	NR
	PB-1145	MW-1	500 feet from ASR-1	265608 800823	13	1,270	1975	0-400 0-990	12.00 5.00	NR NR	995-1,270	
Boynton Beach East WTP	PB-1194	ASR-1	NE S33, 45S, 43E	263050 [1]800346	18.9	1,260	04-13-92	0-38 0-399 0-804	36.00 26.00 16.00	Steel Steel Steel	804-909	16
	PB-1195	MW-1	~50 feet south of ASR-1		18.9	435	05-21-92	0-300 [2]300-320	4.00 4.00	PVC PVC	[3]300-320	4
Delray Beach North Storage Reservoir	PB-1702	ASR-1	S17, 46S, 43E	262800 800600	21.2	1,200	08-24-96	0-400 352-1,016	20.00 14.00	Steel Steel	1,016-1,120	18.5

Table 2. Well Identification, location, and construction data for aquifer storage and recovery system wells in southern Florida --(Continued)

[Depths are in feet below land surface. Completed open intervals are open hole unless noted otherwise. Diameter of open interval for open-hole completions is size of bit used to drill or ream out hole. Abbreviations and annotations: USGS, U.S. Geological Survey; WTP, water treatment plant; WWTP, wastewater treatment plant; PVC, polyvinyl chlorinated; ?, unknown; NR, not reported]

Site name	USGS local well no.	Other well identifier	Land-net location	Latitude and longitude	Altitude of land surface (feet)	Total hole depth (feet)	Date at end of construction	Depth to top and bottom of casing (feet)	Casing diameter (inches)	Type of casing	Completed open interval (feet)	Diameter of open interval (inches)
Palm Beach County--Continued												
West Palm Beach WTP	PB-1692	ASR-1	~100 feet east of MW-1	264259 [1]800349	19.13	1,200	01-29-97	0-56 0-389 0-985	42.00 36.00 24.00	Steel Steel Steel	985-1,200	22
	PB-1693	MW-1	NW S21, 43S, 43E	264257 [1]800350	18.97	1,410	11-13-96	0-65 0-379 0-975	30.00 24.00 12.75	Steel Steel Steel	975-1,191	12
System 3 Palm Beach County	PB-1763	ASR-1	S?, 46S, 42E	262859 800811	NR	1,155	01-99	0-60 0-365 0-223	36.00 24.00 18.00	Steel PVC Steel	1,065-1,155	14
	PB-1764	MW-1			NR	1,500	01-98	215-1,065 0-155 0-1,050 0-1,052	16.00 16.00 10.00 5.00	PVC Steel Steel PVC	1,052-1,270	10
Western Hillsboro Canal, Site 1	PB-1765	EXW-1 (ASR-1)	NR	262119 [1]801743	NR	1,225	03-31-00	0-205 0-1,015	36.00 24.00	Steel Steel	1,015-1,225	24
	PB-1766	PBF-10	300 feet northwest of EXW-1	262120 [1]801746	NR	2,370	?	0-375 0-1,000 0-1,505 0-2,130	24.00 18.00 12.00 2.38	Steel Steel Steel ?	1,505-1,670 2,130-2,260	12 12
	PB-1767	PBF-10R[4]	300 feet northwest of EXW-1	262120 [1]801746	NR	1,225	08-00	0-1,015	3.00	NR	1,015-1,225	8
St. Lucie County												
St. Lucie County	STL-356	ASR-1 SLF-50	SE S14, 36S, 39E	272017 802953	31.75	1,000	02-82	0-130 0-600	12.00 6.00	PVC PVC	600-775	5.125
	STL-357	MW-1 SLF-51	148 feet northeast of ASR-1	272019 802053	25.56	775	02-82	0-130 0-600	12.00 6.00	PVC PVC	600-775	5.125
	STL-355	MW-2 SLF-49	420 feet northwest of ASR-1	272020 802954	25.09	893	?	0-560	NR	NR	560-893	NR

[1]Latitude-longitude determined in the field using a hand held global positioning system accurate to ± 0.2 seconds.
[2]Top and bottom depth of screen.
[3]Screened interval plus gravel pack above or below screen.
[4]Replacement well to PBF-10, upper zone.

Table 3. Hydraulic test data from aquifer storage and recovery well systems in southern Florida

[Depths are in feet below land surface. Test type: M, multiwell constant rate; P, Packer test; R, single well constant rate recovery; S, step drawdown. Method of analysis: SC, specific capacity; Theis, Theis (1935) confined aquifer; C-J, Cooper and Jacob (1946) confined aquifer; Theis Rec, Theis (1935) residual drawdown recovery; H-J, Hantush and Jacob (1955) leaky aquifer; Walton, Walton (1962) leaky aquifer; J-L, Jacob and Lohman (1952). Other annotations: WTP, water treatment plant; WWTP, wastewater treatment plant; -, not applicable; NR, not reported]

Test date	Production well identifier	Open interval tested (feet)	Test type	Monitoring well	Pumping rate (gallons per minute)	Length of test (hours)	Transmissivity (square feet per day)	Storage coefficient (unitless)	Leakance (1/day)	Method of analysis	Specific capacity (gallons per minute per foot)	Background measurements	Problems and comments
Broward County													
Deerfield Beach West WTP													
NR	ASR-1	956-1,130[1]	S	--	950-2,100	NR	--	-	--	--	42.6-32.0	NR	Step-drawdown test was performed prior to multiwell, but date of test was not given in report
12-10-92	ASR-1	956-1,130[1]	M	MW-1	1,200	5.7	24,200	$1.33x10^{-6}$	$6.3x10^{-2}$	H-J	--		
Broward County WTP 2A													
11-21-96	ASR-1	995-1,200[1]	S	--	1,050-2,950	8	-	--	--	--	90.6-51.1	Data collected for multi-well test but no information on whether corrections were made	Walton method should give same transmissivity if no leakance as C-J method(?) Curve matches look okay
11-26-96	ASR-1	995-1,200[1]	M	MW-1	1,000	24	28,900	$1.1x10^{-4}$	None	Walton	--		
11-26-96	ASR-1	995-1,200[1]	M	MW-1	1,000	24	37,200	$5.3x10^{-5}$	--	C-J	--		
11-26-96	ASR-1	995-1,200[1]	M	ASR-1	1,000	24	44,000	--	--	Theis Rec	NR		
09-19-96	MW-1	990-1,200[1]	S	--	480	6	--	--	--	--	20		
Sprintree WTP													
06-06-97	ASR-1	1,110-1,270[1]	S	--	700-1,900	8	--	--	--	--	18.4-16.5	NR	Acidization of well done after step test and before constant rate test. Interpretation of recovery data favored late time data
07-28-97	ASR-1	1,110-1,270[1]	R	--	2,115	48	5,700	--	--	Theis Rec	22.75		
Fiveash WTP													
01-12-98	FMW-1	998-1,028	P, R	--	160	4	4,700	--	--	Theis Rec	4.7	NR	Third packer test showed apparent failure after about 10 minutes, which may have affected data. FMW-1 apparently not used in 24-hour test of ASR-1
01-13-98	FMW-1	998-1,042	P, R	--	160	4	8,000	--	--	Theis Rec	5		
01-15-98	FMW-1	1,058-1,175[1]	P	--	600	10 min	23,500	--	--	C-J	46		
03-16-98	FMW-1	1,055-1,175[1]	S	--	100-160	4	--	--	--	--	3.8-3.6		
03-17-98	FMW-1	1,055-1,175[1]	S	--	164	24	NR	--	--	--	~3.5		
03-25-98	ASR-1	1,055-1,200[1]	S	--	968-2,104	4	--	--	--	--	25.5-17.7		
03-30-98	ASR-1	1,055-1,200[1]	R	--	2,100	24	19,500	--	--	Theis Rec	~17.5		
Charlotte County													
Shell Creek WtP													
11-05-97	ASR-1	700-755	P	--	300-550	NR	--	--	--	--	10.0-5.6	NR	
11-17-97	ASR-1	700-764	S	--	231-597	12	--	--	--	--	5.3-4.6		
11-18-97	ASR-1	700-764	R	--	546	54	1,300	--	--	SC	4.4		
06-28-99	ASR-1	764-933[1]	S	--	610-600	8	--	--	--	--	10.6		
Englewood South Regional WWTP													
NR	TPW-1	563-583	P, R	--	10	1.33	450	--	--	Theis Rec	1	NR	Multiwell aquifer test planned in the future
03-07-00	TPW-1	630-807	P	--	131	4.00	1,300	--	--	SC	5		
03-31-00	TPW-1	507-700[1]	S	--	490-1,050	NR	4,700	--	--	SC	17.34 (avg)		
04-20-00	SZMW-1	510-700[1]	S	--	31-101	NR	3,700	--	--	SC	13.87 (avg)		
04-18-00	IMW-1	280-320	S	--	28.3-59.5	NR	2,300	--	--	SC	5.5-4.0		
04-18-00	SMW-1	170-205	S	--	9.3-17.7	NR	300	--	--	SC	1 (avg)		

Table 3. Hydraulic test data from aquifer storage and recovery well systems in southern Florida --(Continued)

[Depths are in feet below land surface. Test type: M, multiwell constant rate; P, Packer test; R, single well constant rate recovery; S, step drawdown. Method of analysis: SC, specific capacity; Theis, Theis (1935) confined aquifer; C-J, Cooper and Jacob (1946) confined aquifer; Theis Rec, Theis (1935) residual drawdown recovery; H-J, Hantush and Jacob (1955) leaky aquifer; Walton, Walton (1962) leaky aquifer; J-L, Jacob and Lohman (1952). Other annotations: WTP, water treatment plant; WWTP, wastewater treatment plant; -, not applicable; NR, not reported]

Test date	Production well identifier	Open interval tested (feet)	Test type	Monitoring well	Pumping rate (gallons per minute)	Length of test (hours)	Transmissivity (square feet per day)	Storage coefficient (unitless)	Leakance (1/day)	Method of analysis	Specific capacity (gallons per minute per foot)	Background measurements	Problems and comments
Collier County													
Manatee Road													
11-90	MW-A	360-460	P, S	--	NR	NR	2,400	--	--	See comment	NR	NR	All of the step-drawdown tests are indicated to be packer tests; however, some could have been a test of an open interval below casing. For step test, transmissivity was determined at each step by an unspecified method in Walton (1970). Then an adjusted estimated value of transmissivity was obtained by plotting transmissivity against flow rate for each step. For the multiwell test, 670 gallons per minute was an injection rate
11-90	MW-A	465-530[1]	P, S	--	NR	NR	20,000	--	--	See comment	NR		
11-90	MW-A	680-760	P, S	--	NR	NR	15,000	--	--	See comment	NR		
11-90	MW-A	930-1020	P, S	--	NR	NR	6,700	--	--	See comment	NR		
11-90	MW-A	1,180-1,220	P, S	--	NR	NR	6,300	--	--	See comment	NR		
11-90	MW-A	1,345-1,606	P, S	--	NR	NR	5,700	--	--	See comment	NR		
NR	ASR-1	465-528[1]	M	MW-B	670	17	9,400	$1.00x10^{-4}$	$3.7x10^{-4}$	H-J	--		
NR	ASR-1	465-528	M	MW-B	670	17	12,000	--	--	Theis Rec	--		
Marco Lakes													
NR	DZMW	296-399	S	--	220-600	NR	67,000	--	--	Walton	220-170	NR	Estimated transmissivity in lower Hawthorn zone I (550 to 622 feet) was too low for consideration as an aquifer storage and recovery interval. No dates were reported for any tests. Good agreement between tests
NR	DZMW	296-399	R	--	600	3	42,400	--	--	Theis Rec	NR		
NR	DZMW	550-622	P, R	--	5	4	47	--	--	Theis Rec	NR		
NR	DZMW	745-811[1]	R	--	187	4.5	8,200	--	--	Theis Rec	NR		
NR	ASR-1	745-790[1]	M	ASR-1	463	8.3	16,300	--	--	Theis Rec	NR		
NR	ASR-1	745-790[1]	M	DZMW	463	8.3	9,100	$6.5x10^{-5}$	$7x10^{-4}$	H-J	--		
NR	ASR-1	745-790[1]	M	DZMW	463	8.3	12,000	--	--	Theis Rec	--		
NR	ASR-2	736-780[1]	S	ASR-1	400-650	NR	--	--	--	--	25-24		
NR	ASR-3	736-780[1]	S, M	ASR-2, ASRZMW	400-820	NR	8,000 to 8,100	--	--	C-J	17.4-15		
Lee County													
Lee County WTP													
NR	ASR-1	445-600[1]	M	NR	350	48	800	$1.00x10^{-4}$	$1.0x10^{-2}$	H-J	NR	NR	Storage zone in ASR-1 is located in the lower Hawthorn producing zone of the Upper Floridan aquifer as defined by Reese (2000)

Table 3. Hydraulic test data from aquifer storage and recovery well systems in southern Florida --(Continued)

[Depths are in feet below land surface. Test type: M, multiwell constant rate; P, Packer test; R, single well constant rate recovery; S, step drawdown. Method of analysis: SC, specific capacity; Theis, Theis (1935) confined aquifer; C-J, Cooper and Jacob (1946) confined aquifer; Theis Rec, Theis (1935) residual drawdown recovery; H-J, Hantush and Jacob (1955) leaky aquifer; Walton, Walton (1962) leaky aquifer; J-L, Jacob and Lohman (1952). Other annotations: WTP, water treatment plant; WWTP, wastewater treatment plant; -, not applicable; NR, not reported]

Test date	Production well identifier	Open interval tested (feet)	Test type	Monitoring well	Pumping rate (gallons per minute)	Length of test (hours)	Transmissivity (square feet per day)	Storage coefficient (unitless)	Leakance (1/day)	Method of analysis	Specific capacity (gallons per minute per foot)	Background measurements	Problems and comments
Lee County--Continued													
Corkscrew WTP													
08-94	MW-A	428-515	P	--	NR	NR	500	--	--	SC	2.5	Data collected for multi-well test in September 1995	Test of MW-A, interval 744 to 778 feet, was of upper 34 of 240 feet thick Suwannee Limestone.Second multi-well test of ASR-1 followed back-plugging of MW-A to injection zone.Transmissivity values for step-drawdown test of ASR-2, 3, 4, and 5 were obtained by modified Walton method. Second step test of ASR-5 was post-acidization of the well. Additional multiwell tests of ASR-1 and ASR-3 were conducted during the expansion project
08-17-94	MW-A	524-578	P	--	39	5 min.	500	--	--	SC	NR		
08-24-94	MW-A	744-778	P, S	--	15-72	4	13,000	--	--	SC	1.3-0.6		
NR	MW-B	452-504	NR	--	NR	NR	100	NR	NR	NR	NR		
09-95	ASR-1	328-397[1]	M	MW-C	400	115.5	3,410	$7.70x10^{-5}$	$1.6x10^{-5}$	Hantush	--		
09-95	ASR-1	328-397[1]	M	MW-C	400	115.5	3,380	$6.70x10^{-5}$	--	C-J	--		
09-95	ASR-1	328-397[1]	M	MW-C	400	115.5	3,460	--	--	Theis Rec	--		
06-96	ASR-1	328-397[1]	M	MW-A	415	120	1,760	$2.30x10^{-4}$	--	Theis	--		
06-96	ASR-1	328-397[1]	M	MW-A	415	120	1,900	$1.70x10^{-4}$	--	C-J	--		
06-96	ASR-1	328-397[1]	M	MW-C	415	120	3,180	$5.70x10^{-5}$	--	Theis	--		
06-96	ASR-1	328-397[1]	M	MW-C	415	120	3,410	$4.90x10^{-5}$	--	C-J	--		
07-13-99	ASR-2	337-397[1]	S	--	115-410	NR	2,040	--	--	SC	7.8-6.6		
02-12-99	ASR-3	285-347[1]	S	--	129-497	NR	7,350	--	--	SC	26.9-19.4		
06-25-99	ASR-4	310-368[1]	S	--	153-450	NR	4,020	--	--	SC	15.0-11.7		
07-08-99	ASR-5	253-291[1]	S	--	163-380	NR	-	--	--	-	7.4-5.2		
07-20-99	ASR-5	253-291[1]	S	--	130-490	NR	13,400	--	--	SC	50.0-36.1		
North Reservoir													
12-07-98	MW-1	480-518	S	--	92-430	NR	14,400	--	--	SC	44.4-41.3	Data collected for 3 days prior to the multiwell test	Fit of line to ASR-1 recovery data for multiwell test is poor
12-09-98	MW-1	529-619[1]	P, S	--	73-295	NR	5,200	--	--	SC	9.7-3.5		
12-11-98	MW-1	640-703	P, S	--	79-281	NR	2,040	--	--	SC	6.6-2.8		
12-16-98	MW-1	808-890	P, S	--	55-190	NR	680	--	--	SC	2.8-1.8		
12-18-98	MW-1	904-977	P, S	--	85-322	NR	9,590	--	--	SC	10.5-3.1		
03-03-99	ASR-1	540-642[1]	S	--	162-590	4	2,220	--	--	SC	8.65-7.00		
03-08-99	ASR-1	540-642[1]	M	MW-1	379	72	8,290	$3.27x10^{-4}$	$7.33x10^{-4}$	H-J	--		
03-08-99	ASR-1	540-642[1]	M	MW-1	379	72	8,740	$4.64x10^{-4}$	- -	C-J (recovery)	--		
03-08-99	ASR-1	540-642[1]	M	ASR-1	379	72	8,570	--	- -	C-J (recovery)	NR		

Table 3. Hydraulic test data from aquifer storage and recovery well systems in southern Florida --(Continued)

[Depths are in feet below land surface. Test type: M, multiwell constant rate; P, Packer test; R, single well constant rate recovery; S, step drawdown. Method of analysis: SC, specific capacity; Theis, Theis (1935) confined aquifer; C-J, Cooper and Jacob (1946) confined aquifer; Theis Rec, Theis (1935) residual drawdown recovery; H-J, Hantush and Jacob (1955) leaky aquifer; Walton, Walton (1962) leaky aquifer; J-L, Jacob and Lohman (1952). Other annotations: WTP, water treatment plant; WWTP, wastewater treatment plant; -, not applicable; NR, not reported]

Test date	Production well identifier	Open interval tested (feet)	Test type	Monitoring well	Pumping rate (gallons per minute)	Length of test (hours)	Transmissivity (square feet per day)	Storage coefficient (unitless)	Leakance (1/day)	Method of analysis	Specific capacity (gallons per minute per foot)	Background measurements	Problems and comments
Lee County--Continued													
Winkler Avenue													
NR	ASR-1	455-554[1]	S	--	135	15 min	--	--	--	--	59.7	Ninety hours collected prior to multiwell test, but apparently not used to correct drawdown data	Pumping rate for multiwell test was 1,540 for first 6.5 hours, then changed to 1,400. No attempt was made to analyze multiwell test data for storage coefficient or leakance. Storage zone is located in the lower Hawthorn producing zone of the Upper Floridan aquifer
NR	ASR-1	455-647	S	--	160	15 min	--	--	--	--	86.3		
6-16-99	ASR-1	455-574[1]	P	--	479	70 min	29,100	--	--	C-J (recovery)	NR		
6-17-99	ASR-1	455-575[1]	P	--	483	18 min	26,600	--	--	C-J (recovery)	NR		
10-23-99	ASR-1	455-553[1]	M	ASR-1	1540-1400	27	24,700	--	--	C-J	NR		
10-23-99	ASR-1	455-553[1]	M	ASR-1	1540-1400	27	25,400	--	--	C-J (recovery)	--		
10-23-99	ASR-1	455-553[1]	M	SZMW-1	1540-1400	27	27,400	NR	NR	C-J	--		
10-23-99	ASR-1	455-553[1]	M	SZMW-1	1540-1400	27	29,000	--	--	C-J (recovery)	--		
San Carlos Estates													
06-07-99	TPW-1	650-701[1]	S	--	710-1,480	8	--	--	--	--	250-130	Unknown for multiwell test. Test followed 10 days of recharge at 1,955 gallons per minute and then 6-day static period.	High specific capacity in TPW-1 due to two pilot holes in open interval. Pumping rate for test on 11/10/99 of 985 gallons per minute was natural flow. C-J solution for drawdown in SZMW-1R is suspect. Solution is for very late time only, and background changes due to prior recharge may have affected response
07-29-99	SZMW-1R	659-721[1]	S	--	170-350	8	--	--	--	--	15-9.0		
08-02-99	SMW-1	234-321	S	--	150-220	8	--	--	--	--	8.9-6.5		
11-10-99	TPW-1	650-701[1]	M	SZMW-1R	985	8	39,000	$1.00x10^{-2}$	--	C-J	--		
11-10-99	TPW-1	650-701[1]	M	SZMW-1R	985	8	70,000	--	--	Theis Rec	--		
Olga WTP													
01-05-99	MW-1	515-605	S	--	110-400	NR	2,500	--	--	SC	NR	Measured for multiwell test, but unknown if used to correct drawdown	H-J results for multiwell test agree better with single well and packer test than C-J results. A second constant rate test was run but is not reported here. Storage zone is about 150 feet below top of Suwannee Limestone
01-07-99	MW-1	612-689	P	--	70-200	NR	1,300	--	--	SC	NR		
02-03-99	MW-1	835-935[1]	P	--	70-355	NR	7,600	--	--	SC	NR		
02-04-99	MW-1	710-935	P	--	70-350	NR	7,600	--	--	SC	NR		
02-04-99	MW-1	835-935[1]	P	--	70-350	NR	7,600	--	--	SC	NR		
02-08-99	MW-1	945-1,101	P	--	6 to 15	NR	33	--	--	SC	NR		
03-17-99	MW-3	740-820	S	--	78-480	NR	1,900	--	--	SC	NR		
03-25-99	MW-3	830-945[1]	P	--	80-340	NR	9,000	--	--	SC	NR		
03-25-99	MW-3	854-945[1]	P	--	75-350	NR	6,400	--	--	SC	NR		
03-26-99	MW-3	857-945[1]	R	--	300	NR	8,700	--	--	Theis Rec	NR		
11-01-99	ASR-1	859-920[1]	S	--	112-545	5	5,000	--	--	SC	14.9-8.5		
11-03-99	ASR-1	859-920[1]	M	MW-1	500	60	7,200	$5.10x10^{-5}$	$5.2x10^{-3}$	H-J	--		
11-03-99	ASR-1	859-920[1]	M	MW-1	500	60	12,000	$4.10x10^{-5}$	--	C-J	--		
11-03-99	ASR-1	859-920[1]	M	MW-3	500	60	9,400	$5.50x10^{-5}$	$6.0x10^{-2}$	H-J	--		
11-03-99	ASR-1	859-920[1]	M	MW-3	500	60	11,000	$4.20x10^{-4}$	--	C-J	--		

Table 3. Hydraulic test data from aquifer storage and recovery well systems in southern Florida --(Continued)

[Depths are in feet below land surface. Test type: M, multiwell constant rate; P, Packer test; R, single well constant rate recovery; S, step drawdown. Method of analysis: SC, specific capacity; Theis, Theis (1935) confined aquifer; C-J, Cooper and Jacob (1946) confined aquifer; Theis Rec, Theis (1935) residual drawdown recovery; H-J, Hantush and Jacob (1955) leaky aquifer; Walton, Walton (1962) leaky aquifer; J-L, Jacob and Lohman (1952). Other annotations: WTP, water treatment plant; WWTP, wastewater treatment plant; -, not applicable; NR, not reported]

Test date	Production well identifier	Open interval tested (feet)	Test type	Monitoring well	Pumping rate (gallons per minute)	Length of test (hours)	Transmissivity (square feet per day)	Storage coefficient (unitless)	Leakance (1/day)	Method of analysis	Specific capacity (gallons per minute per foot)	Background measurements	Problems and comments
Miami-Dade County													
Hialeah													
02-10-75	MW-1	953-1,060[1]	M	ASR-1	250	1.66	11,000	$8.4x10^{-5}$	--	J-L	--	NR	Transmissivity estimate from Meyer (1989b). Storage coefficient estimated by model simulation of pumping test
West Well Field													
01-26-97	ASR-1	850-1,302[1]	S	--	1,400-4,000	8	--	--	--	--	269-52.1	Measured for multiwell test. Correction was not done, due to negligibility.	All three aquifer storage and recovery wells were heavily acidized prior to all tests. Late time drawdown data problematic because of pump going down several times.
02-25-97	ASR-2	845-1,250[1]	S	--	1,500-3,800	8	--	--	--	--	126.6-51.1		
04-08-97	ASR-3	835-1,210[1]	S	--	1,500-3,800	8	--	--	--	--	46.1-38.2		
12-09-97	ASR-1	850-1,302[1]	M	ASR-1	3,500	72	10,300	N/A	N/A	C-J	NR		
12-09-97	ASR-1	850-1,302[1]	M	ASR-2	3,500	72	15,400	$3.90x10^{-4}$	$1.6x10^{-3}$	Walton	--		
12-09-97	ASR-1	850-1,302[1]	M	ASR-2	3,500	72	18,200	$2.90x10^{-4}$	N/A	C-J	--		
12-09-97	ASR-1	850-1,302[1]	M	ASR-3	3,500	72	15,400	$4.40x10^{-4}$	$3.9x10^{-5}$	Walton	--		
12-09-97	ASR-1	850-1,302[1]	M	ASR-3	3,500	72	19,700	$3.30x10^{-4}$	N/A	C-J	--		
Monroe County													
Marathon													
05-03-90	ASR-1	387-432[1]	M	OW-1	105	25	2,290	$3.20x10^{-4}$	NR	Walton	--	Measured for 3 weeks prior to multiwell test. A regional increasing trend in water level was determined	Leakance using Walton (1962) method not determined
05-03-90	ASR-1	387-432[1]	M	OW-1	105	25	2,510	$3.70x10^{-4}$	--	C-J	--		
05-03-90	ASR-1	387-432[1]	M	OW-1	105	25	1,760	--	--	Theis-Rec	--		
05-03-90	ASR-1	387-432[1]	M	OW-2	105	25	2,180	$5.20x10^{-4}$	NR	Walton	--		
05-03-90	ASR-1	387-432[1]	M	OW-2	105	25	4,090	--	--	Theis-Rec	--		
05-06-90	ASR-1	387-432[1]	S	--	95-350	NR	--	--	--	--	3.9-2.7		
Okeechobee County													
Taylor Creek-Nubbin Slough (Lake Okeechobee)													
04-20-98	MW-1	1,175-1,227	P	--	10	6.4	706	NR	--	C-J	NR	Water-level data taken for 5 days prior to constant rate test; corrections made using a long-term increasing trend	Leakance derived by extrapolation; longer pumping period required for more accurate value
04-20-98	MW-1	1,175-1,227	P, R	--	10	6.4	2,940	--	--	Recovery	NR		
08-02-98	ASR-1	1,268-1,710[1]	M	ASR-1	6,500	24	620,000	N/A	N/A	C-J (recovery)	1,600		
08-02-98	ASR-1	1,268-1,710[1]	M	MW-1	6,500	24	586,000	$1.25x10^{-3}$	0.01-0.001	H-J	1,600		
08-02-98	ASR-1	1,268-1,710[1]	M	MW-1	6,500	24	765,000	$1.90x10^{-4}$	N/A	C-J (recovery)	1,600		

Table 3. Hydraulic test data from aquifer storage and recovery well systems in southern Florida --(Continued)

[Depths are in feet below land surface. Test type: M, multiwell constant rate; P, Packer test; R, single well constant rate recovery; S, step drawdown. Method of analysis: SC, specific capacity; Theis, Theis (1935) confined aquifer; C-J, Cooper and Jacob (1946) confined aquifer; Theis Rec, Theis (1935) residual drawdown recovery; H-J, Hantush and Jacob (1955) leaky aquifer; Walton, Walton (1962) leaky aquifer; J-L, Jacob and Lohman (1952). Other annotations: WTP, water treatment plant; WWTP, wastewater treatment plant; -, not applicable; NR, not reported]

Test date	Production well identifier	Open interval tested (feet)	Test type	Monitoring well	Pumping rate (gallons per minute)	Length of test (hours)	Transmissivity (square feet per day)	Storage coefficient (unitless)	Leakance (1/day)	Method of analysis	Specific capacity (gallons per minute per foot)	Background measurements	Problems and comments
Palm Beach County													
Boynton Beach East WTP													
04-09-92	ASR-1	804-900[1]	S	--	320-2,100	NR	6,800-13,000	NR	--	C-J	18-28	NR	Second step test is with permanent equipment installed in well. Average of estimates for transmissivity was 70,000 gallons per day per foot
10-15-92	ASR-1	804-909[1]	S	--	798-1,723	NR	Not calculated	--	--	C-J	29-27		
Delray Beach North Storage Reservoir													
06-05-96	ASR-1	849-899	P	--	49	NR	--	--	--	--	0.37	NR	Second step test performed after acidization of well. For the second step test, pump malfunctioned after about 10 minutes of pumping during the last step at 2,550 gallons per minute
06-11-96	ASR-1	900-952	P	--	83	NR	--	--	--	--	0.90		
06-14-96	ASR-1	974-1,020	P	--	90	NR	--	--	--	--	2.40		
06-18-96	ASR-1	1,020-1,100	P	--	98	NR	--	--	--	--	2.00		
09-20-96	ASR-1	1,020-1,200[1]	S	--	575-1,100	24	--	--	--	--	10.8-7.8		
02-24-98	ASR-1	1,020-1,200[1]	S	--	760-2,550	13.2	--	--	--	--	17.2-15.7		
West Palm Beach WTP													
08-22-96	FAMW	975-1,091	P, S	--	64-142	NR	--	--	--	--	194-86	NR	Recovery was allowed following step test of ASR-1 before multiwell test was begun. Large deviation from Theis curve during late time, but leaky aquifer solution not used
09-14-96	FAMW	1,304-1,384	P, S	--	55-110	NR	--	--	--	--	220-110		
08-29-96	FAMW	975-1,090	S	--	300-584	NR	--	--	--	--	75-58		
09-01-96	FAMW	975-1,190[1]	S	--	300-584	NR	--	--	--	--	110-101		
09-04-96	FAMW	975-1,290	S	--	550-740	NR	--	--	--	--	116-105		
09-06-96	FAMW	975-1,384	S	--	550-740	NR	--	--	--	--	116-99		
11-19-96	FAMW	975-1,191[1]	S	--	550-732	NR	--	--	--	--	62-42		
01-30-97	ASR-1	985-1,200[1]	S	--	508-704	24	--	--	--	--	390-306		
02-01-97	ASR-1	985-1,200[1]	M	FAMW	700	24	138,000	1.00×10^{-4}	--	C-J	--		
02-01-97	ASR-1	985-1,200[1]	M	FAMW	700	24	108,000	8.00×10^{-4}	--	Theis	--		
Western Hillsboro Canal, Site 1													
04-05-00	EXW-1	1,160-1,225	P	--	95	NR	--	--	--	--	22.6	NR	Acidized EXW-1 with 4,300 gallons of 36 percent HCl on 6-2-00
04-10-00	EXW-1	1,015-1,150	P	--	105	NR	--	--	--	--	10.9		
05-25-00	EXW-1	1,015-1,225[1]	S	--	1,000-3,000	NR	--	--	--	--	31.1-26.6		
St. Lucie County													
08-24-82	MW-1	600-775[1]	M	ASR-1	388	72	5,910	1.64×10^{-4}	4.3×10^{-2}	H-J (drawdown)	--	NR	Also conducted four pump tests of ASR-1 during drilling with total depth ranging from 627 to 1,000 feet and casing at 600 feet. Transmissivity was calculated from these tests based on recovery data from ASR-1
08-24-82	MW-1	600-775[1]	M	ASR-1	388	72	6,430	2.67×10^{-4}	4.7×10^{-2}	H-J (recovery)	--		

[1]Open interval tested is the same (or about the same) as the storage zone.