"Aquifer Storage and Recovery at the South Florida Water Management District – CERP and Beyond"

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Abstract
The South Florida Water Management District (SFWMD) is responsible for overall water management across a huge area of southern Florida including the cities of Miami, Fort Myers, Naples, West Palm Beach, and southern Orlando. As part of their overall responsibilities, the SFWMD also is charged with water supply planning for a rapidly growing population of over five million persons. Due to the rapidly growing population, water supply demands have soared over the last decade. The SFWMD has funded several Aquifer Storage and Recovery (ASR) projects – through an "Alternate Water Supply Grant" program - for utilities to conduct water banking and managing peak flows during high demand periods.

Concurrently, the Comprehensive Everglades Restoration Plan (CERP) is moving ahead at a rapid clip. The CERP includes a proposal to construct 330 ASR wells to provide a flexible water storage and supply for Lake Okeechobee and other urbanized areas as well as important natural areas. The CERP ASR Program includes construction of several ASR pilot projects and a south-Florida-wide ASR Regional Study, including the development of a regional groundwater model. The schedule for the eventual construction of the CERP ASR system will likely take place through 2020.

During the past few years, south Florida has also experienced numerous hurricanes and wet weather periods that have caused massive degradation of the water quality in Lake Okeechobee and necessitated the release of huge quantities of water into the estuary systems, damaging the ecosystems there. In October 2005, Governor Jeb Bush initiated the Lake Okeechobee and Estuary Recovery (LOER) plan to help restore the ecological health of Lake Okeechobee and the St. Lucie and Caloosahatchee Estuaries. The SFWMD is one of the key agencies charged with implementing this plan, which includes construction and operation of new ASR systems in tandem with other measures.

This paper will endeavor to discuss the ASR programs along with the progress each one has made. It will also focus upon the unique technical challenges of each program and why cutting edge science has been required to solve some of the more complex issues. Lastly, the paper will discuss and comment upon ongoing and future policy issues that have been identified.

The South Florida Water Management District
SFWMD's boundaries extend from central Florida to Lake Okeechobee, and from coast to coast, from Fort Myers to Fort Pierce, south through the Everglades to the Florida Keys. The South Florida Water Management District (SFWMD) manages and protects regional water resources by balancing and improving water quality, flood control, natural systems and water supply. Figure 1 depicts the political boundary and area of operations for SFWMD.

The "seeds" for the creation of the SFWMD were planted in the late 1940s, by flood and drought. Today, the agency's responsibilities include regional flood control, water supply and water quality protection as well as ecosystem restoration. The region's subtropical extremes of hurricane, flood and drought – combined with efforts to safely populate this "new frontier" – led the U.S. Congress to adopt legislation creating the Central and Southern Florida Flood Control Project (C&SF) in 1948. In 1949, the Florida Legislature created the Central and Southern Florida Flood Control District, the predecessor to the South Florida Water Management District (SFWMD), to manage the huge project being designed and built by the U.S. Army Corps of Engineers. In 1972, with the Florida Water Resources Act (Chapter 373), the state created five water management districts, with expanded responsibilities for regional water resource management and environmental protection. In 1976, voters approved a constitutional amendment giving the districts the authority to levy property taxes to help fund these activities. Today, the South Florida Water Management District operates and maintains approximately 1,800 miles of canals and levees, 25 major pumping stations and about 200 larger and 2,000 smaller water control structures. Major canals are shown on figure 1.

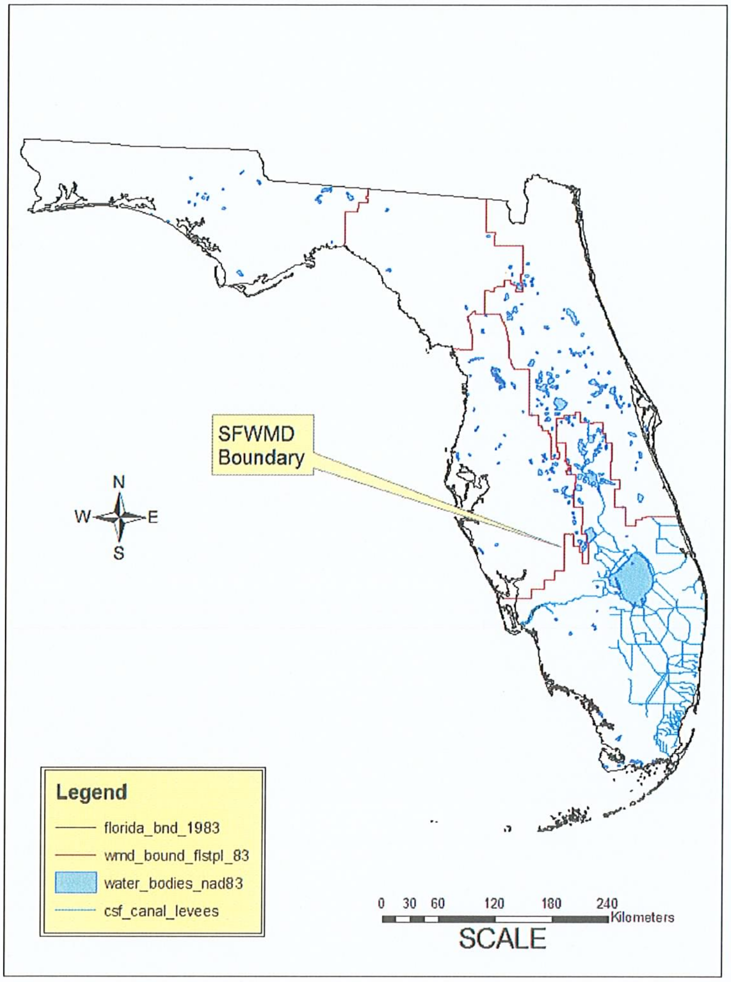

Figure 1. SFWMD Boundary

Hydrogeology of South Florida
The unconfined Surficial Aquifer System (SAS) extends from land surface (top of the water table) to a depth of between 100 to 200 feet bls. It consists of Holocene and Pliocene-Pleistocene aged sands and shelly limestone. Below the SAS lies an "Intermediate Confining Unit" extending to between 700 to 900 feet bls (Miller, 1997). The Peace River and Arcadia Formations of the Miocene-Pliocene aged Hawthorn Group act as confining units separating the FAS from the SAS. The Hawthorn Group sediments consist predominately of soft, non-indurated detritial clays, silts and poorly to moderately indurated mudstones/wackestone with minor amounts of sand and shell (Scott, 1988).

Beneath the Hawthorn Group lies the Floridan Aquifer System – the prime zone for ASR in south Florida. The Floridan aquifer system consists of a series of Tertiary limestone and dolostone units. The system includes sediments of the lower Arcadia Formation, Suwannee and Ocala Limestones, Avon Park Formation, and the Oldsmar Formation. The top of the FAS, as defined by the Southeastern Geological Society AdHoc Committee on Florida Hydrostratigraphic Unit Definition (1986) coincides with the top of a vertically continuous permeable early Miocene to Oligocene-aged carbonate sequence. The upper Floridan aquifer consists of thin, high permeability water-bearing horizons interspersed with thick, low permeability units of early Miocene to middle-Eocene age sediments, including the basal Arcadia Formation, Suwannee and Ocala Limestones, and the Avon Park Formation. Generally, two predominant permeable zones exist within the upper FAS with the uppermost typically lies between 700 and 1,200 feet bls. The most transmissive part usually occurs near the top, coincident with an unconformity at the top of the Oligocene or Eocene aged formations. The Paleocene-age Cedar Keys Formation – consisting of low permeability evaporitic gypsum and anhydrite - forms the lower boundary of the FAS. The hydrogeology of south Florida is generally compatible with the application of ASR technology – particularly in the "deep" artesian Floridan Aquifer System (FAS). Multiple ASR projects are currently operating in south Florida with most utilizing some portion of the FAS as a storage repository.

ASR Development in South Florida

ASR technology has been explored at over 30 sites in southern Florida beginning the 1980's. Initial ASR concepts were developed in 1983 at the Peace River site located outside of the SFWMD boundary south of Tampa, Florida (Pyne, 1996). Additional ASR studies in Florida at the Cocoa Beach and Hialeah ASR sites were conducted by the United States Geological Survey (USGS) and the U.S. Army Corps of Engineers (USACE) from 1983 to 1986 (Merritt, 1983; Merritt, 1986). Most of the ASR systems have been installed by public water supply utilities, with the intent of banking fully treated drinking water, reclaimed water, raw groundwater or partially treated surface water. Most of these facilities were constructed in the 1990's. Some sites have been in operation for at least 10 years including the Boynton Beach and Port Malabar/Palm Bay (Brown, 2005) projects. Other sites are relatively new including multiple sites located in southwest Florida such as Olga. ASR projects in Florida have been successful for the most part but some projects have performed sub-optimally (Reese, 2002). Isolated ASR problems documented in Florida include salt-water upcoming, excessive mixing between ambient brackish water and recharged freshwater, and in-situ geochemical reactions related to release of pyrite (Brown, 2005; Price and Pichler, 2006).

SFWMD Alternative Water Supply Program

The SFWMD has been cooperatively developing, funding and implementing "alternative" water supply projects – including ASR - for 10 years under the various state initiatives and grant programs. Between 1997 and 2004, these projects have created more than 340 million gallons of water per day through development of saline water sources, reclaimed water and ASR. In the past decade, the SFWMD has funded 28 ASR-related construction projects across seven counties at over a dozen public utility water facilities. The projects have involved construction of exploratory wells, ASR wells and associated monitoring wells. The projects involved reclaimed water, potable water and treated surface water. Many of the projects have expanded to become multi-well facilities and undergone multiple cycles of recharge, storage and recovery.

The Comprehensive Everglades Restoration Program (CERP)

The Comprehensive Everglades Restoration Plan (CERP) is a framework and guide to restore, protect, and preserve the water resources of central and southern Florida.

- The Plan has been described as the world's largest ecosystem restoration effort and includes more than 60 major components.
- Because the region's environment and economy are integrally linked, the Plan provides important economic benefits.
- Thus, the Plan will result in a sustainable south Florida by restoring the ecosystem, ensuring clean and reliable water supplies, and providing flood protection.

The Comprehensive Everglades Restoration Plan provides a framework and guide to restore, protect, and preserve the water resources of central and southern Florida, including the Everglades. It covers 16 counties over an 18,000-square-mile area, and revolves around a major re-plumbing of the entire C&SF Project. The C&SF Project provides water supply, flood protection, water management and other benefits to south Florida. For close to 50 years, the C&SF Project has performed its authorized functions well. However, the project has had unintended adverse effects on the unique and diverse environment that constitutes south Florida ecosystems, including the Everglades and Florida Bay. The Water Resources Development Acts in 1992 and 1996 provided the U.S. Army Corps of Engineers with the authority to re-evaluate the performance and impacts of the C&SF Project and to recommend improvements and or modifications to the project in order to restore the south Florida ecosystem and to provide for other water resource needs. The resulting Comprehensive Plan (USACE & SFWMD, 1999) was designed to capture, store and redistribute fresh water previously lost to tide and to regulate the quality, quantity, timing and distribution of water flows.

The Plan was approved in the Water Resources Development Act of 2000. It includes more than 60 elements, will take more than 30 years to construct, and will cost an estimated $7.8 billion. The major Plan components include reservoirs, stormwater treatment areas, and approximately 333 ASR wells located throughout the study area. The CERP ASR components are expected to take surplus freshwater (collected in surface reservoirs during wet periods), treat it as required and then store it deep underground in the FAS for subsequent recovery during dry periods. Implementation of regional ASR technology within the south Florida basin is anticipated to significantly increase freshwater storage capacities. It is also forecasted to help minimize damaging high-volume freshwater releases from surface water sources (such as Lake Okeechobee) to the estuaries. During dry periods, water recovered from ASR wells would be utilized to augment surface water supplies and maintain the surface water levels and/or flows within Lake Okeechobee, the St. Lucie and Caloosahatchee Rivers and associated canals throughout southern

Florida. Of the 68 project components recommended in the CERP, several recommended inclusion of ASR wells. The six project locations authorized in the plan are:

- Lake Okeechobee ASR (component GG) – 200 wells
- Caloosahatchee (C-43) Reservoir ASR (component D) – 44 wells
- L-8 Basin ASR (components K and GGG) – 10 wells
- C-51 Canal ASR (component LL) – 34 wells
- Central Palm Beach County (Agricultural Reserve) Reservoir ASR (component VV) – 15 wells
- Site 1/Hillsboro ASR (component M) – 30 wells

Additional ASR wells are currently under consideration for inclusion in conjunction with the CERP ACME Basin B reservoir and the C-9 Water Preserve Area (WPA). The exact number of wells has not been finalized. In addition, the final number and disposition of ***all*** proposed ASR wells will be determined through further scientific investigations conducted under a comprehensive regional study. The ASR Regional Study, the associated ASR Pilot Projects and required Project Implementation Report (PIR) studies for each CERP ASR component will be under development until 2010 or later. The primary focus of the ASR Regional Study is to provide additional scientific studies of the proposed CERP ASR project to ensure that the project is feasible at the scale originally conceived in 1999. The ASR Regional Study is outlined in a comprehensive project management plan prepared by the USACE and the SFWMD and subsequently reviewed and critiqued by the National Research Council (NRC, 2002; USACE & SFWMD, 2004). The ASR Regional Study will address 8 major issues or areas of uncertainty including:

- Characterization of the quality of prospective source waters, spatial and temporal variability,
- Characterization of regional hydrogeology of the Upper Floridan Aquifer: hydraulic properties and water quality,
- Analysis of critical pressure for rock fracturing,
- Analysis of site and regional changes in head and patterns of flow,
- Analysis of water quality changes during movement and storage in the aquifer,
- Potential effects of ASR on mercury bioaccumulation for ecosystem restoration projects, and
- Relationship among ASR storage interval properties, recovery rates, and recharge volume.
- Ecological affects and studies related to recovery and use of stored ASR water

One large component of the overall ASR Regional Study is the development of a peninsular numerical model of the FAS so that simulations of the proposed CERP ASR operation may be conducted. Several model types and resolutions are under consideration in order to efficiently address the study issues. Figure 2 depicts the anticipated model domains under consideration for the study.

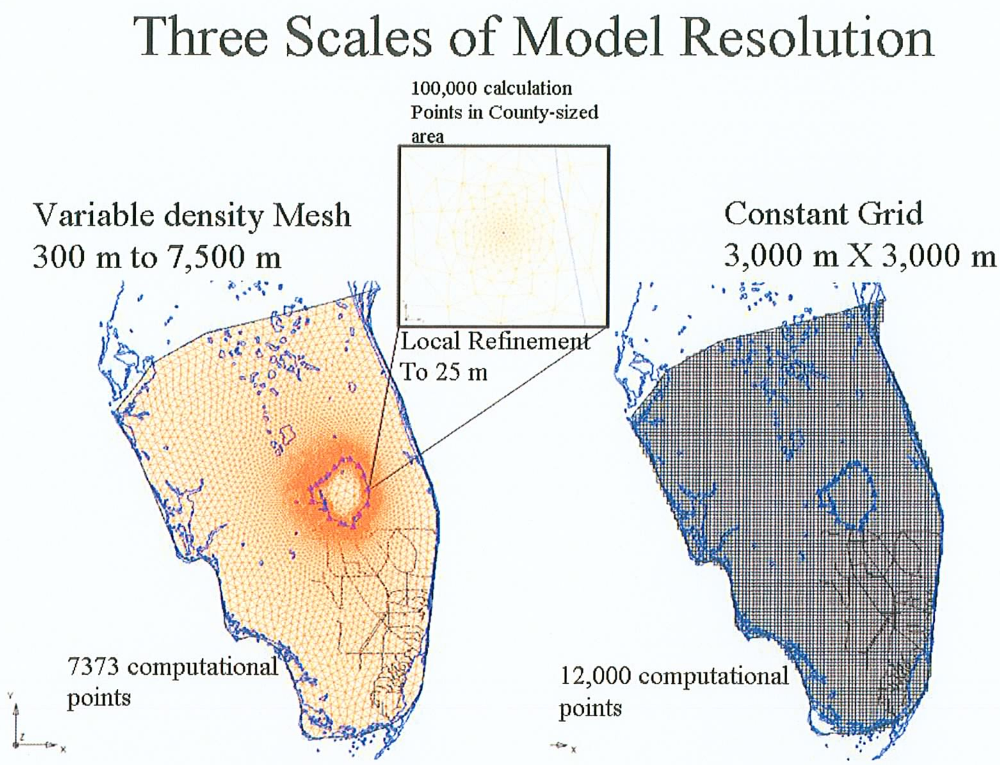

Figure 2. Preliminary Domains and Resolutions for ASR Regional FAS Model

CERP ASR Pilot Projects

The scale of the proposed ASR program in the Comprehensive Everglades Restoration Plan (CERP) is unprecedented, and "pilot projects" were envisioned to address the technical and regulatory uncertainties associated with its implementation at a local level. The pilot tests were designed to reduce uncertainties relative to ASR design and operation by investigating options for surface water withdrawal, injection and pumping cycles, water treatment technology, and effects of these pumping cycles on the groundwater and ecosystem in the test region. Operating pilot tests will also provide insight into construction and operational costs, aiding in a comparison of ASR technology with conventional storage technologies such as surface water reservoirs.

Three (3) ASR pilot projects were initially envisioned as comprising the CERP ASR Program - at Lake Okeechobee, the Hillsboro Canal and at the Caloosahatchee River. Because the extent of ASR envisioned around Lake Okeechobee was so large, the Lake Okeechobee Pilot Project was subsequently split into 3 distinct project localities – at Moore Haven, the Kissimmee River, and at Port Mayaca. The Project Management Plans for the Lake Okeechobee and Hillsboro Pilot Projects - which contained the work plan and schedule at each of the pilot project locations were developed and finalized in 2001. The Caloosahatchee River ASR (CRASR) Pilot Project Management Plan was subsequently approved in February 2002. The PMPs included steps to construct exploratory wells, conduct source water (the water that would be pumped into the wells) sampling, design studies, permitting, construction and operation (cycle testing).

Exploratory Wells and Initial Pilot Project Tasks

After the PMPs were approved, exploratory wells were constructed at each of the 5 pilot project locations. The exploratory wells were used to characterize the hydrogeology of each of the sites, to confirm that ASR could be implemented in the Floridan Aquifer. Additionally, water quality sampling, design evaluations and permitting were also conducted. Concurrent with the exploratory wells, designs for the treatment and pumping systems were developed at each of the pilot project locations.

Pilot Project Design Reports and Environmental Impact Statements

When the initial designs were complete, a combined Pilot Project Design Report and Environmental Impact Statement was prepared (USACE & SFWMD, 2004). Those documents contained the recommended design, construction and operation of each of the pilot projects and an evaluation of the potential environmental effects of the pilot projects. A Record of Decision accepting the findings and recommendations of the PPDR/EIS was released in October 2005. As part of the PPDR/EIS document, a cost estimate for the eventual construction of each pilot project was prepared. The cost estimate indicated that the construction of the three Lake Okeechobee sites would exceed the initial authorization – hence it was determined that construction of the Moore

Haven pilot project would be deferred. Hence, the Kissimmee and Port Mayaca pilot systems would be the only pilot projects to be constructed in the near term.

Pilot Project Details

The Kissimmee River ASR pilot project has been designed to be a one-well, 5 million gallon per day (MGD) system on the western bank of the Kissimmee River, just north of Lake Okeechobee. The system will use a "pressure media" filter coupled with ultraviolet radiation disinfection to treat river water before it is recharged into the ASR well. The system is currently under construction, and will become operational in late 2007. The Port Mayaca pilot project has been designed to be a multi-well ASR facility, with 3 ASR wells planned. This project will be useful in determining the effect that multiple wells will have on each other during operation and recovery. Currently, one large diameter ASR well and a dual-zone monitor well have been constructed at the site. The USACE will be constructing additional wells and the surface facilities for this system in late 2007 and through 2008. The Hillsboro or Site 1 is located west of Boca Raton about six miles west of S.R. 7 (U.S. Hwy 441) on Loxahatchee Road. The site is on SFWMD-owned land referred to as "Site 1", adjacent to Loxahatchee Road and the Hillsboro Canal.

The Site 1 ASR system has been designed to provide a capacity to recharge and recover approximately 5 MGD from FAS. The ASR system will withdraw surface water from the Hillsboro Canal through construction of a proposed new inlet and outlet structure, pumps and piping. The raw surface water will be treated to meet primary drinking water standards via screen filtration with ultraviolet (UV) disinfection prior to recharge into the ASR well. During recovery, the water will be treated via aeration prior to discharge back into the Hillsboro Canal. It is anticipated that the system will begin cycle testing in late 2007.

The Caloosahatchee River ASR (CRASR) pilot project was sited at Berry Groves in Hendry County, the future site of an impoundment related to the C-43 Reservoir Project. The exploratory well was constructed between May 2003 and July 2004. The well was completed with a final casing cemented to 640 feet below land surface (bls) – the "top" of the FAS. The open hole was extended to a total depth of 900 feet bls, developed, and subjected to a series of pumping tests. During these tests, the well produced water at rates of up to 2,450 gallons per minute (equivalent to approximately 3.5 MGD). However, copious quantities of fine-grained quartz sand were also produced, and the open hole would collapse and "backfill" with sand.

As a result of the difficulties encountered at the exploratory well - a continuous core boring was installed at the CRASR site – about 1,000 feet west of the exploratory well. The objective of the continuous core boring was to obtain detailed stratigraphic information, to confirm the lateral persistence of the problematic sand interval encountered at the top of the FAS and to stay within the footprint of the conceptual design. The continuous core boring was constructed between October 2004 and January 2005 and succeeded in recovering a nearly complete interval of sediments from 200 to 1,000 feet bls. The continuous core boring has confirmed that the problematic sand interval is also present at this location, albeit at a somewhat shallower depth (between approximately 550 and 660 feet bls). Below that depth, the formation appears more stable – however, the scope of work for the core boring did not include hydraulic testing that would verify the well capacity. The core boring has since been completed with a temporary cap on the wellhead.

At present, the USACE and SFWMD have collected extensive subsurface information at the Berry Groves site, but have not determined the ASR well capacity or its ability to produce water without problematic quantities of sand. This uncertainty has resulted in a delay in finalizing the surface facility design – primarily related to the uncertainty of the ASR well to produce 5 mgd. It was originally anticipated that this project would be constructed in FY05 and operated for a two year cycle testing period through FY07 – well in advance of construction of the impoundment at Berry Groves. However, due to these technical delays and CERP program budgetary constraints, construction is scheduled to start no earlier than FY06 – which could impinge upon the construction of features related to the C-43 impoundment, which is now part of the Acceler8 program.

The Lake Okeechobee and Estuary Recovery Plan (LOER)

Announced October 10, 2005 by Governor Jeb Bush, LOER was a response to identified water resource needs, legislative directives, and demands of Florida citizens. This action plan was developed to help restore the ecological health of Lake Okeechobee and the St. Lucie and Caloosahatchee Estuaries. Key state agencies charged with carrying out this plan include the South Florida Water Management District (SFWMD), the Department of Environmental Protection (FDEP), the Department of Agriculture and Consumer Services (FDACS) and the Department of Community Affairs (FDCA). Through the leadership of the Governor and Legislature, initial funding has been provided for a series of "fast-track" capital projects to help provide meaningful water quality improvements.

The Lake Okeechobee Fast Track projects include the following components: an 800-plus acre expansion of the Nubbin Slough Stormwater Treatment Area (STA); the construction of a 4,000-acre reservoir in Taylor Creek; the construction of another 2,700-acre STA at Lakeside Ranch (south and west of Nubbin Slough); the re-routing of flows from the S-133 and S-191 basins to the Lakeside Ranch STA; and, potentially, the re-routing of flows from the S-154 basin also to the Lakeside Ranch STA. The combined storage and phosphorus reduction benefits are estimated at 48,000 acre feet and 65 to 75 metric tons, respectively.

In addition to the "turn-dirt" construction projects, several other far-reaching and innovative components – some which do not require large capital outlay – can also provide more immediate and measurable improvements in the condition of Lake Okeechobee, the St. Lucie Estuary and the Caloosahatchee Estuary. Combined, these initiatives comprise a bold and aggressive recovery plan.

To help achieve a better balance among management objectives – flood control, water supply and navigation, and the competing needs of the lake, estuaries and greater Everglades ecosystem – the U.S. Army Corps of Engineers (USACE) will revise the lake regulation schedule by December 2006. The ultimate goal is to achieve lower lake water levels and reduce high volume discharges to the estuaries. As structural components, such as the Acceler8 reservoirs are completed, the USACE will continue to revise the schedule. The SFWMD and other supporting agencies will be working in tandem to revisit water supply demand estimates, supply side management strategies and the modeling and design of forward pumps.

Three ASR projects have been initiated under the LOER initative including:

- Reactivation of the Taylor Creek ASR system (originally constructed and tested in the early 1990's);
- Partner with the Seminole Tribe to construct a pilot ASR system at the Brighton Indian Reservation; and
- Construct a 10-well ASR system somewhere in the vicinity of Lake Okeechobee.

Emerging Issues

For all ASR projects, performance factors relating to the aquifer itself are important. The aquifer hydrogeology will control the distribution of the injected water within the aquifer storage zone. The aquifer hydraulic conductivity controls the distribution of water level or potential (pressure) in the aquifer. Aquifers exhibiting low to moderate hydraulic conductivity may result in induced high water levels or aquifer pressure. Inordinately high water levels may result in surface flooding or loss of injected water through surface runoff. Inordinately high aquifer pressures may result in local hydraulic fracturing of the aquifer material itself or surrounding confining units in the case of a confined aquifer. Aquifers exhibiting low porosity or aquifers where fluid flow is concentrated in fractures rather than aquifer pore space, may increase groundwater flow velocity or may induce high rates of diffusion (Gale, 2002; Anderson and Lowry, 2004); either of these phenomena may reduce recoverability of injected water.

Besides the ASR performance factors related to hydrogeology, ASR performance can also be negatively affected by geochemical reactions that occur between the aquifer matrix and the injected water or the ambient groundwater and the injected water. Geochemical issues at multiple ASR sites around the globe have hindered further project development efforts and led to mistrust of the technology by regulators. Geochemical issues related to arsenic and pyrite have been very problematic in Florida.

Geochemical reactions around recharge and recovery wells have been reported for decades. ASR wells have only come into being in the early 1980s so that literature specific to ASR wells is relatively recent. Mirecki (2004) studied geochemical data at 11 ASR sites located in south Florida. Mirecki observed that several of the sites had elevated concentrations of arsenic, radionuclides, ammonia, and sulfate. Seven of eleven ASR sites studied reported arsenic results; only one of these sites reported arsenic concentrations in excess of water quality standards. Three of the eleven sites reported ammonia concentrations in the recovered water in excess of Florida surface water regulatory standards.

Price and Pichler (2006) found that arsenic was present within the Suwannee Limestone portion of the Upper Floridan Aquifer System. Bulk arsenic concentrations ranged from a few part per million (ppm) to 11,200 ppm. The study also concluded that pyrite is "ubiquitous throughout the Suwannee Limestone" in the form of framboidal pyrite and is "most abundant in high porosity zones". The study also discounts other potential arsenic sources such as hydrous ferric oxides, clay minerals, and apatite. The average As concentration for all 306 samples that were collected during the study was 3.5 ppm, which is higher than the global average for limestone (2.6 ppm).

Another emerging issue is competition between users of the FAS for water supply and ASR projects. The upper portion of the FAS is not only a good zone for ASR, but is also an excellent source of artesian water for agricultural and public water supply. In the past twenty years, water withdrawals from the FAS have doubled, from 2 billion gallons per day (BGD) to slightly more than 4 BGD. Through the alternative water supply grant program and other environmental initiatives designed to wean users off the Surficial Aquifer system, the SFWMD has encouraged users to exploit the FAS. As a result, the proximity between ASR projects and water supply (withdrawal) projects is diminishing, forcing the permitting agencies to utilize more complex analyses for determining permittable quantities and the most beneficial use of the resource.

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