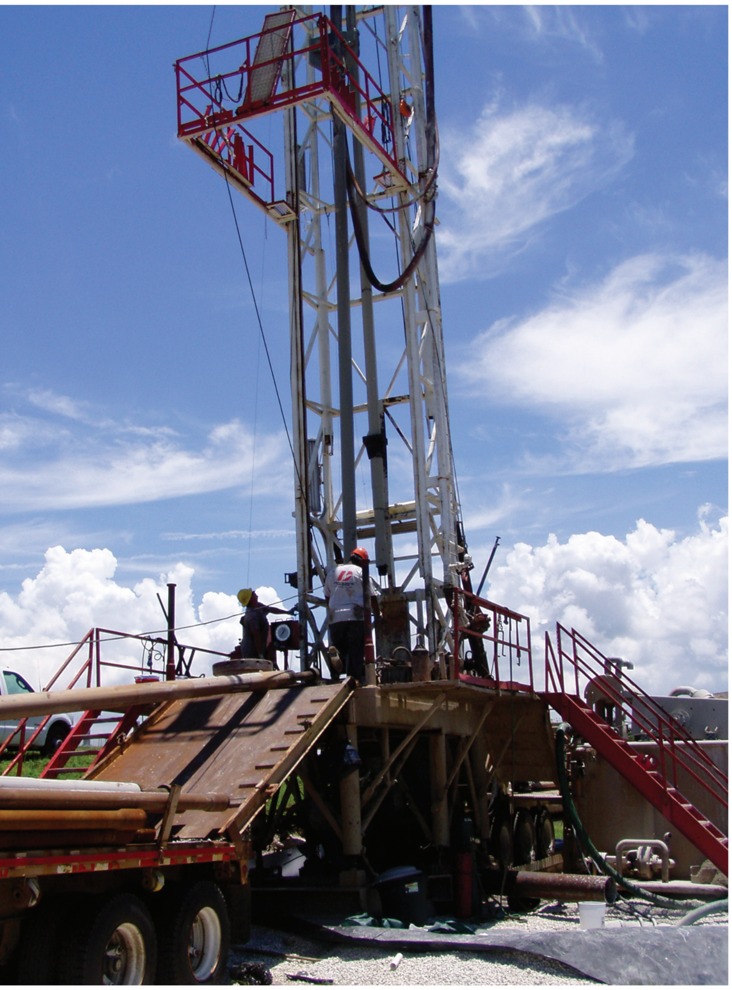
SOUTH FLORIDA WATER MANAGEMENT DISTRICT



the journey to restore America's Everglades

Comprehensive Everglades Restoration Plan

AQUIFER STORAGE & RECOVERY PROGRAM

INTERIM REPORT 2008

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Foreword

The South Florida Water Management District and the U.S. Army Corp of Engineers present the Aquifer Storage and Recovery (ASR) Interim Report. This foreword tells a brief history of the Comprehensive Everglades Restoration Plan's (CERP) ASR Program to provide the context needed to understand what has been accomplished to date.

Up to 333 ASR wells have been proposed by the CERP to recharge, store, and recover water underground to ensure water for the Everglades, improve conditions in Lake Okeechobee, and prevent damaging releases of fresh water to coastal estuaries. Acknowledging this unprecedented use of ASR technology, the plan includes pilot projects to address and reduce uncertainties about its grand-scale use. However, a great deal of skepticism and apprehension has been voiced about the CERP's ASR concept.

Concerns have been expressed about the use of ASR in the CERP: possible fracturing of rock formations and the movement of stored water within the aquifer; potential adverse impacts to wetlands and wildlife habitat; perceived growth management conflicts; preference for "natural" rather than "artificial or engineered" solutions; possible increases in arsenic levels; and so on.

Technical uncertainties about ASR have also been numerous and varied, especially due to limited understanding of regional-scale ASR implementation. These questions prompted the formation of a multiagency team of scientists, engineers, and planners to develop plans for and conduct the CERP ASR Regional Study, in coordination with the ASR pilot projects. Designed to evaluate CERP ASR feasibility, plans were approved in 2002–2003 and an intensive effort began.

Today, despite tremendous challenges and constraints, many studies have been performed and a great deal of knowledge has been gained about ASR for Everglades restoration. The best available data and state-of-the-art methods and models have been used throughout the study process. This Interim Report documents the results of the first five years of scientific and engineering investigations. Brief summaries of research and results are presented in this volume and the attached CD contains expanded documentation of each study. This publication continues our commitment to communicate with the public as work progresses toward restoration of the south Florida ecosystem.

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Executive Summary

Aquifer storage and recovery (ASR) is defined as the storage of water in an aquifer via the use of a dual-purpose well that can be used for both recharge and recovery. ASR technology offers the potential to store and supply vast quantities of water without the need for large tracts of land, and as such it is a vital component to the Comprehensive Everglades Restoration Plan (CERP) implemented by the South Florida Water Management District and the United States Army Corps of Engineers.

This CERP ASR Program Interim Report presents the first five years of scientific and engineering progress in conducting the ASR pilot projects and the ASR Regional Study. These projects have been developed in response to questions and comments posed by stakeholders, the ASR Issue Team, and the Committee on the Restoration of the Greater Everglades Ecosystem. As the ASR Program nears the point of pilot project cycle testing, this is an opportune time to share the program's progress with interested stakeholders and the public.

This work represents the efforts of a multiagency, multidisciplinary team of hydrogeologists, engineers, and environmental scientists who have developed plans, responded to reviews and critiques, formulated strategies, and conducted experiments to answer technical questions about the role of ASR in the CERP. The information provided in this report represents sound science and engineering to support prudent environmental management and decision-making for the future.

- To date, no "fatal flaws" have been uncovered that might hinder the implementation of CERP ASR. It is believed that ASR will work almost anywhere in south Florida on some scale and with some degree of efficiency.

Among the many ASR Program accomplishments over the past few years, exploratory wells have been constructed at five separate pilot project locations around Lake Okeechobee, and along the Hillsboro Canal and the Caloosahatchee River. Favorable hydrogeologic conditions for ASR have been found at four out of the five locations.

- ASR pilot projects have been constructed along the Kissimmee River (in Okeechobee County) and the Hillsboro Canal (in Palm Beach County). Cycle testing is about to begin, which will take place over the next few years.

The pilot project tests will provide field data to augment scientific and engineering studies that have been conducted and will help to determine:

- Optimal operations to maximize storage and recovery

- The effectiveness of water treatment technologies prior to recharge
- Water-quality changes that take place during recharge, storage, and recovery
- The potential for mercury bioaccumulation from recovered water
- The relationship between storage zone properties and recovery efficiency
- An understanding of the water-rock mixing and geochemical reactions within the aquifer
- The impact of recovered water on the ecology through extended bioassay testing, monitoring, and ecosystem modeling

> A massive hydrogeologic, water-quality, and ecological monitoring network has been constructed to observe the "current state of the system" and reveal any changes that might take place as a result of ASR.

A vast hydrogeologic database has been compiled and developed into a comprehensive hydrogeologic framework of the Floridan aquifer system in south Florida. While building the database, numerous areas of missing information, or "data gaps" were identified. Extensive geological and geophysical investigations were then performed to fill in the missing information – including construction of seven new test wells and core borings throughout south Florida.

> A geotechnical analysis indicated that the potential for rock fracturing from ASR is very low, as long as recharge pressures are kept low and the wells are spaced at safe distances apart from one another.

Various geophysical studies were conducted to fill hydrogeologic data gaps, analyze site and regional changes in groundwater flow patterns of the Floridan aquifer system, and analyze critical pressure for rock fracturing. Geophysical investigations—including a lineament survey, a seismic survey of Lake Okeechobee, cross-well tomography, and a fracture evaluation—were performed to supplement the new geological data.

> Two powerful, augmenting groundwater models are being constructed, which will be used to simulate potential local and regional effects of ASR on the groundwater system.

Groundwater models represent the latest in cutting-edge computer programming. They can simulate the effects of density, pressure, flow, and transport on both local and regional scales. When the groundwater modeling results become available, they will be used to:

- Evaluate the potential effects that a regional-scale ASR system, as envisioned in the CERP, may have on south Florida

- Analyze the local- and regional-scale changes in groundwater levels and flow directions
- Determine the potential effects of aquifer pressure changes during recharge and recovery operations
- Predict regional water-quality changes within the Floridan aquifer system
- Propose locations, the number of ASR wells, and facilities that optimize benefits and minimize or eliminate potential risks

The results of the pilot projects and the various geological and geophysical investigations will continue to be integrated into the models, which will undergo refinement and calibration over the next few years.

> Arsenic has emerged as a constituent of concern regarding south Florida ASR, as it has been detected in some operational systems. Geochemical studies and cycle testing of the ASR pilot projects are being conducted to find a way to reduce the mobilization of arsenic.

Study planners now have a deeper understanding of the complex geochemical and biological reactions that can take place within the Floridan aquifer system as a result of recharge, storage, and recovery of treated water.

Teaming with the Florida Geological Survey, the U.S. Geological Survey, and others, a variety of geochemical studies and techniques have been developed to assess the effects of ASR on the quality of water recovered from the Floridan aquifer system. These studies will continue as the pilot projects become operational.

> A preliminary mercury assessment suggests that water recovered from ASR will not likely result in added mercury to the ecosystem.

A baseline environmental monitoring program and preliminary ecological tests have been performed to assess and predict the effects of the ASR Program on the south Florida ecosystem. Studies on the effects of chemicals on organisms and ecosystems, as well as potential for mercury contamination have been completed.

> Ecological studies of varying mixtures of Floridan aquifer water with surface water did not show toxic effects on organisms and showed only minimal effects on reproduction or absorption of chemicals, except when the most extreme concentrations of solutions were used.

Results from these studies will be integrated into a conceptual ecological model with data obtained during pilot project cycle testing over the next few years. The conceptual ecological model will provide insight into understanding the relationships between potential stressors and receptors on the environment resulting from CERP ASR. The model will be an important step toward performing an ecological risk assessment that will help to reveal the potential environmental benefits and risks that might occur from the proposed CERP ASR Program.

Numerous scientific and engineering investigations have been conducted over the past five years resulting in a wealth of knowledge and understanding of the dynamic physical, chemical, and biological components of the Greater Everglades ecosystem in response to the application of ASR technology. Additional investigations and studies are planned to provide restoration managers with strong, scientific and engineering information for making technically sound decisions. Results of future studies will be incorporated into the final ASR Program Technical Data Report, which is expected to be available by 2012.

? FREQUENTLY ASKED QUESTIONS

Q Is ASR a new technology?

A No. Artificial recharge of aquifers has been used in the United States since the 1940s. The first ASR system in the United States was constructed in 1968 in Wildwood, New Jersey. The states of California, Florida, Nevada, New Jersey, and Texas now have multiple ASR systems. On a global scale, ASR systems have been or are currently under construction in Canada, England, The Netherlands, Israel, and Australia.

Q How will ASR help restore the environment?

A ASR is intended to work in combination with the other CERP features to better manage the level of Lake Okeechobee, reduce harmful discharges to the St. Lucie and Caloosahatchee River estuaries, and restore the quality and timing of water deliveries to the Everglades, which should benefit the flora and fauna of south Florida. Additionally, ASR offers the ability to store large quantities of water (similar to large reservoir) for prolonged recovery periods. During times of severe drought, water recovered from ASR systems can provide supply and base flow to natural systems when there might otherwise be none.

Q Will polluted water be pumped into the aquifer?

A No. The water that will be pumped into the ASR wells will come from Lake Okeechobee and the major canals within the SFWMD. The water will be treated through filtration and disinfection before being pumped into the wells to meet federal and state regulatory standards, which include Primary Drinking Water standards before being pumped into the aquifer. The treated recharge water will be cleaner than the water in its original state.

More questions? See Appendix A: Frequently Asked Questions.

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Acronyms and Abbreviations

ASR	aquifer storage and recovery
ASR Issue Team	Aquifer Storage and Recovery Issue Team
ASTM	American Society for Testing and Materials, now known as ASTM International
C&SF	Central and Southern Florida Flood Control
CERP	Comprehensive Everglades Restoration Plan
CERPRA	Comprehensive Everglades Restoration Plan Regulation Act
CROGEE	Committee on the Restoration of the Greater Everglades Ecosystem
DBHYDRO	SFWMD's corporate environmental database
District	South Florida Water Management District
DNA	deoxyribonucleic acid
EIS	Environmental Impact Statement
FDEP	Florida Department of Environmental Protection
FETAX	Frog Embryo Teratogenesis Assay *Xenopus*
FGS	Florida Geological Survey
ft	feet
FWC	Florida Fish and Wildlife Conservation Commission
GIS	geographic information system
GPS	global positioning system
Interim Report	ASR Program Interim Report
MeHg	Methylmercury
MGD	million gallons per day
MODFLOW	MODular 3-dimensional finite-difference groundwater FLOW model
MT3DMS	modular 3-dimensional multispecies transport model
NASA	National Aeronautics and Space Administration
NELAC	National Environmental Laboratory Accreditation Conference
PIR	Project Implementation Report

PMP	Program Management Plan
PPDR	Pilot Project Design Report
PRD-1	a small lipid-containing bacteriophage
psi	pounds per square inch
RECOVER	REstoration COordination VERification
Redox	Reduction/oxidation reaction
Restudy	Central and Southern Florida Project Comprehensive Review Study
RNA	ribonucleic acid
ROMP	Regional Observation Monitoring Program
SEAWAT	fully coupled or uncoupled density-dependent flow and transport model
SFWMD	South Florida Water Management District
SFWMM	South Florida Water Management Model
SWFWMD	Southwest Florida Water Management District
SWI Package	Sea Water Intrusion Package
TDS	total dissolved solids
µg/l	micrograms per liter
U.S.	United States
USACE	United States Army Corps of Engineers
USEPA	United States Environmental Protection Agency
USFWS	United States Fish and Wildlife Service
USGS	United States Geological Survey
WASH123D	Distributed, physics-based, density-dependent flow and transport watershed model

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Introduction to the CERP ASR Program

To restore and preserve the Everglades and south Florida's natural environment, enhance water supplies, and maintain flood protection, the U.S. Army Corps of Engineers (USACE), in partnership with the South Florida Water Management District (SFWMD or District), developed a plan called the Comprehensive Everglades Restoration Plan (CERP). Successful implementation of the CERP requires finding ways to store water to improve quantity, quality, timing, and distribution of flows to the Everglades system. Several possible technologies are being evaluated to accomplish this storage and distribution of water, of which aquifer storage and recovery (ASR) is the most challenging.

Although ASR technology has been used successfully in Florida since 1983, concerns have been expressed about the regional-scale use of ASR as envisioned in the CERP. These concerns were outlined in a report by the ASR Issue Team to the South Florida Ecosystem Restoration Working Group and subsequent reports by the National Academy of Sciences Committee on the Restoration of the Greater Everglades Ecosystem (CROGEE). The CERP ASR pilot projects and ASR Regional Study were designed to address many of the technical, scientific, engineering, and environmental questions that have been raised concerning the feasibility of regional-scale ASR implementation. This ASR Program Interim Report (Interim Report) documents the initial products of the ASR Regional Study. Several ongoing and new tasks will be conducted over the next few years to augment the studies documented in this report.

This chapter provides a brief overview of ASR technology, ASR's role in the CERP, and the purpose of the ASR Regional Study and ASR pilot projects.

AQUIFER STORAGE AND RECOVERY

Used in the United States for more than 30 years, aquifer storage and recovery refers to the process of recharge, storage, and recovery of water in an aquifer. Available surface waters are collected during times when water is plentiful (typically during the wet season in south Florida), treated to meet federal and state drinking water standards, and then pumped into an aquifer through a well. In south Florida, most ASR systems store treated water in the Floridan aquifer system, which contains brackish (slightly salty) water. When recharged into the aquifer, the "stored" water displaces the salty aquifer water. The diagram in **Figure 1** depicts this concept.

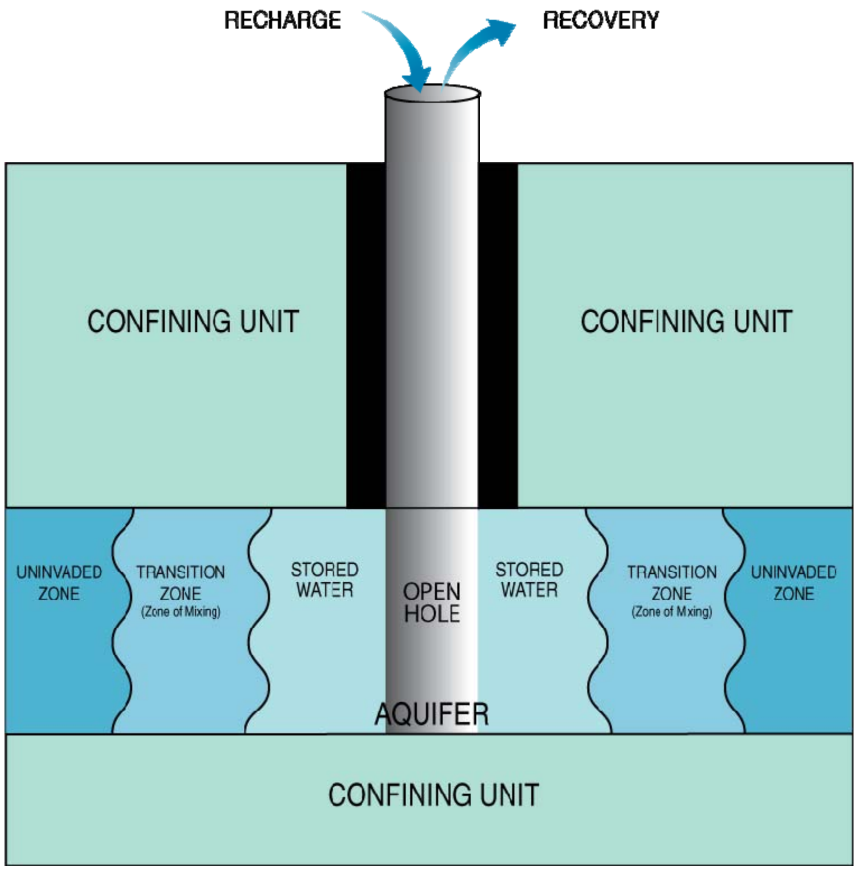

Figure 1. ASR Well in a Confined Aquifer Depicting Idealized Stored Water and Transition Zones.

Stored underground, the fresh water is later "recovered" (by pumping it out of the same well) and distributed for beneficial use (ecosystem restoration and other water needs in south Florida), typically during Florida's dry periods. This process of recharge, storage, and recovery is called a cycle. Cycle tests serve as the primary means to analyze the feasibility of ASR on a pilot site-specific scale.

The use of ASR is increasing nationally and worldwide as the need for alternative water management options grows. In south Florida, regional-scale implementation of ASR is envisioned as a significant component of the CERP.

ASR AND THE COMPREHENSIVE EVERGLADES RESTORATION PLAN

South Florida's existing water management system consists of an extensive network of canals, levees, and water control structures, constructed as part of the Central and Southern Florida Flood Control Project (C&SF Project). Authorized by Congress in the late 1940s, the C&SF Project was constructed to: provide flood control; provide water supply for municipal, industrial, and agricultural uses, as well as for Everglades National Park; help prevent saltwater intrusion; and help protect fish and wildlife resources.

Typical ASR Wellhead

Today, due to water management system limitations, discharges to the Everglades and estuaries are often too much or too little, and frequently occur at the wrong time of year. Studies show that the remaining south Florida ecosystem no longer exhibits the functions and richness that defined the pre-drainage system. In addition, the C&SF Project sends billions of gallons of fresh water to the sea that could be captured and stored for use when needed.

The use of ASR technology to support CERP water management goals was first envisioned in 1996 as part of the Governor's Commission for a Sustainable South Florida. The commission recommended, "ASR technology should be investigated to determine its feasibility on a regional scale."

The *Central and Southern Florida Project Comprehensive Review Study* (Restudy), conducted jointly by the USACE and SFWMD and published in 1999, presents a framework for Everglades restoration, preservation, and protection of the south Florida ecosystem, while providing for other water-related needs of the region, such as municipal, industrial, and agricultural water supply and flood protection. The Restudy, now known as the Comprehensive Everglades Restoration Plan (CERP), is a cooperative effort containing 68 components, including structural and operational changes to the existing C&SF Project. Implementation of the CERP is designed to improve the quality, quantity, timing, and distribution of water flows, restore and enhance natural systems, and improve fish and wildlife habitats to promote recovery of native flora and fauna, including threatened and endangered species.

Of the 68 project components recommended in the CERP, seven components involve ASR wells. These components include, combined, as many as 333 wells with a total capacity of nearly 1.7 billion gallons per day. To address the uncertainties of ASR technology prior to regional implementation of these components, the CERP also recommended the construction of ASR pilot projects along the Caloosahatchee River, the Hillsboro Canal and adjacent to Lake Okeechobee. The ASR pilot projects are discussed in **Chapter 2**.

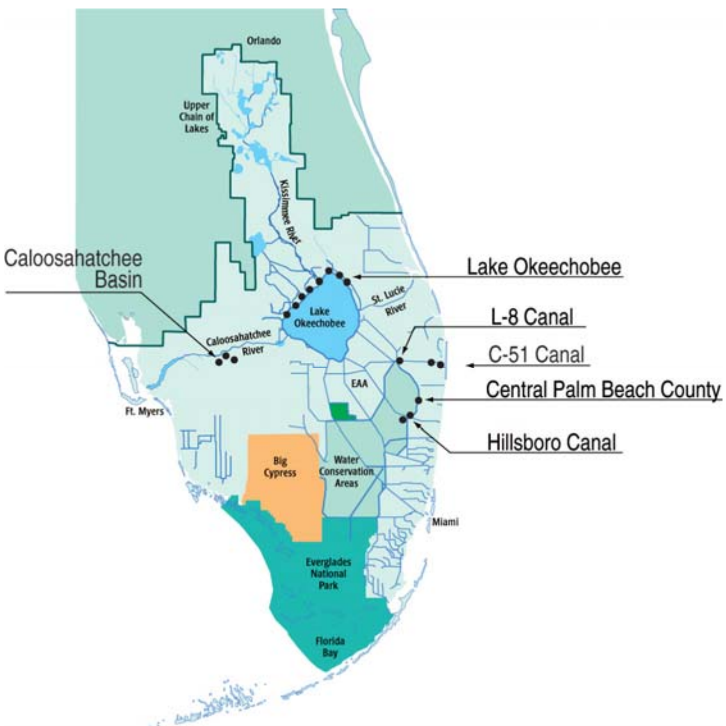

Figure 2. Generalized CERP ASR Project Locations.

The CERP ASR components are expected to take surplus fresh surface water, treat it as required, then store it in the Floridan aquifer system for subsequent recovery during dry periods. Implementation of ASR within south Florida is anticipated to significantly increase freshwater storage capacities. It is also expected to help manage the level of Lake Okeechobee, and in doing so, minimize damaging high-volume freshwater releases to the St. Lucie and Caloosahatchee estuaries. During dry periods, water recovered from ASR wells would augment surface water supplies and maintain the water levels and/or flows within Lake Okeechobee, the St. Lucie and Caloosahatchee rivers, and associated canals throughout south Florida. **Figure 2** shows the generalized locations of the CERP ASR wells.

The CERP also proposes to use ASR in longer-range water supply planning by storing water during wet years and delaying recovery until it is needed, potentially years later and during multiyear droughts common in south Florida. Although ASR wells have been used in Florida for seasonal storage, the technology has never been implemented on such an unprecedented regional, multiyear scale.

DEVELOPMENT OF THE CERP ASR REGIONAL STUDY

Due to the limited understanding of effects from regional-scale ASR implementation, the South Florida Ecosystem Restoration Working Group formed the ASR Issue Team in September 1998 to conduct an independent scientific review of the conceptual CERP ASR system. The team's charter was to develop an action plan and identify projects needed to address the hydraulic, hydrogeologic, and geochemical uncertainties associated with ASR facilities. The final report from the ASR Issue Team was published in July 1999 and recommended the study of seven issues as follows:

1. Characterization of the quality and variability of source waters that could be pumped into the ASR wells.
2. Characterization of regional hydrogeology of the Floridan aquifer system.
3. Analysis of critical pressure for rock fracturing.
4. Analysis of local and regional changes in groundwater flow patterns.
5. Analysis of water-quality changes during storage in the aquifer.
6. Potential effects of ASR on mercury bioaccumulation for ecosystem restoration projects.
7. Relationships among ASR storage interval properties, recovery rates, and recharge volume.

The CERP ASR pilot projects and ASR Regional Study were conceived to address many of these uncertainties. The pilot projects provide the ASR Regional Study with platforms to conduct scientific and engineering studies as part of the adaptive management strategy. The seven issues identified by the ASR Issue Team were later augmented by other concerns raised by the National Academy of Sciences Committee on the Restoration of the Greater Everglades Ecosystem's (CROGEE) and the public. In general, the CROGEE recommendations mirrored those published in the ASR Issue Team report, with one exception. It was noted that the biological effects of 1.7 billion gallons per day of recovered water discharged back to the Everglades ecosystem was poorly understood. Therefore, the CROGEE recommended further studies to document or predict the effects of ASR recovered water on the Greater Everglades ecosystem.

The goals of the ASR Regional Study, in coordination with the ASR pilot projects, are as follows:

- Answer the questions concerning the feasibility of regional-scale CERP ASR implementation.
- Reduce uncertainties related to regional-scale CERP ASR implementation by conducting scientific and engineering studies based on existing and newly acquired data.
- Develop a regional groundwater model of the Floridan aquifer system.
- Identify an appropriate magnitude of ASR capacity with minimal impact to the environment and existing users of the Floridan aquifer system.

The tasks required to perform the ASR Regional Study are described in the original *Comprehensive Everglades Restoration Plan, Aquifer Storage and Recovery Regional Study Project Management Plan* (ASR Regional Study PMP). This study was developed by a multiagency team consisting of staff from the following entities: the SFWMD; the USACE; the Florida Geological Survey (FGS); the Florida Department of Environmental Protection (FDEP); the U.S. Geological Survey (USGS); the U.S. Fish and Wildlife Service (USFWS); the U.S. Environmental Protection Agency (USEPA); the Florida Fish and Wildlife Conservation Commission (FWC); and local government agencies.

The CROGEE conducted an independent technical review of the ASR Regional Study PMP to examine the adequacy of the proposed scientific methods to answer the issues raised by the ASR Issue Team and the original CROGEE review. To access the ASR Issue Team report and two CROGEE studies, see the References for Additional Information section at the end of this chapter.

ORGANIZATION OF THE ASR PROGRAM INTERIM REPORT

The issues raised by the ASR Issue Team, CROGEE, and other stakeholders are addressed in this Interim Report by discipline. These disciplines, which address multiple uncertainties, are incorporated into the following chapters:

- The CERP ASR Pilot Projects
- Hydrogeologic Investigations
- Geophysical Investigations
- Groundwater Modeling
- Geochemical Studies
- Microorganisms in Aquifers Studies

- Ecological Studies
- Plan Formulation

This report summarizes the various efforts that have taken place to date. The attached CD includes expanded technical memos and reports **as noted by an asterisk (*)** in the References for Additional Information section at the end of each chapter.

As mandated by the *Water Resources Development Act of 2000* and the Programmatic Regulations, the CERP, including the ASR Regional Study, employs an adaptive management approach. Such an approach provides the CERP with a framework that allows the plan to move forward recognizing considerable uncertainty associated with several of the critical projects, such as ASR, and assesses performance on an interim basis as projects are implemented and modified to achieve desired results. This approach also supports recent recommendations by the National Academy of Sciences for pursuit of "incremental adaptive restoration."

The final number and location of CERP ASR wells will be determined through further scientific investigations conducted under the ASR Regional Study, the associated ASR pilot projects, and required Project Implementation Report (PIR) for each CERP ASR component.

FUTURE DIRECTIONS

This Interim Report documents the progress of the ASR Program to date. Years of work involving additional investigations and studies are planned, and these findings will be incorporated into the final ASR Program Technical Data Report. It is expected that the final report will be available by 2012.

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* see enclosed CD

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(* Main Report: chap1_2_asr_pmp_main_body.pdf)

2

The CERP ASR Pilot Projects

POINTS OF INTEREST

- Exploratory wells have been constructed at five pilot project locations. Four of the five locations look favorable for high-capacity ASR.
- Pilot systems on the Kissimmee River and the Hillsboro Canal are about to begin cycle testing.
- Exploratory work at Berry Groves, along the Caloosahatchee River, indicated that high-capacity ASR in that area is not feasible.
- Funding limitations have delayed the construction of pilot systems at Port Mayaca and Moore Haven.

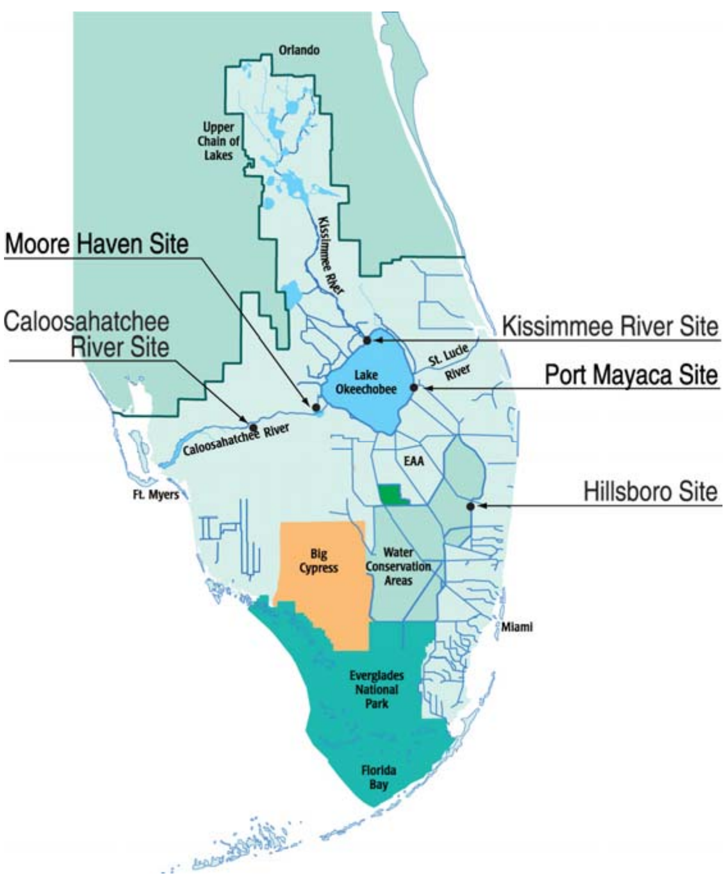

Figure 3. Locations of the CERP ASR Pilot Projects.

When fully implemented, the CERP ASR Program may be the largest application of ASR technology in the world. To date, the largest ASR system in operation is in Las Vegas, Nevada, using 64 wells pumping approximately 157 million gallons per day (MGD). The CERP may construct and operate up to 333 wells pumping approximately 1,665 MGD. This equates to individual wells pumping at a rate of 5 MGD.

The ASR Project Team will address uncertainties associated with regional-scale CERP implementation by analyzing ASR on a pilot scale and a regional (full) scale. Cycle tests at ASR pilot sites are designed to reduce uncertainties relative to ASR design and operation by investigating strategies for surface water withdrawal, recharge and pumping cycles, water treatment technology, and effects of these pumping cycles on the groundwater and surface water ecosystems in the Greater Everglades. Functional pilot sites will also provide insight into construction and operational costs, enabling a comparison of ASR with other storage technologies, such as surface water reservoirs.

Initially, three ASR pilot projects were envisioned as comprising the CERP ASR Program: Lake Okeechobee, Hillsboro Canal, and Caloosahatchee River. Because the scope of ASR envisioned around Lake Okeechobee was so extensive, the Lake Okeechobee ASR Pilot Project was split into three distinct project locations – Kissimmee River, Port Mayaca, and Moore Haven, bringing the total to five pilot project sites in all. **Figure 3** shows the locations of the proposed pilot projects.

Sites for the ASR pilot projects were chosen based on location, land ownership, proximity to available surface water, and the lack of sensitive species or natural resources likely to be affected by pilot project operations. A siting analysis was conducted for all well sites based on such factors as availability of surface water, property constraints, impacts to people, wetlands, and threatened and endangered species, cultural resources, and aesthetics. Sites selected for recommendation were all similar in that they were publicly owned properties and had been previously developed or disturbed, thus minimizing the impact of pilot project construction.

EXPLORATORY WELLS AND INITIAL STUDIES

Construction of exploratory wells was one of the first tasks completed at each pilot project location. The purpose of the exploratory wells was to confirm at each site that the Floridan aquifer system was present at depths close to 1,000 feet below land surface and that suitable hydrogeologic conditions existed for construction of high-capacity ASR well systems.

Exploratory Well Drilling Site

The exploratory wells provided information about the geology of each site, and enabled the collection of water samples and geophysical data to determine aquifer characteristics. The hydraulic capacity of the aquifer is particularly important so that individual wells can be pumped at approximately 5 MGD.

During the exploratory well program, other information was collected from each pilot project site, such as a quarterly collection of surface water samples. A water treatment and pumping process was designed to meet regulatory permitting criteria. When compiled, permit applications were filed for each pilot project. The following permits were required for each pilot project:

- Underground Injection Control Construction Permit for a Class V Exploratory Well (issued by the FDEP)
- Underground Injection Control Construction Permit for a Class V, Group 6 Aquifer Storage and Recovery Well System (issued by the FDEP)
- Petition for a Water Quality Criteria Exemption (issued by the FDEP)
- National Pollution Discharge Elimination System Permit for Groundwater Produced During Construction (issued by the FDEP)
- National Pollution Discharge Elimination System Permit for ASR System Operation (issued by the FDEP)
- Comprehensive Everglades Restoration Plan Regulation Act (CERPRA) Permit (issued by the FDEP)
- Water Use Permit (issued by the FDEP)
- Nationwide 18 Construction Permit (issued by the USACE)

The Pilot Project Design Report (PPDR) and Environmental Impact Statement (EIS): Lake Okeechobee, Hillsboro, Caloosahatchee (C-43) River ASR Pilot Projects was completed in 2004. This report contains design, construction, and operation recommendations for each of the pilot projects. Cost estimates were also prepared as part of the PPDR/EIS. The cost estimates indicated that construction of the three Lake Okeechobee sites would exceed the Congressional authorization budget for the projects; therefore, design and construction of the Moore Haven ASR Pilot Project site was deferred. An exploratory well have been constructed and a preliminary design has been completed for the Port Mayaca ASR Pilot Project, but due to budget limitations, construction of this pilot system has been delayed. The Kissimmee River and Hillsboro Canal ASR facilities are the only pilot projects constructed to date.

Kissimmee River ASR Pilot Project


Kissimmee River ASR Pilot Project

The Kissimmee River ASR Pilot Project is located on the eastern bank of the C-38 Canal (Kissimmee River), 5 miles west of the City of Okeechobee. This facility is designed as a single-well ASR system having a production capacity of 5 MGD. Surface water is drawn from the Kissimmee River, and treated with a pressure media filter (sometimes referred to as a sand filter) coupled with ultraviolet disinfection to meet primary drinking water standards prior to recharge into the Floridan aquifer system. The filter media is a combination of gravel, sand, and anthracite. Treated surface water is stored at depths between 572 and 880 feet below land surface. A cycle-testing strategy involving short and long recharge, storage, and recovery periods will be evaluated at the Kissimmee River ASR pilot project site. The system has been constructed and cycle testing is scheduled to begin in 2008. When stored water is recovered and retreated, it will be discharged through a constructed cascade to aerate the water to make it compatible with surface water before it enters the river.

Hillsboro Canal ASR Pilot Project


Hillsboro Canal ASR Pilot Project

The Hillsboro Canal ASR Pilot Project site is located west of Boca Raton adjacent to the Loxahatchee National Wildlife Refuge and the Hillsboro Canal. This facility is designed as a single ASR well system having a production capacity of 5 MGD. The ASR system will withdraw surface water from the Hillsboro Canal through an intake-discharge structure. Similar to the Kissimmee River ASR Pilot Project, the surface water will be treated to meet primary drinking water standards via screen filtration with ultraviolet disinfection prior to recharge. Treated surface water is stored at depths between 1,015 and 1,225 feet below land surface. A cycle-testing strategy involving shorter recharge, storage, and recovery durations will be evaluated at the Hillsboro Canal ASR pilot site. It is anticipated that the system will begin cycle testing in 2008.

Port Mayaca ASR Pilot Project

The Port Mayaca ASR Pilot Project has been designed and an exploratory well has been constructed. The Floridan aquifer is present at depths between 800 and 900 feet below land surface, which is favorable for ASR implementation. The Port Mayaca ASR Pilot Project is of particular interest to the CERP ASR Program because the design calls for a multi-well facility, which would be useful in determining what effects several ASR wells in close proximity might have on one another. Funding has not yet been allocated for the final design and construction of this system, however, it is expected that construction of the Port Mayaca facility may be initiated in the near future.

Caloosahatchee River ASR Pilot Project

An exploratory drilling program was conducted at the Caloosahatchee River ASR Pilot Project site near LaBelle in Hendry County to characterize subsurface conditions. A significant amount of sand was encountered in the Floridan aquifer system during drilling of the well near Berry Groves. The nature of the sandy formation raised questions about its suitability for open-hole, high-capacity ASR wells. As a result, the Caloosahatchee ASR Pilot Project has been deferred until an alternative site is found. Although disappointing, the conditions found at Berry Groves are believed to be a localized occurrence, and not regionally extensive because several successful wells are known to have been drilled both east and west of the site.

SUMMARY

Two new CERP ASR pilot facilities are about to become operational along the Kissimmee River and the Hillsboro Canal. Exploratory wells were constructed at all five ASR pilot project locations. Funding constraints have delayed the construction of the Port Mayaca and Moore Haven Pilot Project facilities. The exploratory test at the Caloosahatchee River Pilot Project indicated that a high-capacity, open-hole ASR well pilot facility was not feasible in the area west of LaBelle. The Kissimmee River and the Hillsboro Canal ASR Pilot Project facilities are both slated to begin cycle testing in 2008.

Although these CERP ASR pilot projects will yield valuable information, extensive regional data are needed for regional-scale implementation. This information can best be obtained through a well-designed, rigorous, regional scientific and engineering study program conducted simultaneously with the operation of the ASR pilot facilities. **Chapter 3** presents the hydrogeologic investigations performed to provide a detailed, preliminary characterization of the hydrogeologic framework of the Floridan aquifer system. As a result of this preliminary hydrogeologic framework, gaps in data indicate the need for exploratory/test wells and additional field studies, which are also discussed in **Chapter 3**.

FUTURE DIRECTIONS

Operational cycle testing of the Kissimmee River and Hillsboro Canal ASR Pilot Project facilities will begin in 2008. The pilot projects will be operated and monitored for about two years. However, at the time of this writing, record low water levels in the regional system have resulted in water restrictions, which could limit the quantity of water available for testing. If this situation continues, additional time might be required to complete the cycle testing. Information gathered during the cycle testing will ultimately be used to evaluate the feasibility of ASR technology. All findings will be presented in the final CERP ASR Program Technical Data Report.

The future of the Port Mayaca and Moore Haven ASR Pilot Projects sites is dependent on federal funding allocations for construction and testing. As with the other pilot projects, the information gathered during the operational testing phase will ultimately be used in the Technical Data Report.

The future direction of the Caloosahatchee River ASR Pilot Project is less certain. As discussed earlier, alternative sites will be evaluated, possibly within a basin containing a surface water storage reservoir. As reservoir sites are identified within this basin for other CERP efforts, opportunities to construct more exploratory wells will be considered.

Cycle Testing

During operational cycle testing of these systems, water will be recharged, stored and recovered for varying periods of time. It is anticipated that cycle testing will be conducted for about two years. The objectives of cycle testing are as follows:

- Evaluate the hydraulic characteristics of the storage zone.
- Monitor water-quality changes during recharge, storage, and recovery; evaluate the early "recovery efficiency" of the system.
- Begin storing fresh water around the ASR well.

An extensive monitoring plan, to be conducted during cycle testing, can be found in the ASR Regional Study PMP. Formal monitoring plans have been prepared and reviewed by the Quality Assurance Oversight Team. To access the full PMP report, see the References for Additional Information section at the end of the chapter.

Although ASR systems are not proposed to operate continuously, cycle testing will also provide an understanding of the power requirements and operating and maintenance procedures and costs needed to keep the systems running. Other evaluations conducted during cycle testing may address:

- The ecological impacts related to operation of the system
- The clogging susceptibility of the well
- The effects of buoyancy and upconing on the stored fresh water
- The pressure within the aquifer to ascertain the potential for hydrofracturing
- An operation and maintenance routine for the system
- The economic viability of the treatment technology
- The effect of residence time on stored and recovered water quality
- The optimal recharge and recovery rates to maximize recovery efficiency

Upon completion of the cycle testing, the results will be integrated into the final CERP ASR Program Technical Data Report.

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Kissimmee River ASR Pilot
Project Groundbreaking Ceremony

The Pilot Project Design Report / Environmental Impact Statement is intended to function as an engineering decision document for the pilot tests recommended by the Central and Southern Florida Project Restudy Report (1999) and authorized in the Water Resources Development Acts of 1999 and 2000. These tests are required, along with other evaluations, before the co-sponsors of the CERP ASR Program (U.S. Army Corps of Engineers and South Florida Water Management District) can determine the feasibility of regional-scale implementation of ASR technology proposed in the CERP.

? FREQUENTLY ASKED QUESTIONS

Q How much water can an ASR well store?

A Theoretically, there is no limit to the amount of water that can be stored by an ASR well. One of the benefits of ASR is that water can be recharged and stored in wells over multiple seasons and multiple years during periods of excess water and recovered during periods of water need, such as during droughts. Therefore, the storage capacity available from ASR is nearly infinite as compared to reservoirs, which are limited in size because of land acquisition costs and design considerations; and moreover, the stored water will not be subject to evaporation.

The limitation of ASR lies with the amount of water that can be recovered at the location where it was recharged. In other words, as more water is pumped into the well, the water migrates farther away from the well. The water that travels the farthest from the well may not be recoverable.

Q Is ASR too expensive to work effectively?

A No. Since ASR systems can provide for multiyear storage and recovery, they offer a solution that surface reservoirs cannot. ASR systems do not require the purchase of extensive tracts of land; therefore, the upfront capital outlays are not nearly as large as those required for surface reservoirs. In addition, CERP ASR would only recharge when there is excess water, such as during high flow events, and recover when there is water need, such as during water shortages. As a result, the per-gallon cost of water supplied by ASR compares very favorably with other storage technologies considered in the CERP.

Q Will the water pumped into ASR wells contaminate the drinking water aquifers?

A No. The brackish water naturally found within the Floridan aquifer system is considered drinking water although it would not taste very good and require extensive treatment before it would be acceptable for consumption. The water pumped into the ASR wells will be fresh water treated to federal drinking water standards, so it is actually of higher quality than the water naturally found within the aquifer.

Q Where does the water go when it is pumped out of the ASR well?

A When the water is recovered, it will flow back into the same canal, reservoir, or lake from which it came. The state has rigid permitting requirements for discharging water into the surface waters, and the recovered water will be filtered or treated to meet those standards.

More questions? See Appendix A: Frequently Asked Questions.

3

Hydrogeologic Investigations

The ASR Regional Study and pilot projects are designed to address the surface water, hydrogeologic, geophysical, water-quality, and geochemical uncertainties regarding the use of the Floridan aquifer system for regional-scale implementation of ASR as envisioned in the CERP. To address some of these uncertainties, the USACE, SFWMD, and collaborating agencies are conducting hydrogeologic investigations to gain a better understanding of the subsurface structure and the water quality and geochemistry of the Floridan aquifer system.

POINTS OF INTEREST

- A new, comprehensive understanding of the Floridan aquifer system has been developed by melding peer-reviewed literature with new data.
- Areas lacking hydrogeologic data have been identified and explored using test wells to fill-in data gaps.
- A new, regional monitoring network has been established to track the movement and quality of groundwater in the Floridan aquifer system through time.
- An innovative technique of core analysis, called sequence stratigraphy, was applied to create "virtual" relationships between rock layers and groundwater flow.

One of the key objectives of the ASR Regional Study is the development of a groundwater model of the Floridan aquifer system to evaluate the technical feasibility of the proposed ASR wells in the CERP. Therefore, the physical properties of the Floridan aquifer system must be accurately defined for successful model development. To begin model development, a preliminary hydrogeologic framework was needed to present a unified geological understanding of the Floridan aquifer system's hydrogeology, and to identify areas where data gaps exist. **Figure 4** presents a conceptual geologic cross-section of Florida's hydrogeologic units.

TERMINOLOGY

Hydrogeologic unit
Any rock unit or zone that, because of its hydraulic properties, has a distinct influence on the storage or movement of groundwater.

This chapter describes the development of the preliminary hydrogeologic framework and the hydrogeologic/geophysical tests implemented to provide additional information about the Floridan aquifer system.

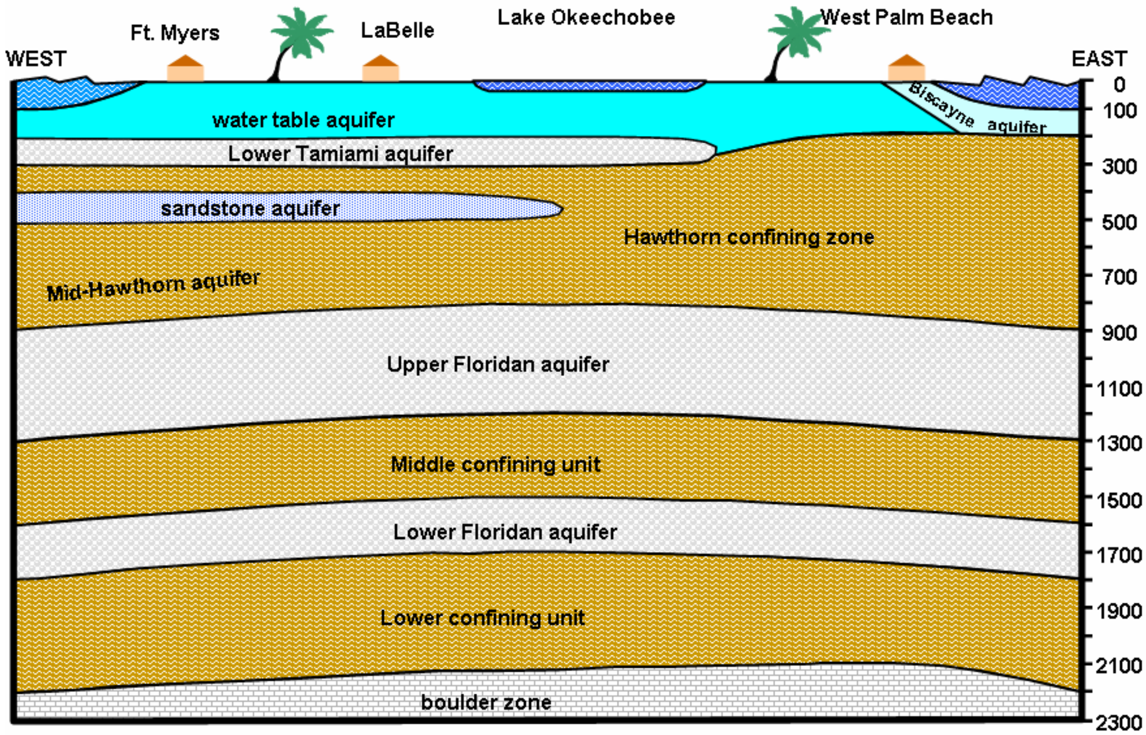

Figure 4. Conceptual Geologic Cross-section of South Florida's Hydrogeologic Units.

PRELIMINARY HYDROGEOLOGIC FRAMEWORK

The Floridan aquifer system is a thick sequence of layered shells, sandstone, limestone and dolomite underlying Florida, and is targeted as the most desirable zone for CERP ASR for the following reasons:

- It is regionally extensive throughout south Florida
- It provides an isolated underground reservoir for storage of clean, naturally flowing fresh water (though currently brackish) in south Florida
- It is present at depths that clean fresh water can be reasonably tapped by current well drilling technology
- Its formations could yield high capacities of water, allowing for the construction of high-capacity wells
- It is overlain (confined) by a thick sequence of clays (the Hawthorn Group) that tends to prevent upward migration of stored water away from the storage zone of the Upper Floridan aquifer

- It has excellent water storage properties that have supported the successful implementation of ASR by several utilities along the east and west coasts of Florida

The ASR Issue Team recognized that information about the Floridan aquifer system throughout most of south Florida was limited, especially within inland areas where most of the proposed CERP ASR projects would be located. Therefore, a detailed characterization of the hydrogeology of the Floridan aquifer system was needed to help assess the feasibility of ASR at the magnitude envisioned in the CERP.

Working jointly on this effort, the USGS, SFWMD, USACE, and FGS developed the preliminary hydrogeologic framework through the synthesis of existing data and literature to begin to develop an understanding of the Floridan aquifer system from Orlando to Key West.

ASR Literature Compilation

A massive ASR literature database was compiled as part of the ASR Regional Study. An extensive literature search was completed, called the ASR Regional Study Reference List, including a list of key documents related to ASR technology, the hydrogeology of south Florida, and the CERP ASR Program. The Reference List includes reports from federal and state agencies, universities, consulting engineering firms, and other public and private organizations.

The literature search involved compiling various bibliographic references into categories and reviewing a large portion of these references. Key data descriptions and codes were used to separate the various references into searchable categories. The Reference List includes more than 1,600 separate documents. Other documents may be added to the working list and the database will be updated during the ASR Regional Study. This virtual literature database is available from the CERP Web site: http://green.cerpzone.info/asr/default.jsp.

Data Acquisition

A detailed review of eight regionally significant publications about the Floridan aquifer system (primarily USGS regional aquifer analysis reports) was conducted to construct the hydrogeologic framework. Combined, these reports encompass the entire study area and present a fairly comprehensive (though disconnected) picture of the current hydrogeologic knowledge of the Floridan aquifer system.

In addition to the literature, hydrogeologic data from approximately 400 deep wells were examined and used to refine the hydrologic framework. These data included lithologic descriptions, geophysical logs, interpreted elevations for lithologic and hydrostratigraphic formations, aquifer pumping tests, and water-quality analyses. All data for the project are located in SFWMD's environmental database, DBHYDRO.

TERMINOLOGY

Geophysical Log
A record of the structure and composition of the earth with depth encountered when drilling a well or similar type of test or boring hole.
Hydrostratigraphy
A geologic framework consisting of a body of rock having considerable lateral extent and composing a reasonably distinct hydrologic system.
Lithology
The scientific study and description of rocks, usually with the unaided eye or with little magnification; the structure and composition of a rock formation.

Data Analysis

Geologic cross-sections across the study area were used to identify and resolve discrepancies in the literature (**Figure 5**). This enabled the ASR Project Team to generate maps, such as the transmissivity map shown in **Figure 6**, for the major hydrostratigraphic units within the Floridan aquifer system. In general, the amount of data available from wells decreased with depth because fewer wells are drilled to the depths fully penetrating the Floridan aquifer system (about 3,000 feet deep). A need for additional hydrostratigraphic data was identified in several areas, including central Palm Beach County and the Lower Kissimmee Basin. Additional information about the hydraulic properties of the Floridan aquifer system along an area thought to be a hydrologic "divide" in the center part of the state was also identified. These data gaps were used to guide subsequent data collection efforts.

TERMINOLOGY

Hydrostratigraphic unit
Bodies of rock with considerable lateral extent that act as a reasonably distinct hydrologic system.
Transmissivity
The ability of an aquifer to transmit water.

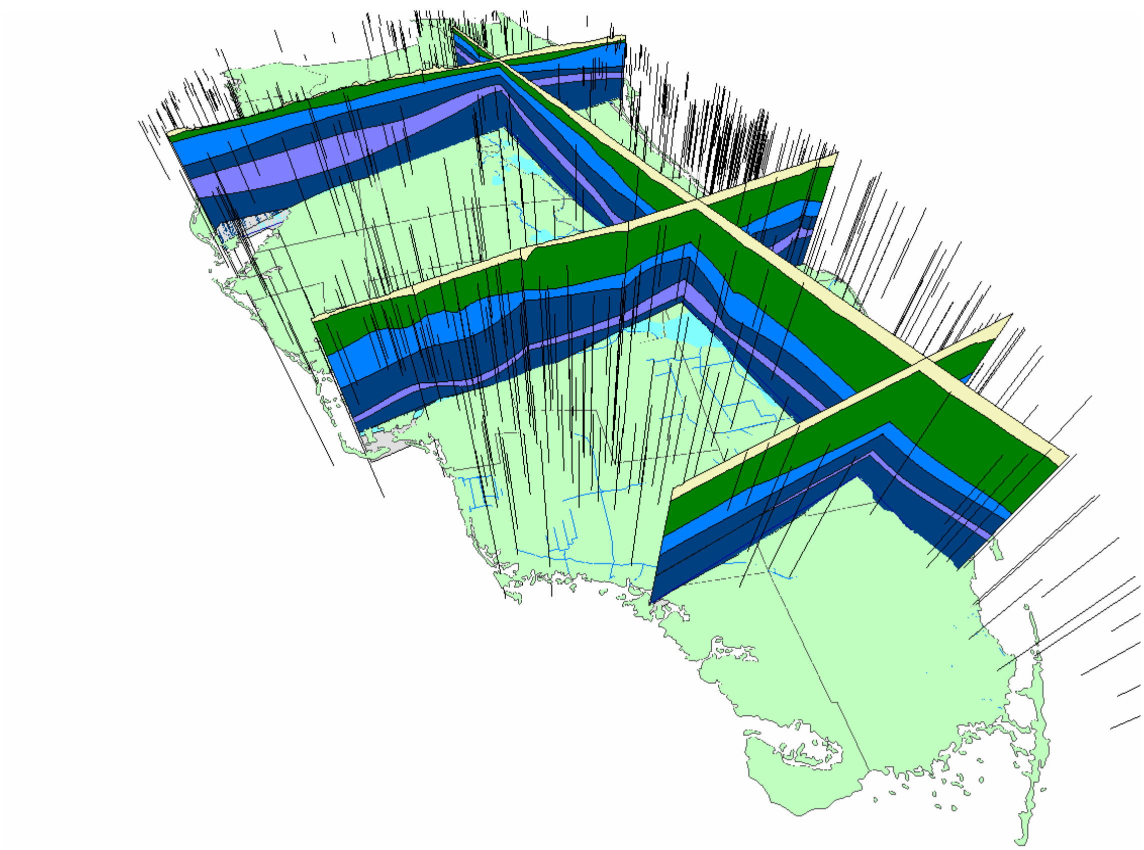

Figure 5. Geologic Cross-sections Correlating Wells (black lines) Across the Study Area.

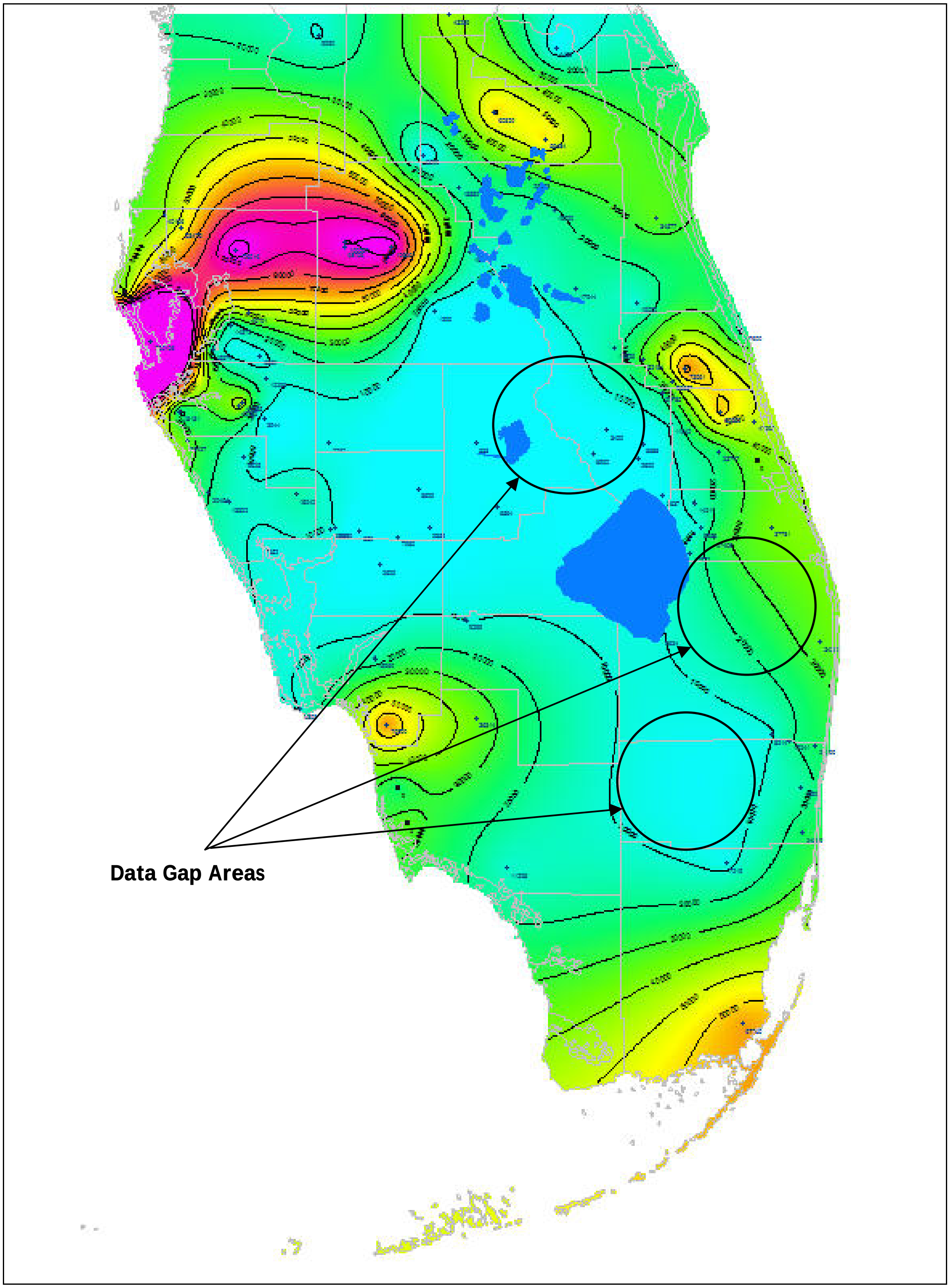

Figure 6. Identified Data Gaps in Floridan Aquifer System Variability of Transmissivity.

MONITORING NETWORKS

Previous investigations of the Floridan aquifer system in south Florida identified the lack of adequate and sufficient water-level data to develop a comprehensive groundwater model. Water-level data are needed to calibrate the groundwater model to predict existing and future groundwater levels. The geographic distribution of the available water-level data was centered primarily along the coasts, whereas very little data were available in the interior of the state. A critical need for sites showing the vertical distribution of water levels within the Floridan aquifer system was also identified. The ASR Regional Study allowed for the installation and maintenance of continuous water-level recorders at several Floridan aquifer system wells in key locations to improve the quality and quantity of data available for groundwater modeling purposes.

Water-Level Monitoring

Figure 7 shows the former extent of the Floridan aquifer system network of continuous water-level recorders prior to the ASR Regional Study (May 2003), and the extent of the network today. Thirty sites have been added to the network, with many of the sites monitoring multiple depth intervals within the Floridan aquifer system. The current network consists of 70 sites monitoring 95 discrete zones within the Floridan aquifer system. Each monitored interval has been surveyed and instrumented with automatic recorders, pressure transducers, and telemetry equipment to transmit the recorded pressure data to the SFWMD. These data are reviewed by SFWMD staff, converted to water-level data and uploaded to DBHYDRO. All sites are visited monthly for maintenance service and an instrumentation calibration check.

Water-level Recorder at a Monitoring Well

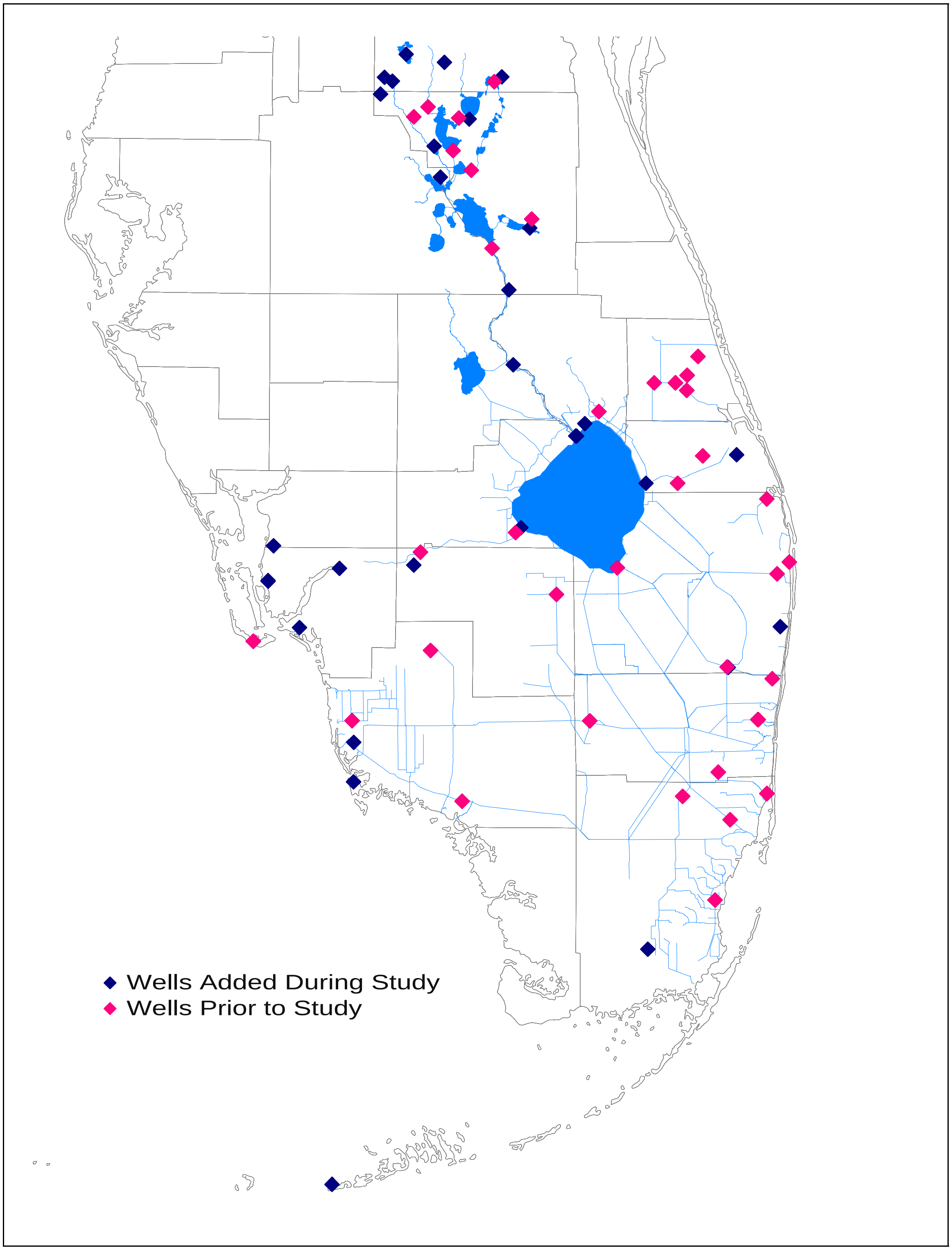

Figure 7. Distribution of Wells with Continuous Water-level Recorders in the Floridan Aquifer System Prior to and Since the ASR Regional Study.

Water-Quality Monitoring

A water-quality monitoring network, different from the water-level monitoring network, was developed to ascertain a broad understanding of water quality within the Floridan aquifer system and the degree to which it varies over time and distance. The water-quality data will also be used in the groundwater model (**Chapter 5**) to simulate the effects of buoyancy, mixing, upconing, and saltwater intrusion.

The Floridan aquifer system water-quality monitoring network was developed to accomplish the following:

- Maximize the distribution of wells, both spatially and vertically.
- Maximize available funding by prioritizing sites with wells in multiple aquifers.
- Prioritize wells where water-level data are also available and water-quality data would be required to correct the data for differences in density.

The size of this water-quality network has varied over the life of the project. The first water-quality sampling event was completed in June 2004. As new access agreements were negotiated or technical problems arose, wells were added or dropped from the network. The current (2008) network consists of 60 wells at 31 locations (see **Figure 8**).

The wells are sampled quarterly and analyzed for the following parameters: chloride, alkalinity, bicarbonate, pH, sulfate, sodium, potassium, magnesium, total dissolved solids, specific conductance, salinity, temperature, and turbidity. The samples are analyzed by laboratories certified by the National Environmental Laboratory Accreditation Conference (NELAC), a standards adoption body, and submitted to a rigorous quality assurance protocol before being archived in the District's DBHYDRO database.

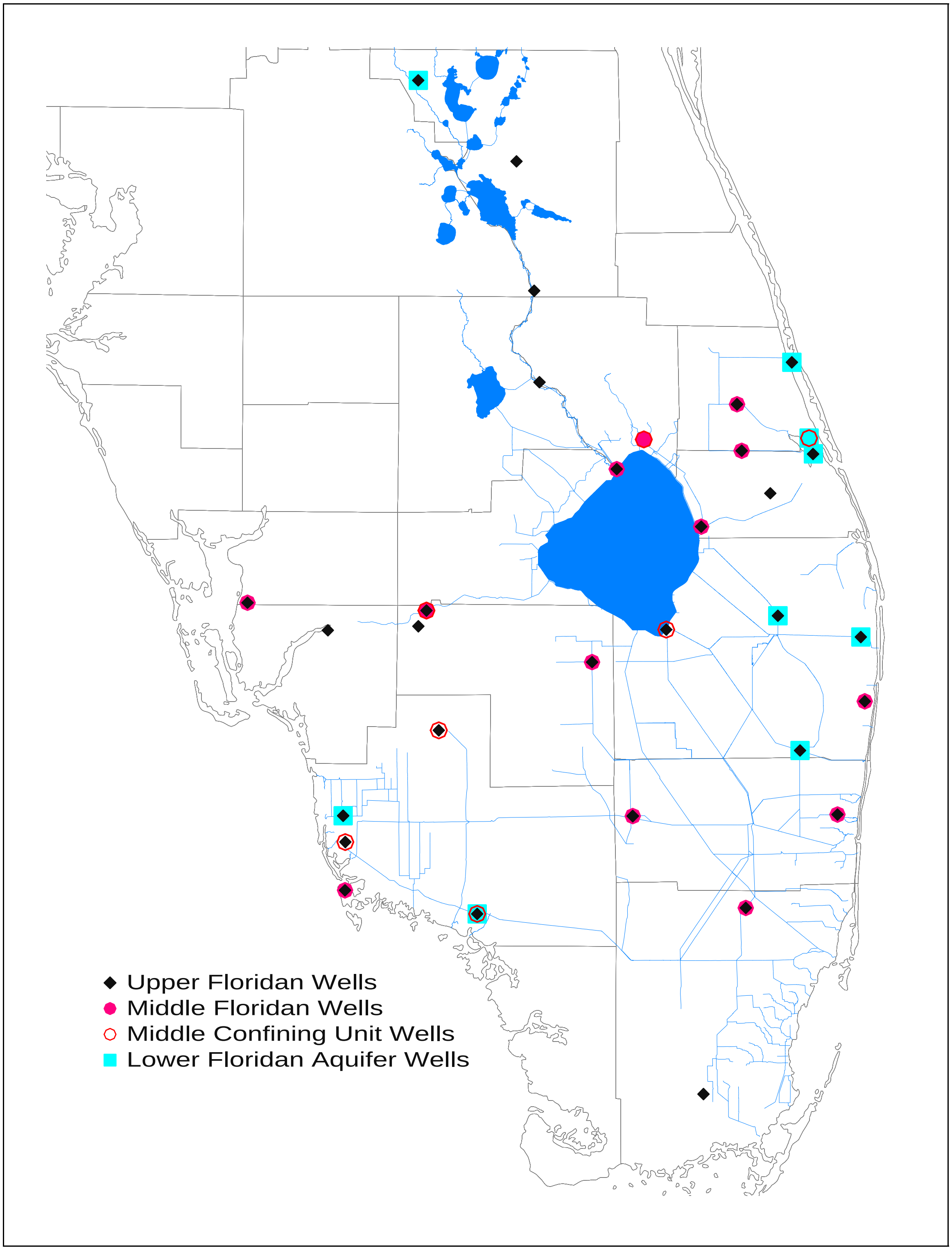

Figure 8. Water-Quality Monitoring Network of the Floridan Aquifer System.

TEST WELLS

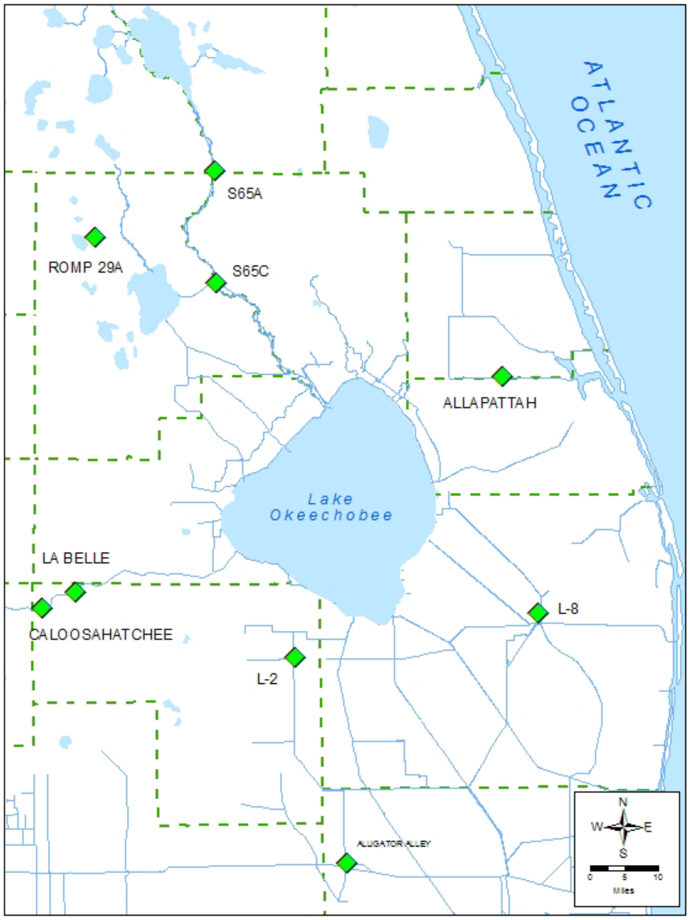

Figure 9. CERP Test Wells and Corehole Sites.

The preliminary hydrogeologic framework identified areas where data gaps existed. Therefore, test wells (different from monitoring wells) were needed to evaluate these areas. Seven sites were chosen based on proximity to source waters for ASR, availability of existing wells and other hydrogeologic factors. Two existing well sites, L-2 and LaBelle, were retrofitted to accommodate further exploration of the Floridan aquifer system. New wells were drilled at Allapattah, Alligator Alley, L-8, S-65A, S-65C, and the Caloosahatchee ASR Pilot Project near Berry Groves. Wells at these sites were designed to provide hydrogeologic information and serve as long-term monitoring sites. **Figure 9** shows the location of the new test wells.

The test wells were designed to investigate distinct zones of the Floridan aquifer system to be monitored during the ASR Regional Study. The ASR zone typically targeted for use is the Upper Floridan aquifer, but the Middle Floridan and the Lower Floridan aquifers may be considered. The geologic units, lithology and hydrogeologic units of Florida's aquifer systems are presented in **Figure 10**.

Series		Geologic Unit		Lithology	Hydrogeologic Unit		Approximate Thickness (ft)	
Holocene to Pliocene		Undifferentiated		Quartz sand, silt, clay and shell	surficial aquifer system	water table aquifer	20–200	
		Tamiami Formation				confining beds		
						Lower Tamiami aquifer		
Miocene and Late Oligocene		Hawthorn Group	Peace River Formation	silt, sandy clay, limestone and sandstone	intermediate aquifer system	confining unit	100–750	
						sandstone aquifer		
						confining unit		
			Arcadia Formation	sandy limestone, shell beds, dolomite, sand, silt and clay		Mid-Hawthorn aquifer		
						confining unit		
					Floridan aquifer system	Lower Hawthorn producing zone	0–300	PRIMARY ZONE OF INTEREST FOR CERP ASR
Early Oligocene		Suwanee Limestone		fossiliferous, limestone		Upper Floridan aquifer	700–1,200	
Eocene	Late	Ocala Limestone		chalky to fossiliferous, limestone				
	Middle	Avon Park Formation		fine-grained limestone, dolomite and gypsum		Middle confining unit	500–800	
	Early	Oldsmar Formation				Lower Floridan aquifer; Boulder zone	400	
Paleocene		Cedar Keys Formation		dolomite and limestone				
				massive anhydrite	Sub-Floridan confining unit		1,200?	

Figure 10. The Geologic Units, Lithology, and Hydrogeologic Units of Florida's Aquifer Systems.

A variety of hydrogeologic data were collected at the test well sites, including water quality, rock cuttings and cores, aquifer performance tests, and downhole geophysical logs to provide information about the lithology and the physical properties of the water, rock, and borehole. **Chapter 4** provides additional information about the types of geophysical logs performed at these test wells and the exploratory wells at the pilot project sites.

TERMINOLOGY

Borehole
A hole bored or drilled into the earth, as an exploratory well; a small-diameter core drilled especially to obtain water.

The following provides a brief description of the location and objective(s) of each test well site.

S-65A Located in proximity to the C-38 Canal (Kissimmee River), this well site was chosen to serve as a hydrostratigraphic point between the Southwest Florida Water Management District (SWFWMD) to the west, St. Johns River Water Management District (SJRWMD) to the east, and the Kissimmee River ASR Pilot Project site to the south.

Allapattah Located near the C-23 Canal, which divides Martin and St. Lucie counties, a test well was drilled to observe the effects of withdrawals from the Floridan aquifer system prior to and from implementation of CERP ASR. St. Lucie and Martin counties historically have been the greatest users of the Floridan aquifer system for water supply and irrigation within SFWMD boundaries.

Drilling Rig

L-8 Located adjacent to the L-8 Canal in central Palm Beach County, a Floridan aquifer system monitoring well was installed to provide a connection between existing SFWMD test wells in South Bay and West Palm Beach. The L-8 Basin was also identified in the CERP as having potential for ASR development.

L-2 Located in Hendry County adjacent to the L-2 Canal, a Floridan aquifer system test well was completed in the Upper Floridan aquifer. The test well was used to conduct an aquifer performance test to help bridge a data gap in the hydraulic properties of the Floridan aquifer system in the south-central portion of the state.

LaBelle An existing production well at LaBelle, adjacent to the Caloosahatchee River, was deepened and retrofitted to isolate the Middle Floridan aquifer producing zone. Results from the preliminary hydrogeologic framework indicated that transmissivity is extremely high in the Middle Floridan aquifer to the north and west of this location, while it decreases rapidly to the south. An aquifer performance test was conducted and provided hydraulic property data to bridge the gap in this transition area.

Caloosahatchee ASR Corehole A continuous core well was constructed at the Caloosahatchee ASR Pilot Project site to a depth of 1,012 feet below land surface, penetrating the Upper Floridan aquifer. The future of this site for ASR development was in question because of the presence of sand in the proposed ASR zone. The corehole was used to determine if the sandy zone is present across the entire property, or if an alternate site on the property would be more favorable. The results confirmed that the upper portion of the Floridan aquifer system is very sandy throughout the site and that the installation of open borehole high-capacity ASR wells would not be feasible at this location.

TERMINOLOGY

Core Sample/Corehole
A core sample is a cylindrical section of a rock or sediment obtained by drilling into the medium with a hollow steel tube called a corer. The hole made for the core sample is called a corehole.

Permeability
The capacity of a porous rock, sediment, or soil for transmitting a fluid.

S-65C Located at Structure S-65C, adjacent to the Kissimmee River in Okeechobee County, this site was selected to provide information about the aquifers and hydraulic properties between the S-65A test well and the Kissimmee River ASR Pilot Project. The test well provided information about the hydraulic properties of the Floridan aquifer system, and was completed as a monitoring well to evaluate the regional impact of the CERP ASR Program.

Alligator Alley (BF-7) Located in west-central Broward County, the Alligator Alley site was envisioned as desirable site for data collection. The existing monitoring well would evaluate the deeper portions of the Floridan aquifer system in a data gap area within the interior of the state. A multizone production well would be installed to test several portions of the aquifer. However, actual construction of a test well is contingent on successful site agreement negotiations with the Miccosukee Tribe.

Final reports on the test wells at S-65A, S-65C, Allapattah, and L-8 are not yet available, but data from these drilling efforts are archived in the SFWMD DBHYDRO environmental database.

SEQUENCE STRATIGRAPHY

Sequence stratigraphy is a specialized branch of geology that links sediment deposition to changes in sea level. The basic idea is mapping of rock layers based on identification of transgressive (sea level rising) and regressive (sea level falling) sequences.

This approach was developed for predicting subsurface patterns in rock material and permeability. A sequence stratigraphic approach to understanding the subsurface geology in the Floridan aquifer system was evaluated in hopes of identifying relationships between sequences and the flow characteristics of the aquifer. This understanding is sought to predict aquifer characteristics in the areas between test wells, which would help determine the regional extent of water bearing layers feasible for ASR installation.

TERMINOLOGY

Confining unit
A relatively low permeability geologic unit that impedes the vertical movement of water.

In 2002, a study was initiated with the USGS to describe and interpret the lithology in a single continuous corehole in the context of sequence stratigraphy, and evaluate the utility of this information for delineation of candidate flow zones and confining units for CERP ASR. The Regional Observation Monitoring Program (ROMP) 29A test core- hole was used for this evaluation. **Figure 9** shows the location of this test corehole.

The ROMP 29A well penetrated the Avon Park Formation, Ocala Limestone, Suwannee Limestone, and Hawthorn Group, representing rocks of Middle Eocene to Miocene age (~40–10 million years before present) (see **Figure 10**). Within this interval, the USGS was able to identify numerous sequences of rock, corresponding to various stages of a rising and falling sea. The USGS compared these sequences to:

Examining a Core Sample

- Distribution of flow in the well from geophysical logs
- A quantification of the primary source of porosity
- Transmissivity from aquifer performance tests in the region

Results of these analyses indicated a correlation between zones of diffuse flow (most suitable for ASR) and certain stratigraphic sequences. This study indicates that use of a sequence stratigraphic approach can greatly reduce the risk of miscorrelation of groundwater flow zones and confining units. This approach will be strongly considered when additional core data become available. To access the full report of this study, see the References for Additional Information section at the end of this chapter.

> **TERMINOLOGY**
>
> **Porosity**
> A measure of the void spaces in a material as a fraction, between 0–1, or as a percentage between 0–100 percent. In rock, the porosity, or space, can be between grains or within cracks or cavities of the rock.

SUMMARY

Completion of the preliminary hydrogeologic framework provided a unified, comprehensive view of the Floridan aquifer system and laid the foundation for the development of a groundwater model (see **Chapter 5**: Groundwater Modeling). The preliminary hydrogeologic framework also identified areas where additional data analysis was needed, which in turn led to field data collection during this reporting period and plans to gather additional data in the coming years. This process involved constructing test wells and collecting numerous hydrogeologic data at these sites, as well as running a variety of geophysical logs. Information about the different types of geophysical logs that were processed can be found in **Chapter 4**. Sequence stratigraphy was also employed to provide a better understanding of the Floridan aquifer system for the CERP ASR Program. **Chapter 4** of this document describes other geophysical and investigative studies that were conducted in response to the issues identified by the ASR Issue Team.

FUTURE DIRECTIONS

As new information from the test wells, and water-level and water-quality data become available, the preliminary hydrogeologic framework will be updated and re-interpreted as a new "working version." In addition, an aquifer performance test will be conducted on the City of Clewiston's new Floridan aquifer

> **TERMINOLOGY**
>
> **Anisotropy**
> The condition under which one or more of the hydraulic properties of an aquifer vary unequally according to the direction of the flow.

system wellfield, and possibly at other sites, to determine the degree of anisotropy and estimate dispersion characteristics of the formation in that area.

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ASR QUESTIONS

Questions to be addressed by the CERP ASR Regional Study

The ASR Issue Team identified seven issues associated with the implementation of regional-scale ASR facilities, which were re-phrased as questions by the Committee on the Restoration of the Greater Everglades Ecosystem in its 2000 review of draft ASR plans for the Lake Okeechobee and the Western Hillsboro areas:

1. Are the proposed ASR source waters of suitable quality for recharge without extensive pretreatment?
2. What regional hydrogeologic information on the Upper Floridan aquifer is needed, but unavailable for regional assessment?
3. Will the proposed ASR recharge volumes result in head increases sufficient to cause rock fracturing?
4. What will be the combined regional head increases from the regional-scale ASR, and how will this affect individual ASR operation, change patterns of groundwater movement, and impact existing ASR wells, supply wells, or underground injection control monitoring wells?
5. What are the likely water-quality changes to the recharged water resulting from movement and storage in the aquifer, and will the quality of the recovered water pose environmental or health concerns?
6. What, if any, is the potential impact of recovered water on mercury bioaccumulation in the surface environment?
7. What are the relationships among ASR storage zone properties, recovery rates, and recharge volumes?

4

Geophysical Investigations

Acting on the ASR Issue Team's recommendations, the ASR Regional Study conducted various geophysical studies to fill hydrogeologic data gaps, analyze site and regional changes in groundwater flow patterns of the Floridan aquifer system, and analyze critical pressure for rock fracturing. If experts understand which flow zones are more likely to have fractures and conduits, they can more accurately estimate the probability of water flow, storage, and recovery efficiencies for the proposed ASR wells in the CERP.

POINTS OF INTEREST

- To augment "traditional" data collection methods, applied techniques such as geophysical logging, a seismic survey of Lake Okeechobee, and cross-well tomography allowed for detailed assessment of the subsurface that would otherwise not be possible.
- A preliminary fracturing study indicated that the potential for ASR to "break" subsurface formations is minimal, as long as recharge pressures are kept low.
- A lineament study revealed surface patterns that could mimic subsurface groundwater flow paths and potential areas for optimal well performance.

Geophysical Logging

As described in **Chapter 3**, test wells provided information about hydraulic properties of the Floridan aquifer system. Extensive geophysical logs were conducted within each test well. By studying these logs, hydro-geologists can determine patterns of flow, confinement, and fracturing. This chapter describes other geophysical investigations that were performed to fill data gaps in the hydrogeologic framework and gather data on groundwater flow and the rock units of interest to this study. These include geophysical log analyses of exploratory wells at the CERP ASR pilot project sites, a lineament analysis, a marine seismic reflection survey, cross-well tomography, and an evaluation of potential pressure-induced constraints and changes (fracturing) in the Floridan aquifer system and Hawthorn Group. Much of the data from these studies will be incorporated into the groundwater model, which is discussed in **Chapter 5** of this document.

GEOPHYSICAL LOG ANALYSES

During construction of the test and exploratory wells, intensive geophysical logging was performed to extract as much information as possible from the drilled boreholes. Geophysical logs provide a precise determination of geologic formation attributes that are penetrated during drilling by recording the response of the formations to different stimuli. Electric logs measured the ability of the formations to resist or conduct an electrical current, which help to locate the top or bottom of distinct formations. Gamma-ray logs recorded the natural radioactivity of the formations, which is related to the clay or phosphate content in the rock. Neutron, density and sonic logs were used to determine the rock matrix (for instance sand, limestone, or dolomite) and the amount of porosity (void space) in the rock. Borehole imaging logs provided a television view of drilled borehole walls. Temperature and flowmeter logs showed zones where water was flowing within the penetrated aquifers. Caliper and fracture identification logs showed where boreholes became enlarged and highly fractured during the drilling process.

The logs were conducted in each drilled borehole. Interpretations of the logs were then made to determine the depths and extent of water-bearing and confining zones within each well. In addition, logs from all of the wells were then correlated and compared between wells to map the lateral and vertical extent of the various geologic formations beneath the land surface. This information was integrated into the preliminary hydrogeologic framework discussed in **Chapter 3**. **Figure 11** shows some of the types of logs conducted at the Caloosahatchee River ASR exploratory well, which was drilled to a total depth near 1,300 feet below land surface.

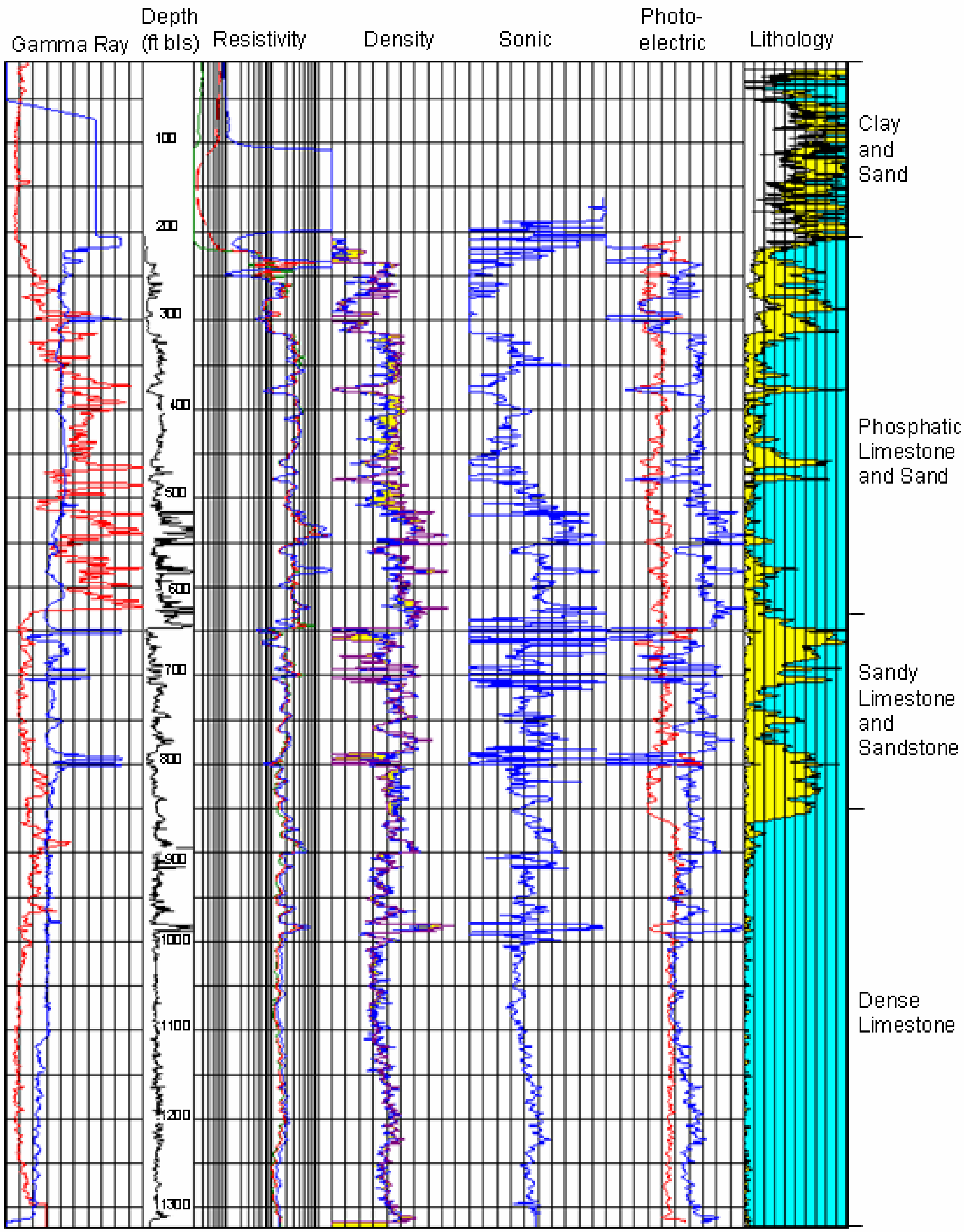

Figure 11. Caloosahatchee River ASR Exploratory Well Geophysical Logs.

LINEAMENT ANALYSIS

The purpose of the lineament analysis was to identify potential linear underground features that could be observed on the land surface of south Florida to show relationships between geologic structures and features that may show areas of greater groundwater flows in the Floridan aquifer system. Frequently, such areas might indicate enhanced groundwater flow.

> **TERMINOLOGY**
>
> **Lineament**
> A linear topographic feature that might result from a subsurface fault or zone of fractures.
>
> **Landsat Program**
> The Landsat Program is a series of Earth-observing satellite missions jointly managed by the National Aeronautics and Space Administration (NASA) and the U.S. Geological Survey (USGS). Since 1972, Landsat satellites have collected information about Earth from space. This science, known as remote sensing, has matured with the Landsat Program.

Because of south Florida's low topographic relief, the surface features used to identify lineaments were sinkholes and solution depressions, stream alignments and river patterns, and changes in soil and vegetation patterns. This investigation involved identifying lineaments on Landsat digital photographs and comparing them with known geologic features to provide correlations to hydrogeologic trends. **Figure 12** shows the lineaments identified in south Florida. The red lines in the figure have been documented in previous lineament studies, whereas the black lines have yet to be confirmed through field observation.

The findings show that the regional geologic structure and hydrogeologic character tend to parallel surface lineament trends. The data suggest that many lineaments may be indicative of fractures (or perhaps faults in some cases) extending from the basement structures through the overlying rock and are reflected on the ground surface. One of the most noteworthy findings of this investigation is the concentration of northeast trending lineaments along the northern Caloosahatchee River corridor and the northwest side of Lake Okeechobee, in which the lineaments seem to correlate to a possible deep basement feature or other deep geologic structure. Water quality in the Floridan aquifer system degrades significantly south of these features.

Further investigation is needed to verify lineaments identified in this study and their relationship to subsurface geologic and hydrogeologic features. Results of such investigations may show that many of these lineaments do not have any relationship to subsurface conditions. Other lineaments, however, may be the surface manifestation of fractures and/or faults extending far up into the geologic section, or may have an effect on the local and regional hydrogeology.

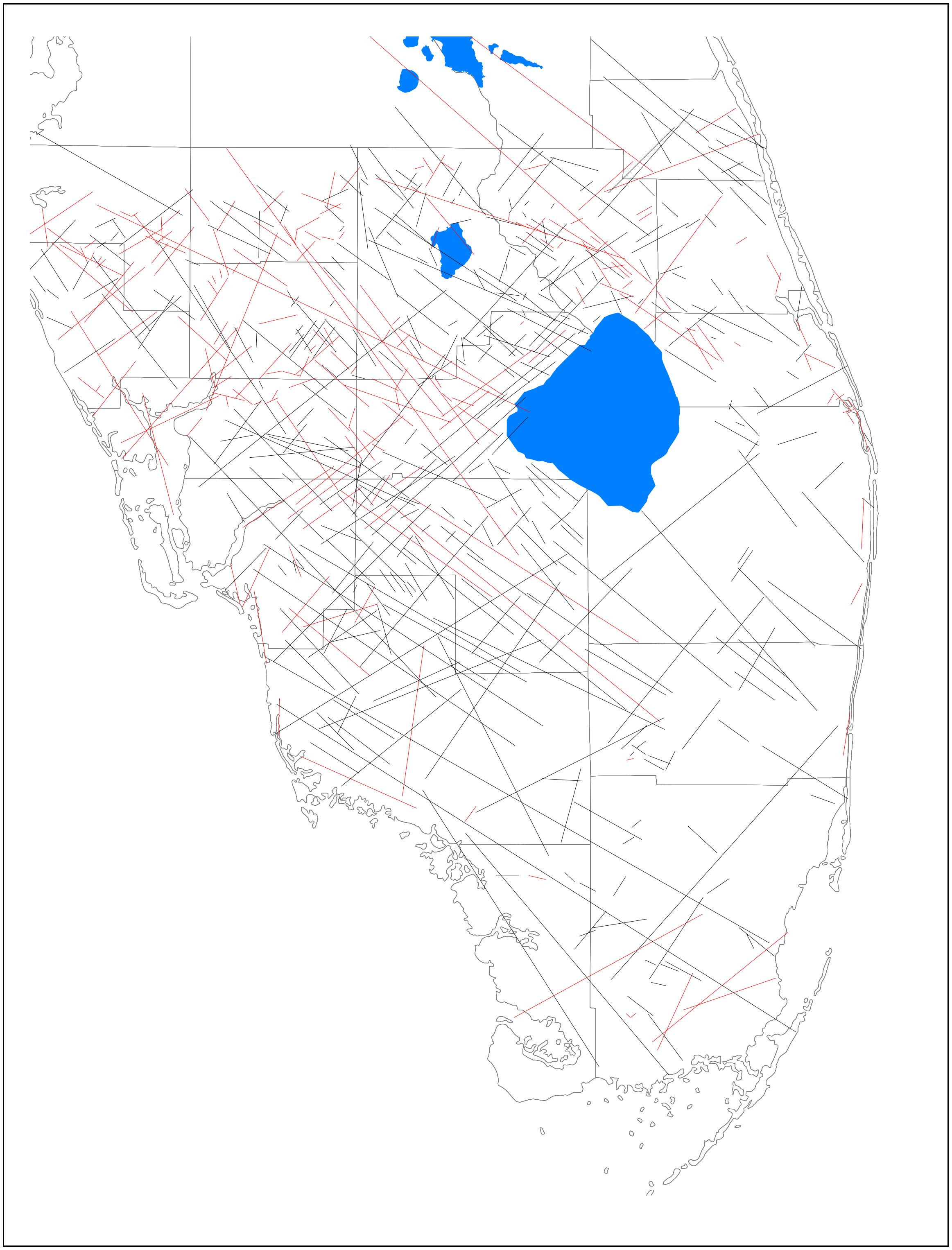

Figure 12. Lineament Map of South Florida. Red Lines Indicate Lineaments Documented by Previous Studies. Black Lines Indicate Potential, Unconfirmed Lineaments.

LAKE OKEECHOBEE SEISMIC SURVEY

The preliminary hydrogeologic framework revealed that the largest single data gap in evaluating the hydrogeology of the Floridan aquifer system was beneath Lake Okeechobee. Therefore, a marine seismic reflection survey was conducted to identify structural trends that could pose obstacles to regional-scale CERP ASR implementation. Seismic reflection uses the principles of seismology to estimate the properties of the Earth's subsurface from reflected seismic waves.

Marine surveys are conducted using vessels capable of towing one or more seismic cables known as streamers. Modern surveys use multiple streamers deployed in parallel to record data suitable for the interpretation of the structures beneath the seabed. A single vessel may tow up to 10 or more streamers, each approximately 6 kilometers in length, spaced 50–150 meters apart. Hydrophones are deployed at regular intervals within each streamer. These hydrophones are used to record sound signals that are reflected back from structures within the rock. To calculate where subsurface features are located, navigators compute the position of both the sound source and each hydrophone group that records the signal. Accurate positioning is achieved by using a combination of acoustic networks, compasses, and Global Positioning System (GPS) receivers.

Feeding Hydrophone Streamers from Boat

Figures 13 and **14** show an example of a seismic line and a map of the seismic survey, respectively. After reviewing the various seismic lines, the most significant geological description to be made is that the formations beneath Lake Okeechobee are generally flat lying, with an apparent dip (fault) and thickening of beds in a southward direction. This is good news to the extent that the Floridan aquifer system is continuous beneath the lake, and no obvious structural hazards are indicated by the seismic lines.

The second most significant geologic feature is the erosional unconformity in the Hawthorn Group seen in the western portion of Lake Okeechobee. This feature appears to show erosion of up to 400 feet through flat lying beds with re-deposition of mostly non-flat lying material. Some apparent paleo (old) channels are visible in the re-deposited material.

A third feature interpreted by the lines is the presence of significant lateral disruptions in the profiles that are caused by softer material near the surface. Fracture zones may also cause these anomalies. Other velocity anomalies probably exist in the deeper beds; however, they are difficult to discern because of the generally discontinuous nature of the reflections in this zone.

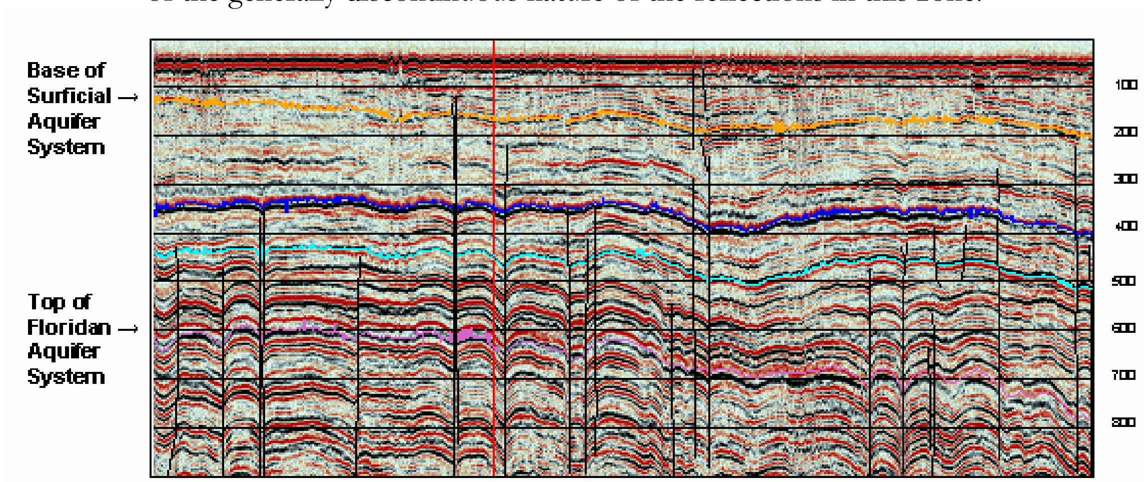

Figure 13. A Portion of a Seismic Line from Lake Okeechobee Seismic Survey.

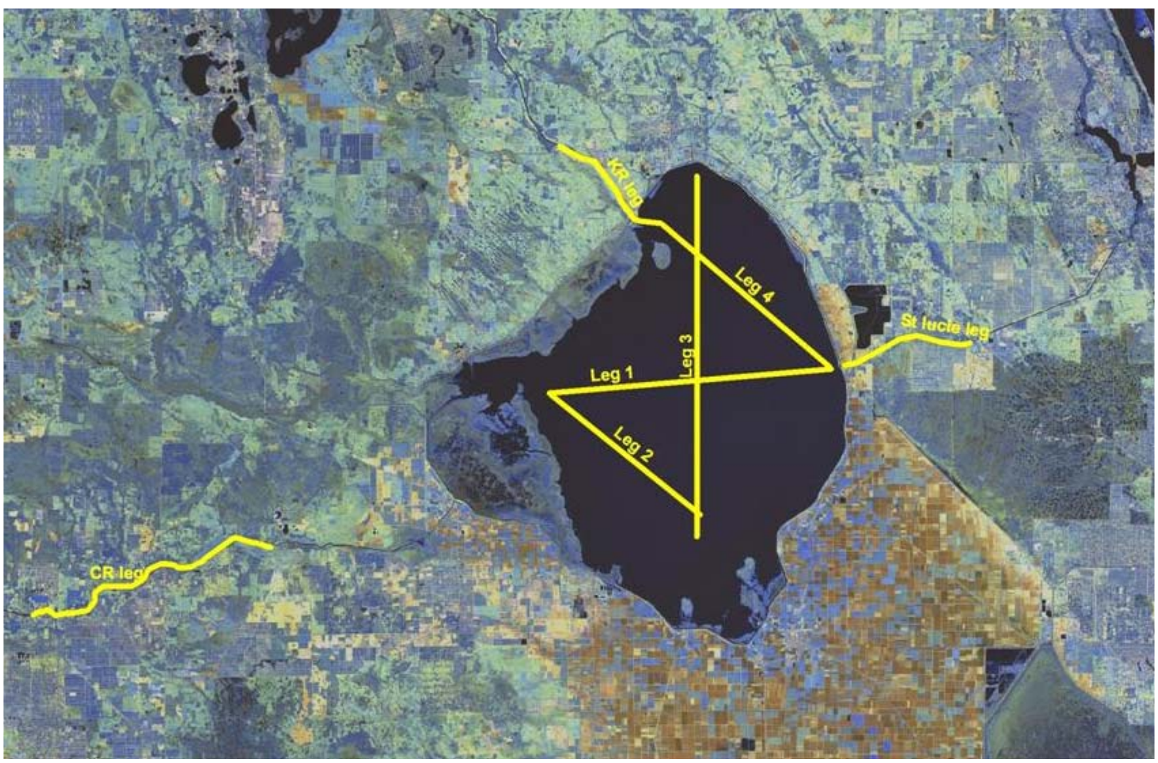

Figure 14. Cross-section Locations for Lake Okeechobee Seismic Survey.

CROSS-WELL TOMOGRAPHY AT PORT MAYACA

Understanding the continuity of flow zones in an aquifer is needed to simulate the flow and transport in a groundwater model. Tomography is a tool that can be used to assess continuity. Seismic tomography is similar to a CAT scan, but instead of using X-rays to create an image, seismic waves are used to digitally map a profile of the Earth.

> **TERMINOLOGY**
>
> **Tomography**
> Geophysical imaging by sections or sectioning. A device used in tomography is called a "tomograph," while the image produced is a "tomogram."
>
> **Seismic Tomography**
> The process whereby a computer first synthesizes data on the velocities of seismic waves from thousands of recent earthquakes to make a series of images depicting successive planes within the Earth, and then uses these images to construct a representation of the Earth's interior.

In cross-well tomography, a tomograph is used to measure an acoustic signal transmitted from a source located in one well to a receiver located in a neighboring well. These data are used to create a map of the properties of the geologic formations between the wells.

At the Port Mayaca ASR Pilot Project site, tomography was conducted between the ASR well and the monitoring well. The tomograph profile was integrated with data from geophysical logs of the wells to relate the tomography data to hydrogeologic parameters. The relationships between the tomograph and geophysical log data were used to generate high-resolution maps showing the distribution of porosity and permeability between the wells. **Figure 15** shows the aquifer permeability at Port Mayaca using cross-well tomography. Warmer colors (toward red) indicate greater permeability, whereas cooler colors (toward blue) represent lesser permeability. These data can be used for site-scale modeling at the Port Mayaca ASR Pilot Project well and will be re-evaluated when the results of cycle testing are available from this pilot project.

PRESSURE-INDUCED FRACTURE EVALUATION

This investigation provided an evaluation of potential impacts to the Floridan aquifer system and the Hawthorn Group that could occur as a result of ASR well pumping. Some of the concerns that have been raised include the following:

- Land subsidence (sinking on the surface)
- Fracturing of the overlying rock formations
- Excessive costs related to drawdown and recharge pressures

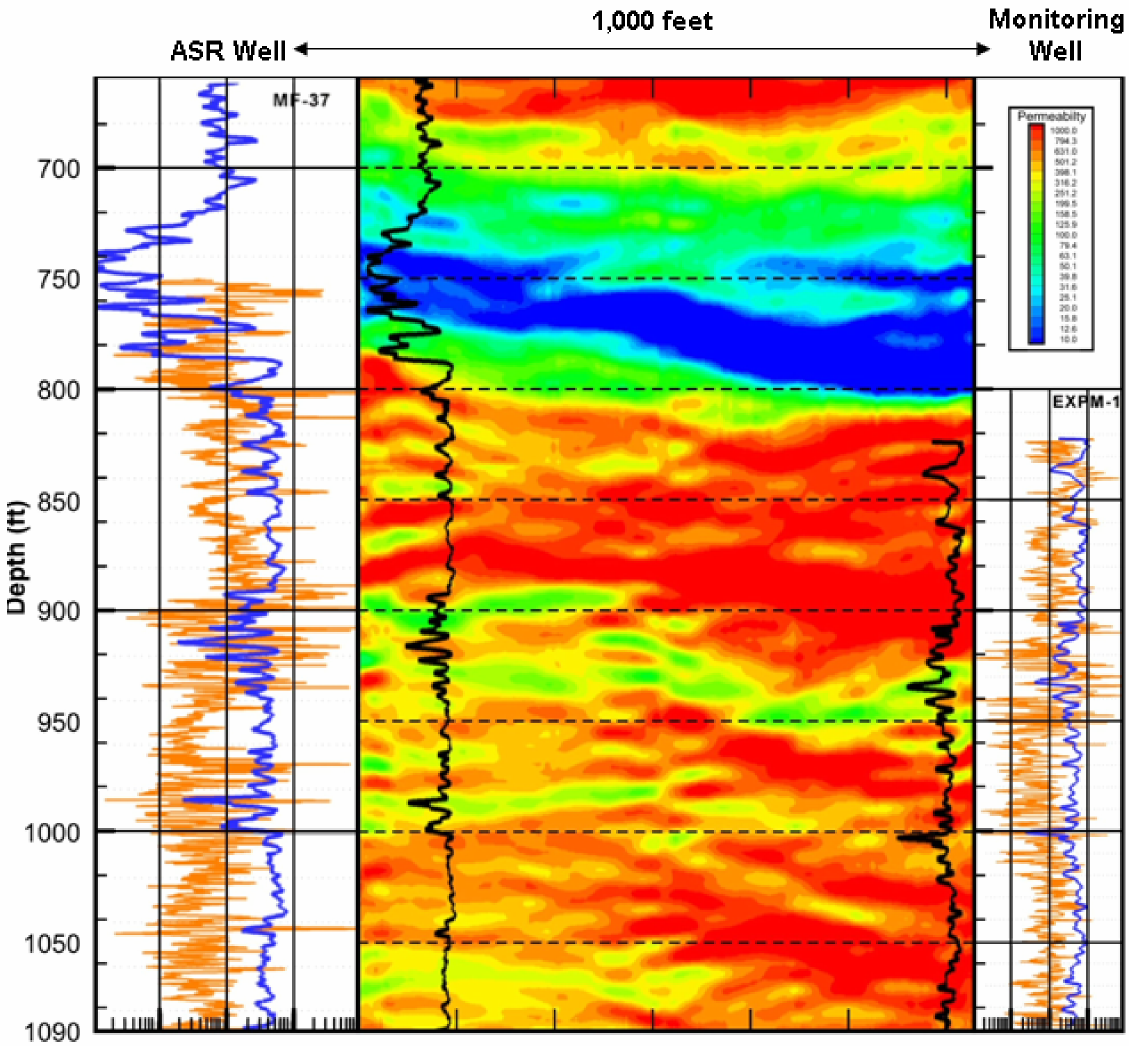

Figure 15. View of the Aquifer Permeability between the Wells at Port Mayaca Using Cross-well Tomography.

This task evaluated both practical engineering constraints related to pump and motor selection, and complex theoretical stress-strain regimes that could be expected within the Floridan aquifer system when ASR is implemented. Each of these evaluations represents a category of pressure-induced changes that could occur under certain conditions.

The analysis demonstrated that pressure-induced hydraulic fracturing of the Floridan aquifer system limestone is highly unlikely if Floridan aquifer system pressures are constrained to reasonable values, including a margin of safety. As for potential subsidence concerns, two factors control the extent of land subsidence:

1. The magnitude of decline in water level or hydraulic head
2. The duration of that decline

The first factor controls the driving force of subsidence, while the second controls the probability of subsidence. Land subsidence takes place only as fast as the pore water can be squeezed out of the clay layer. It usually takes decades for an extensive subsidence to take place, as demonstrated through documented cases of subsidence worldwide. Based on the evaluation in this study, because it is difficult for pore water to drain from a low permeability clay unit (Hawthorn Group sediments), the time required for the estimated subsidence to be complete could be decades, if it occurs at all. This is the case only if ASR wells are pumped continuously over that period. No ASR well, however, will be pumped constantly. The wells will be operated in an alternating manner of pumping and recharge. Therefore, it is most likely that there will be little if any land subsidence induced by ASR operation and it should not pose any ASR development constraints.

TERMINOLOGY

Land Subsidence
The sinking or settling of land to a lower level in response to various natural and man-caused factors, such as earth movements; lowering of fluid pressure (or lowering of groundwater level); removal of underlying supporting materials by mining or solution of solids, either artificially or from natural causes; compaction caused by wetting (Hydro-compaction); oxidation of organic matter in soils; or added load on the land surface.

With respect to groundwater, subsidence most frequently results from overdrafts of the underlying water table or aquifer and its inability to fully recharge.

The results indicated that only a few of the categories of pressure-induced changes examined have the potential to constrain ASR development in south Florida. First, practical limitations involving basic pump availability, pipe pressure limitations, and electricity demand will constrain the total allowable head (or pressure) at each ASR wellhead. Second, pressure-induced change limitations outlined in the report will slightly constrain ASR operations. After a review of all of these constraints, recommendations were developed to aid with ASR planning and future ASR development.

More specifically, it was recommended that individual wells be pumped at no more than 100 pounds per square inch (psi, as measured at the wellhead), unless site-specific conditions permit. This individual pumping pressure will not result in a collective pressure increase from multiple wells within the aquifer that could affect the geologic formations. Additionally, ASR wells should be spaced at distances of at least 500 feet from each other, so the pressure field from one well does not add to the pressure field of the other well. This information is useful in the design of ASR well clusters.

TERMINOLOGY

In Situ
An environmental measurement taken in the field, without removal of a sample to the laboratory.

In this analysis, cores were obtained during well installation and geotechnical lab tests were conducted to provide data to modelers to augment existing core data. Some additional geotechnical data collection is recommended during future data collection efforts. In situ measurements of wellhead pressures during ASR pilot operations will be conducted. These measurements would aid in the calculation of aquifer pressure changes during recharge and recovery operations. High-resolution elevation surveys of all the ASR pilot and monitoring wells are recommended prior to and following cycle testing operations. These data would allow the detection of any subsidence at any of the well sites. Collection of additional rock cores within the Hawthorn Group and the Floridan aquifer system will also be beneficial as new wells continue to be constructed and tested. The samples will continue to be tested in a geotechnical laboratory to determine consolidation and strength properties under high total stress conditions similar to in-situ conditions. To access the complete report of this study, see the References for Additional Information section at the end of this chapter.

SUMMARY

During construction of the exploratory wells, intensive geophysical logging was performed to obtain as much information as possible from each drilled borehole. A lineament analysis of south Florida shows that the regional geologic structure and hydrogeologic character tend to parallel surface lineament trends, suggesting that some lineaments may indicate existing fractures or faults. Because the subsurface of Lake Okeechobee was the single largest data gap in the preliminary hydrogeologic framework, a seismic survey was conducted, revealing that the subsurface units beneath the lake are generally flat lying. Cross-well tomography was performed between two wells at the Port Mayaca ASR Pilot Project to map the distribution of porosity and permeability between the wells. In addition, an evaluation of pressure-induced changes to the Floridan aquifer system and Hawthorn Group was completed. This study addressed concerns relative to land subsidence, fracturing of overlying rock formations, and excessive costs related to drawdown and recharge pressures. The data collected from these studies and the hydrogeologic studies in **Chapter 3** are being synthesized into a comprehensive groundwater model. The development of this model is discussed in **Chapter 5**.

FUTURE DIRECTIONS

Additional tasks will be conducted to fill in conceptual data gaps within the hydrogeologic framework. The geophysical tasks, such as the seismic data collection from Lake Okeechobee, will be integrated into the structural interpretation. Geophysical logs will continue to be evaluated in an effort to map areas that may show fracturing and to correlate this information with the lineament study. Radiometric dating will also be conducted on water samples collected from the Floridan aquifer system to determine the age of the water and develop a more complete understanding of the flow characteristics predicted in the groundwater model.

When the new data are integrated into the hydrogeologic framework, the conceptualization of the Floridan aquifer system will be tested through various simulations using the regional groundwater model, which is discussed in **Chapter 5**. The model scenarios will provide iterative feedback loops to the hydrogeologic framework and be useful in testing various hypotheses and unifying interpretations of the structure, stratigraphy, and hydrogeology of the Floridan aquifer system. After the new information is synthesized into the groundwater model, a "Final Hydrogeologic Framework" will be prepared and summarized in the final CERP ASR Program Technical Data Report.

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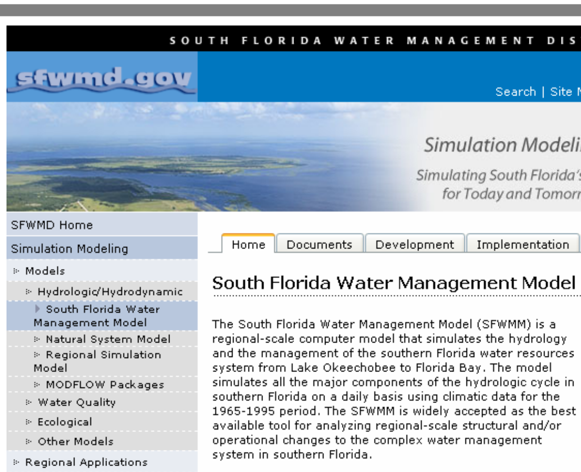
5

Groundwater Modeling

> **POINTS OF INTEREST**
>
> - After a detailed review, testing, and selection process, an intensive groundwater modeling effort is now underway, using two powerful models.
> - The groundwater models will be used to predict regional changes in groundwater flow and quality, saltwater intrusion, impacts to users, wellfield design, and pressure effects. Preliminary results will be available within the next year.
> - An ASR well siting study was conducted and site selection criteria were developed in an effort to compare and rank areas suitable for ASR systems.

One of the centerpieces of the ASR Regional Study is the development of a groundwater model to provide a better understanding of the potential effects of CERP ASR on the groundwater of south Florida. Many of the design assumptions for the CERP ASR components were based solely on output from the South Florida Water Management Model (SFWMM), which only simulates the surficial aquifer system. The Floridan aquifer system, where the proposed ASR wells are to be located, is not included. The groundwater model will be used to help determine the feasibility of ASR implementation by simulating the complexities of the Floridan aquifer system in a meaningful way.



Groundwater Modeling

In order to develop a model, however, locations for the ASR wells were needed to provide accurate data input. The exact locations and distribution of the proposed ASR wells were not determined as part of the Restudy, but were generally concentrated adjacent to reservoirs or Lake Okeechobee. Therefore, as part of the ASR Regional Study, a siting study was developed to identify potential locations for ASR wells. This chapter presents an overview of the groundwater model evaluation and site scoring processes.

MODEL EVALUATION PROCESS

Initial Literature Search

One of the primary goals of the ASR Regional Study is to develop a peninsula-wide groundwater model from Orlando to Key West – essentially the jurisdictional boundaries of the SFWMD. The first step in developing this model was to narrow down the number of existing model codes (software) and layering schemes that might be used for the evaluation. To obtain an objective analysis, the USACE and SFWMD retained an independent consultant to conduct a technical review of existing models and compare the model layering schemes relative to the preliminary hydrogeologic framework.

Several government agencies assisted in providing information to compile a list of models. The list included published models that had been constructed by or for government agencies and subjected to peer review. From a list of 32 models, the following eight groundwater models were selected for evaluation:

- Eastern Tampa Bay Model (SWFWMD 1993)
- Lee County Model (SFWMD 1990)
- Lower East Coast Floridan Aquifer System Model (SFWMD 1999)
- Peninsular Florida Model (Megamodel) (USGS 2002)
- Southern Water Use Caution Area Model (SWFWMD 2003)
- East Central Florida Model (SJRWMD 2002)
- HydroGeoLogic Model (SWFWMD 2002)
- District Wide Regulatory Model (SWFWMD 2004)

Numerous aquifer characteristics were input to a database to compare the groundwater model layering schemes of these models. Following this review, it was determined that the best approach to simulate the hydrogeologic framework would be to represent the surficial, intermediate, and Floridan aquifer systems, and intervening confining zones as discrete layers. A 12-layer model was recommended using finite-element groundwater modeling software. Of these 12 layers, six layers were identified to simulate permeable zones, and three zones were identified as needing further study further for potential ASR sites. **Figure 16** shows some of the different groundwater models that have been conducted within the last decade.

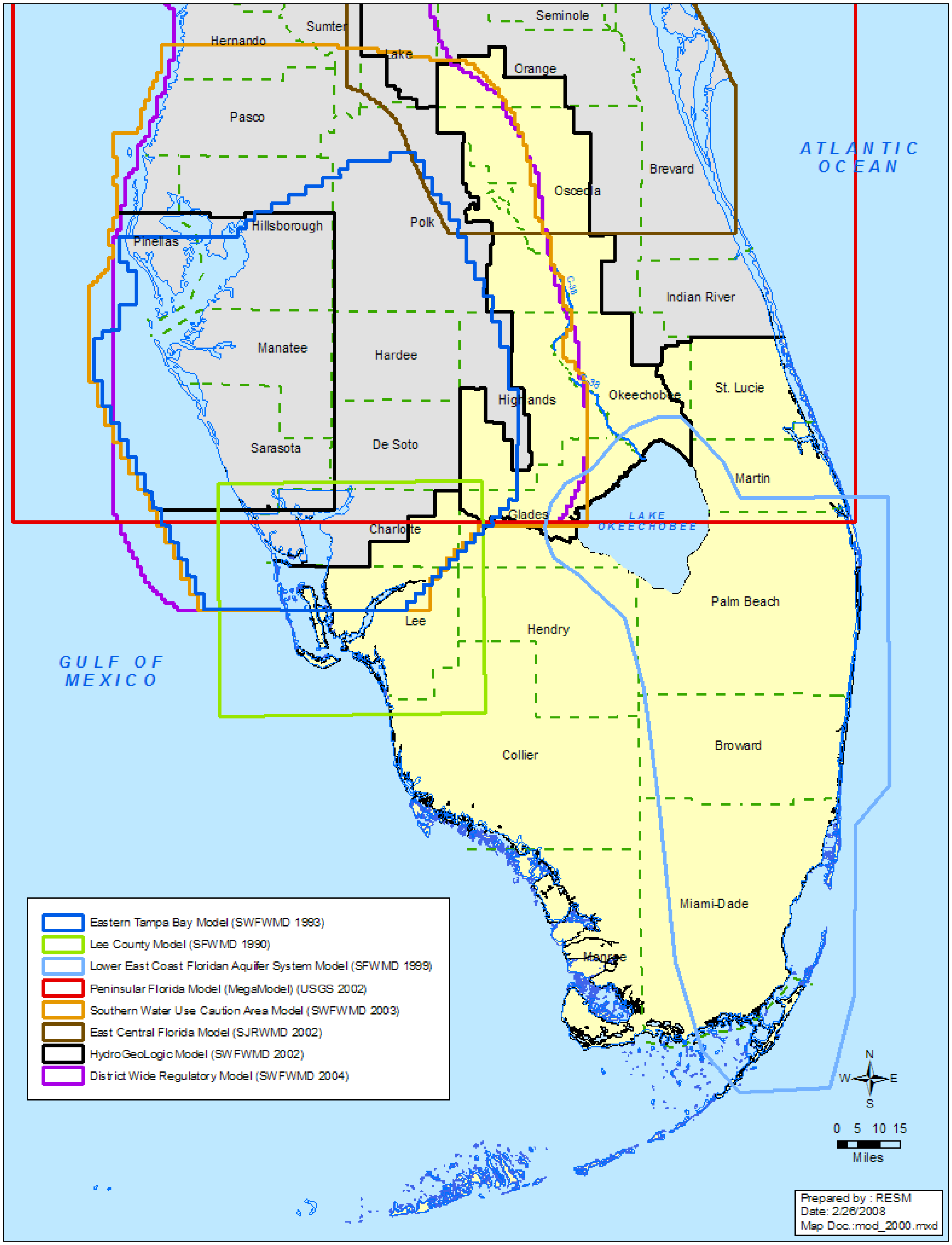


Figure 16. Groundwater Models Selected for Evaluation and Conducted Within the Last Decade.

Benchscale-Modeling Test

Following the initial model study, efforts then focused on the selection of a computer code to simulate regional changes in aquifer pressure and water quality. This undertaking involves many technical challenges, such as addressing seawater boundary conditions; determining the appropriate number of model layers and grid/mesh spacing (cell discretization); developing manageable model computer run-times; evaluating vertical aquifer relationships; testing alternate locations for ASR clusters; developing reasonable ASR recharge and recovery scenarios; and determining whether steady-state modeling is applicable.

To balance the needs of the project with current software and hardware capabilities, a benchscale-modeling test was used to evaluate various model codes and approaches. The primary objectives were to:

- Provide an estimate of model run times for 36-year simulations.
- Provide an understanding of model development issues relating to resolution requirements, boundary types, and starting conditions.
- Uncover model limitations and short-comings.

It was envisioned that the benchscale modeling would develop several identical (constant density standard flow and transport; uncoupled density-dependent flow and transport; fully density-dependent flow and transport) models covering a smaller region than projected for the regional model. The four codes used for this study were as follows:

- MODFLOW and MT3DMS using equivalent freshwater heads to represent saltwater boundaries (constant density flow and transport model)
- SWI (Sea-Water Intrusion) Package for MODFLOW (density-dependent vertically integrated flow with interface tracking)

TERMINOLOGY

MODFLOW
A modular, three-dimensional, finite-difference groundwater modeling code created by the USGS, which is used to simulate the flow of groundwater through aquifers. The SFWMD uses it for subregional groundwater modeling.

MT3DMS
A modular, three-dimensional multispecies transport model for simulating advection, dispersion and chemical reactions of contaminants in groundwater systems.

SWI Package
A code for modeling regional seawater intrusion with MODFLOW. Its main advantage is that each aquifer can be modeled with a single layer of cells.

SEAWAT
A program developed to simulate three-dimensional, variable-density, transient groundwater flow in porous media. The source code for SEAWAT was developed by combining MODFLOW and MT3DMS into a single program that solves the coupled flow and solute-transport equations.

WASH123D
A three-dimensional, finite-element, variable-density computer code that simulates water flow and contaminant and sediment transport in coupled surface water and groundwater systems.

- SEAWAT (fully coupled or uncoupled density-dependent flow and transport)
- WASH123D (fully coupled or uncoupled density-dependent flow and transport)

All of the tested codes represented a reasonable range of code options available, and were determined to be easy-to-moderately difficult to use. In weighing all of the factors and considering improvements that could be made to the model grid/mesh for future models, it appeared that either the WASH123D (finite-element solution) or the SEAWAT (finite-difference solution) codes would be appropriate for the ASR Regional Study model (see **Figure 17**). Both codes seemed to solve the requisite flow and transport equations adequately, and provided a basis for published comparisons with density-dependent case studies. Each code also had inherent disadvantages, including long model run times due to small time-step requirements for mass transport models. It was determined that both model codes should be used for the CERP ASR Study, thus ensuring a higher degree of reliability in overall conclusions and future recommendations.

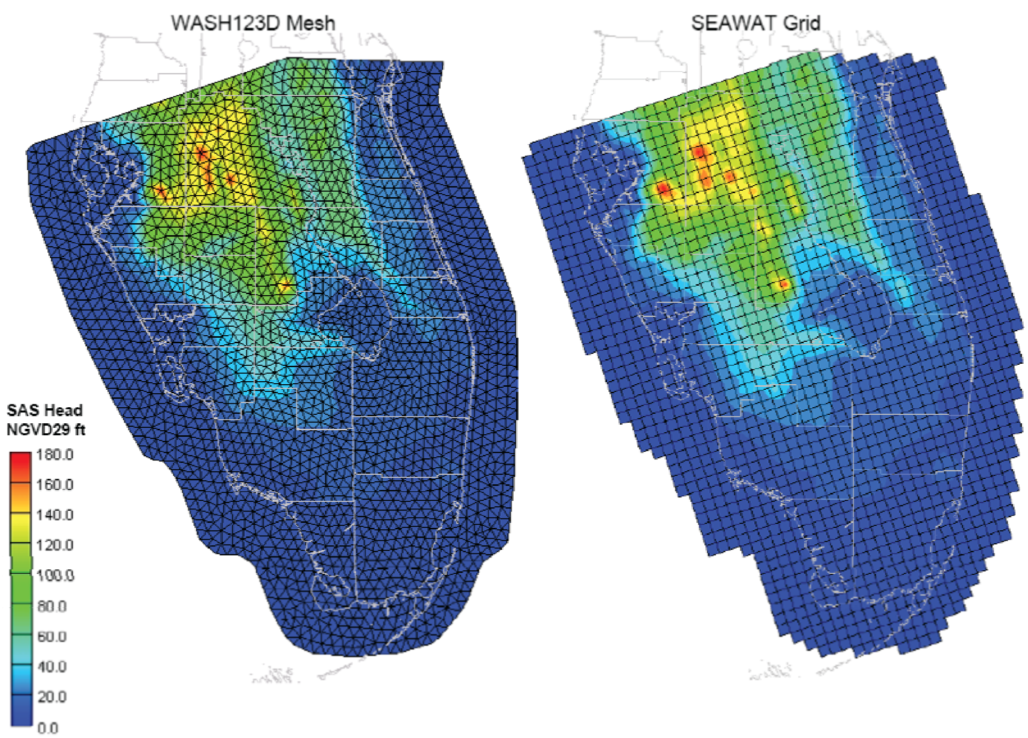


Figure 17. The WASH123D and SEAWAT Models are Under Simultaneous Development for the Regional Groundwater Model of the Floridan Aquifer System.

MODELING PROGRESS TO DATE

The two codes selected, WASH123D and SEAWAT, are being used to simulate the Floridan aquifer system in the study area simultaneously to address numerous regional and subregional concerns. These include the following:

- Potential regional changes in aquifer flow and water quality
- Potential for saltwater intrusion caused by ASR pumping
- Regional impacts to existing well users of the Floridan aquifer system
- ASR well cluster siting, design, layout, and performance considerations, including estimating recovery efficiency
- ASR well site evaluations of pressure-induced changes
- Localized ASR wellfield and pump design

Once the regional model is complete, detailed subregional- and/or local-scale models will be developed to evaluate the CERP ASR Program. The regional-scale model will provide planning level information to address specific issues, while the development of finer resolution subregional models will provide an improved understanding of a particular issue (see **Table 1**).

Table 1. Model Scale Applications.

Model Scale Required to Address Specific Issue	Issues to be Addressed
Local-scale fine-resolution model	• ASR well cluster performance, including estimating recovery efficiency • Localized ASR pump design
Subregional moderate-resolution model	• Regional changes in aquifer flow and water quality • Potential for saltwater intrusion • Impacts to existing well users of the Floridan aquifer system • ASR well cluster design and layout • ASR well site evaluations of pressure-induced changes
Regional-scale moderate-to-coarse resolution model	• Regional changes in aquifer flow and water quality • Potential for saltwater intrusion • Impacts to existing well users of the Floridan aquifer system • ASR well cluster siting, layout, and design • ASR well site evaluations of pressure-induced changes

ASR WELL SITING STUDY

During development of the CERP, modeling and analysis led to a preliminary recommendation to construct up to 333 ASR wells throughout south Florida. Approximately two-thirds of the wells were planned around Lake Okeechobee to maximize water management and flood control benefits, among others. A fewer number of ASR wells would be located in the C-51, Hillsboro Canal, L-8, Central Palm Beach County, and Caloosahatchee River (C-43) basins. During the ASR Regional Study, ASR well and site placement will be examined in detail to provide the groundwater modeling team with sites to populate the model in order to simulate the effects of ASR well pumping.

A siting strategy for ASR wells was developed using sequential evaluation of numerous factors. For all ASR projects, factors relating to the aquifer are important because the hydrogeology will control the distribution of the recharged water within the storage zone. Other important site selection criteria included the following:

- Availability and quality of source water for recharge
- Distance from the source water to the ASR well
- Existing land use and availability, as well as ease of access
- Existence of sensitive habitats and/or threatened or endangered species
- Locations of existing groundwater users
- Availability of existing infrastructure (power supply, reservoirs)
- Operational flexibility

After developing an ASR well siting index, an interagency team used Geographic Information Systems (GIS) and a method to develop an array of potential ASR well locations. The location color-coded ranking index was based on the premise of maximizing ASR feasibility, while minimizing impacts from well construction and operation. Optimal locations for ASR wells could then be used in the groundwater model to simulate the effects of pumping from the proposed CERP ASR Program.

Sites were ranked in a two-tier process. In the first tier, three "pass or fail" criteria were examined:

1. Source water within 3 miles
2. Minimum 5-acre parcel
3. Acceptable (nonsensitive) existing land use

Lands failing any of the three criteria were eliminated from further consideration.

In the second tier, the remaining areas were subdivided into 97 large polygons of varying size and shape. Secondary site selection criteria were based primarily on hydrogeologic and water-quality characteristics, which were then applied to the site selection polygons. Hydrogeologic characteristics included attributes, such as modest aquifer transmissivity and a confining zone overlying the storage interval. These criteria were then combined into a scoring system to rank areas suitable for ASR systems. **Figure 18** shows the results of this site scoring exercise. Color-coded polygons represent the relative suitability of a location for ASR systems. The values closest to dark blue are most suitable for ASR well siting. It is important to note, however, that in-depth site analysis may be needed within each large polygon to construct an actual ASR wellfield.

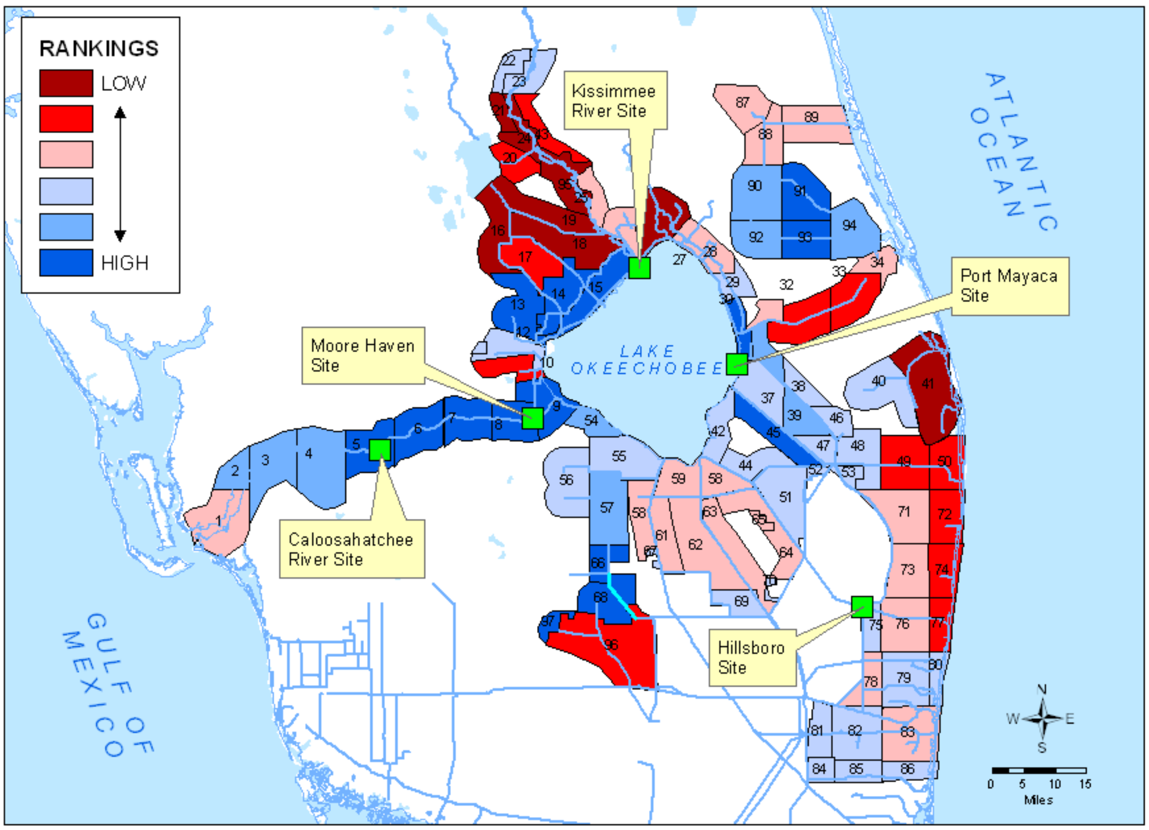


Figure 18. Results of the ASR Well Siting Study. (Numbers within polygons represent polygon number only.)

This exercise was useful in ranking large areas that should be considered for construction of ASR wells. During the groundwater modeling simulations, the highest ranked (best) sites will be populated with wells first. During subsequent modeling scenarios, wells will be simulated in progressively lower ranked polygons.

SUMMARY

Development of a groundwater model is a key objective of the ASR Regional Study. Efforts accomplished so far include the completion of a study to review existing models and compare model layering schemes using data input from the preliminary hydrogeologic framework. Additionally, a benchscale-modeling test compared the codes of four models for their suitability to conduct modeling at the regional and local scales needed for the CERP ASR Program. Of these four models, two were selected for simultaneous development: the WASH123D and SEAWAT. To populate the groundwater model with wells for simulations, a site selection study ranked potential subregional locations for ASR wells.

FUTURE DIRECTIONS

Because of its extent and complexity, the regional modeling effort was divided into two phases. The Phase I model, completed in 2008, serves as a coarse resolution regional test model for the more refined Phase II regional model. Simplifying assumptions were made to maintain the model's ability to represent the regional flow and transport patterns, while facilitating model construction and reducing model run times. The goal of the Phase I model was to:

- Identify regional flow and salt migration pathways.
- Test hydraulic and transport parameters.
- Evaluate and refine the conceptual hydrogeologic model.
- Compare the WASH123D and SEAWAT model results to determine a reasonable range for the input parameters to be used in the more refined Phase II model.

The Phase II regional model, scheduled for completion by 2010, will incorporate refined spatial and temporal resolution, transient boundary conditions, and regional-scale transient groundwater withdrawals. The model will be calibrated to observe water-level and salinity data to ensure that the groundwater model accurately replicates the existing regional groundwater flow system.

Concurrent with the Phase II regional modeling, additional local-scale evaluations will be performed. Several ASR sites will be chosen for local horizontal and vertical refinement, incorporating more detailed geological data for the Upper and Middle Floridan aquifers as compared to the Phase II regional model. These high-resolution models will be used to evaluate the effects of geologic anisotropy on the stored fresh water within the ASR zone. In addition, data collected during ASR cycle testing at these sites will be used to evaluate local-scale flow and transport effects, including ASR well recovery efficiency.

Depending on the results of the groundwater modeling effort, the number of ASR wells to be implemented may need to be reduced or revisited, or alternate areas selected. In anticipation of such an outcome, an ASR optimization study and an ASR contingency study are being conducted. **Chapter 10**: Plan Formulation discusses these study efforts.

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Restoration Based on Sound Science

"**While not all parties agree** on the details of the restoration, there is near universal agreement that the best possible science should support planning, implementation, and, ultimately, operation of restoration projects."

The Science of Restoring the Everglades, National Research Council, 2003.

6

Geochemical Studies

> **POINTS OF INTEREST**
>
> - Cycle test water-quality data from several operational ASR facilities were compiled and analyzed to create a catalog of possible geochemical reactions that have taken place. These data were used to develop "benchscale" models to predict the mixing and transport of chemicals of concern.
> - The Florida Geological Survey conducted studies to determine the extent of trace elements in the aquifer and gained an understanding of the mechanisms that cause element transport, as well as possible ways to minimize mobilization.
> - The SFWMD and the Southwest Florida Water Management District (SWFWMD) are co-funding the installation of an oxygen removal pre-treatment system at the City of Bradenton's ASR site in an effort to lower the concentration of arsenic that is leached from the aquifer.

Geochemistry is the study of the Earth's chemical composition and reactions that control the distribution of minerals, rocks, soil, waters, and atmosphere. Water stored underground (recharge water) may have chemical and physical characteristics that are quite unlike the displaced groundwater. The ASR Issue Team recognized that the interaction between stored water and the water quality and lithology of the Floridan aquifer system warranted further investigation for proper development and monitoring of the CERP ASR Program.

Calcium carbonate (limestone) is the most abundant mineral within the geologic formations comprising the Floridan aquifer system in south Florida. However, trace minerals, such as quartz, pyrite, phosphorite, clays, and metal oxides also occur in varying amounts. The upper portion of the Floridan aquifer system, which serves as the potential storage zone for the CERP ASR wells, consists of carbonates, whereas the overlying Hawthorn Group, which is the confining unit for this storage zone, contains phosphate-rich (and metal rich) sediments. Therefore, it is likely stored waters will be exposed to these sediments to some degree.

In assessing the feasibility of ASR systems, cycle tests will provide a means to directly evaluate the quality of recovered water. During these cycle tests, the chemical differences between native groundwater and surface water stimulate different reactions between water and rock (see **Figure 19**). To anticipate the water-rock interactions that can occur during CERP ASR cycle testing, several geochemical studies were completed. This chapter presents an overview of these studies, which include the following:

- An investigation of water-quality changes during cycle testing at existing operational ASR systems in south Florida
- Development of geochemical models using ASR cycle test data
- A characterization of the rock chemistry and mineralogy within and adjacent to potential ASR zones
- Benchscale leaching experiments to simulate water-rock interactions that could occur during ASR cycle testing

The findings of these studies aided in the development and interpretation of cycle testing plans and data for the CERP ASR pilot projects described in **Chapter 2**.

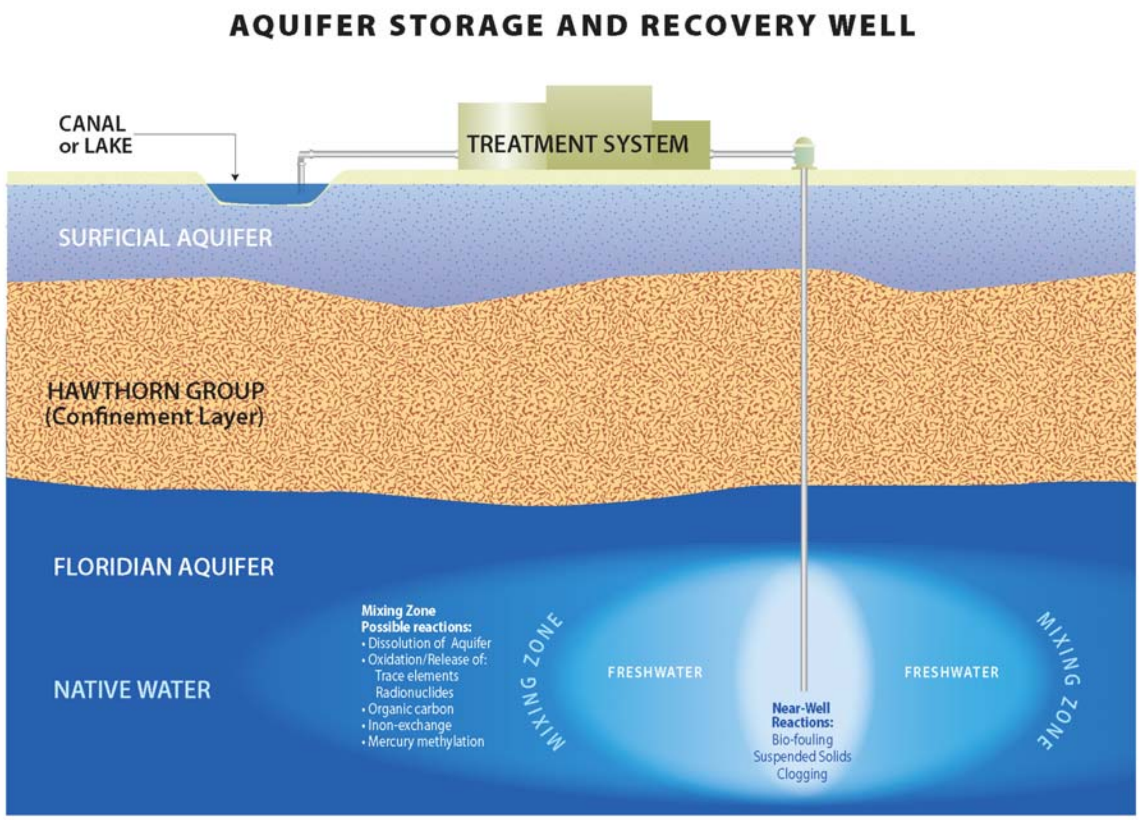


Figure 19. Possible Geochemical Reactions Due to Water-Rock Interactions.

WATER-QUALITY CHANGES DURING CYCLE TESTS AT EXISTING SOUTH FLORIDA ASR SYSTEMS

In an effort to understand what water-quality changes might occur during operation of the CERP ASR wells, a study of existing south Florida ASR systems was performed. To analyze the water-quality changes during ASR cycle tests, the USACE compiled water-quality data from 11 operational ASR systems in south Florida, as shown in **Figure 20**.

Generally, existing utility ASR system studies do not address geochemical or microbiological changes that occur during cycle testing. Typically, groundwater is sampled at the start and end of storage, and geochemical changes are inferred from limited initial and final data. However, storage sample data collected at a few ASR systems from both ASR and monitoring wells are most useful for quantifying geochemical changes that occur during cycle tests.

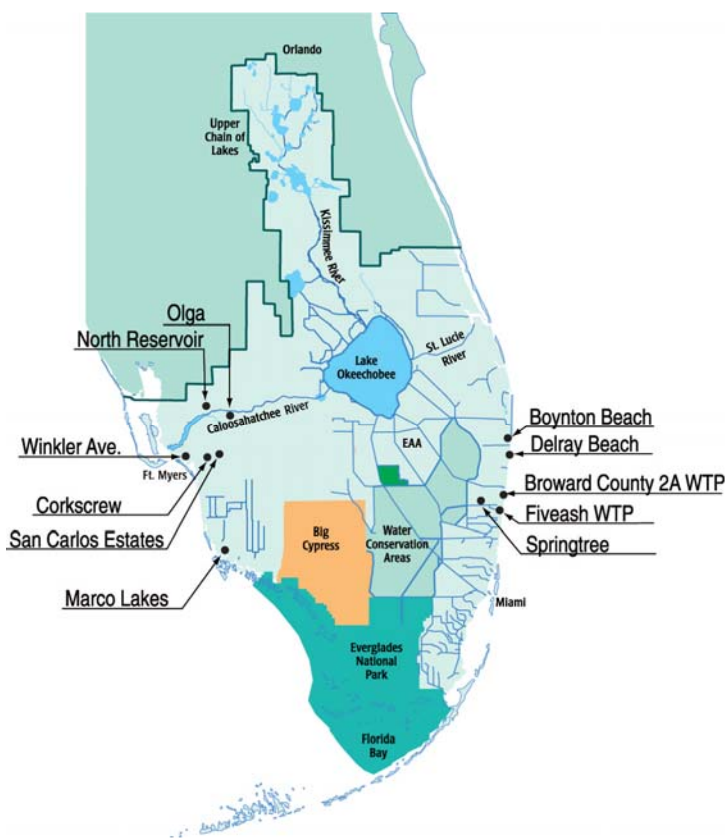


Figure 20. ASR Systems that Provided Water-Quality Data.

Samples collected from ASR wells show the characteristics of stored water for drinking water treatment and fulfill permit requirements, while monitoring well samples are better suited for analyzing physical and chemical changes that occur in the aquifer. Monitoring well samples also provide a more quantitative basis for geochemical modeling efforts by providing mixed water analyses. Data from both well types were analyzed in this report.

During ASR cycle tests, significant water-quality changes can occur, often stemming from reactions associated with the following chemical elements: dissolved oxygen; nitrate and ammonia; sulfate and hydrogen sulfide; gross alpha radioactivity and radium isotopes; and total trihalomethanes.

Despite data gaps, a few broad conclusions were made about recovered water quality. First, major dissolved constituent concentrations (such as sulfate, nitrate, ammonia, and chloride) in recovered water do not exceed state and federal maximum contaminant levels defined in the *Safe Drinking Water Act*. Second, low concentrations of naturally occurring isotopes are generally present in groundwater collected from the Floridan aquifer system, particularly in counties along the southwest Gulf Coast. Naturally occurring dissolved isotopes in native groundwater can mix with recharge water at an ASR system. Third, there was no evidence that disinfection by-products, such as trihalomethanes, increase in concentration during storage in the Floridan aquifer system. Finally, early ASR system water-quality data are insufficient to interpret regional trends of arsenic or other trace metal occurrence. To access the full report of this study, see the References for Additional Information section at the end of this chapter.

TERMINOLOGY

Trihalomethane
Any of several synthetic organic compounds formed when chlorine combines with organic materials in water during the disinfection process.

GEOCHEMICAL MODELS TO SIMULATE WATER-QUALITY CHANGES DURING ASR CYCLE TESTS

To address gaps in the water-quality data from the previously discussed study, the USACE developed geochemical models using data from three operational ASR systems located near planned CERP ASR pilot project sites. The Olga and North Reservoir systems are located in Lee County, where hydrogeologic conditions were expected to be similar to those at the Caloosahatchee River ASR Pilot Project. The Palm Beach County Water Utilities Department's Eastern Hillsboro ASR system is located in southeastern Palm Beach County, where hydrogeologic conditions were expected to be similar to those at the nearby Hillsboro Canal ASR Pilot Project.

The objectives of the geochemical modeling study were to simulate:

- Mixing between native water of the Floridan aquifer system and recharge water during cycle testing
- Geochemical reactions that occur during the storage phase of cycle tests
- Controls on trace element transport and fate during cycle testing

Although some water-quality data gaps existed, geochemical models were successfully developed to represent important reactions that occur during ASR cycle testing at these representative ASR systems.

Mixing of recharge and native groundwater during cycle testing was simulated using chloride as a tracer. Mixing models show that water mixes differently during recharge at the North Reservoir ASR systems versus the Olga ASR system. At the North Reservoir ASR systems, recharge water is transported as plug flow, which is measured in the monitoring wells. In contrast, at the Olga ASR system, recharge water is affected by hydraulic factors.

The magnitude of a water-rock reaction is determined by the "mass transfer value" (moles of an element per kilogram of water). The greatest mass-transfer values resulted from reactions of iron and sulfur at the Olga and North Reservoir ASR systems. Specifically, these reactions included pyrite oxidation with subsequent iron oxyhydroxide (commonly known as rust) precipitation, and sulfate reduction with hydrogen sulfide gas production. These reactions exert a significant influence on stored water quality.

The release and transport of naturally occurring trace elements during cycle testing is of significant concern for ASR feasibility. Therefore, geochemical models were developed to simulate reduction/ oxidation reaction (redox) conditions that facilitate trace element mobility during ASR cycle testing. Most recently, arsenic has become a trace element of concern at several operational ASR systems in southwest Florida. Cycle test water-quality data and rock chemistry data were synthesized to define the conditions that most commonly support element transport in the Floridan aquifer system. Current models suggest that the loss of dissolved oxygen from recharged water, along with the presence of hydrogen sulfide in the storage zone water during ASR storage probably results in the most favorable conditions for trace element transport. To access the full report of this study, see the References for Additional Information section at the end of this chapter.

TERMINOLOGY

Mole
The mass in grams of this amount of a substance, numerically equal to the molecular weight of the substance.

Iron Oxyhydroxide
Commonly known as rust, the oxide that is formed by open-air oxidation of iron.

Plug Flow
A type of flow that occurs in tanks, basins, or reactors when a slug of water moves through without ever dispersing or mixing with the rest of the flow-through water.

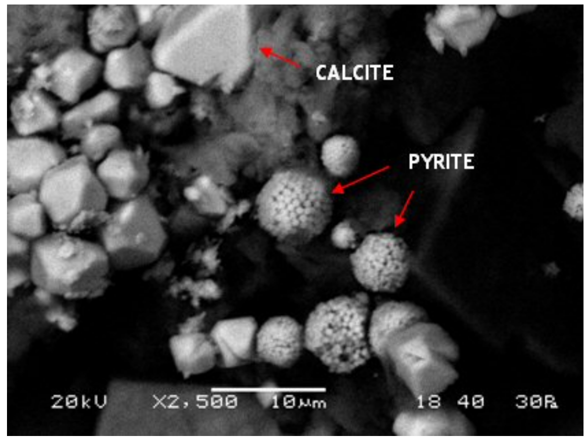
Redox
Shorthand for reduction/oxidation reaction; describes all chemical reactions in which atoms have their oxidation state change.

WHOLE-ROCK GEOCHEMISTRY

The Florida Geological Survey (FGS) conducted a parallel study to characterize the ranges of rock chemical and mineralogical compositions within and adjacent to potential ASR storage zones. The study placed particular emphasis on minerals that might affect the suitability of geologic units that may serve as ASR storage zones.

Several hundred samples were analyzed from rock cores of the Hawthorn Group and Floridan aquifer system. Whole-rock geochemistry analyses consist of multi-element, multimethod analytical techniques, including analyses of stable and radiogenic isotopes. Bulk geochemical analyses of the rock units are supplemented by detailed mineralogical analysis using X-ray diffraction analyses, scanning electron microscopy and electron microprobe analyses.

Pyrite was found in the rock samples. Pyrite is an iron sulfide mineral that occurs naturally in rock and sediments, including the upper portion of the Floridan aquifer system and the overlying Hawthorn Group. Pyrite often contains trace metals other than iron. When pyrite reacts with recharge water during ASR cycle testing, these trace metals are released and can affect stored water quality. The release of arsenic and other metals from pyrite during ASR cycle testing represents a significant challenge to ASR feasibility in Florida.



Scanning Electron Microscope Image of Calcite and Framboidal Pyrite Minerals in the Floridan Aquifer

To access the full report of this study, see the References for Additional Information section at the end of this chapter.

TERMINOLOGY

Framboid/Framboidal
A microscopic aggregate of pyrite grains, often occurring in spheroidal clusters.

ARSENIC AT EXISTING ASR FACILITIES

When the federal drinking water standard for arsenic was lowered from 50 parts per billion to 10 parts per billion in January 2006, arsenic became the primary concern that could affect the success of ASR technology in Florida. The Florida Department of Environmental Protection (FDEP) recently determined that the arsenic standard at ASR sites must be met at all times, including in the aquifer. While most ASR systems in Florida could meet the previous standard, several ASR systems have observed arsenic concentrations that exceed the new standard and may have difficulty meeting the new standard at all times. This poses a significant challenge to the long-term sustainability of ASR as an alternative water supply option in the state. There are several ongoing efforts geared toward understanding how arsenic is "leached" out of the aquifer. Analyses of cycle test data from most ASR systems in south Florida indicate that the concentration of arsenic decreases with repeated cycles of recharge, storage, and recovery, which suggest that certain minerals within the aquifer dissolve and release the chemical.

BENCHSCALE GEOCHEMICAL STUDIES

In addition to the chemical and mineralogical characterization study, the FGS conducted benchscale-leaching studies on storage zone rock samples to evaluate water-quality changes resulting from reactions between recharge water and rock. One conclusion from these leaching studies is that the mineral pyrite is a source of many trace metals that could be released during ASR cycle testing. More than 1,300 benchscale geochemical analyses have been completed to assess and anticipate water-quality changes during ASR cycle testing. Laboratory studies yield data more quickly than field studies. Feedback between laboratory and field study results is critical for objective evaluation of ASR feasibility. To access the full report of this study, see the References for Additional Information section at the end of this chapter.

Benchscale Leaching Studies to Assess Water-Rock Interactions

SUMMARY

Water-rock geochemical processes occur during the ASR cycling process that affects water chemistry and quality. These processes can affect the minerals comprising the aquifer systems and the characteristics of native and recharge waters. The USACE and FGS completed several studies to address these issues. These results will be compared with actual data collected when the ASR pilot projects become operational. In addition to geochemical studies, microorganisms in aquifers studies were conducted, which are discussed in **Chapter 7**.

FUTURE DIRECTIONS

The release of arsenic in the aquifer as a result of ASR storage has become the primary concern that could affect the success of ASR in Florida. Studies show that elevated levels of dissolved oxygen in the recharge water may be the primary factor involved in the arsenic releases. These studies have confirmed that removal of dissolved oxygen along with other adjustments to the water chemistry may prevent the release of arsenic in the aquifer. As a result, the Southwest Florida Water Management District (SWFWMD) and the SFWMD are co-funding a project at the City of Bradenton's ASR system. The city is adding an oxygen removal system to the water treatment process to see if this technology substantially lowers the concentration of arsenic that is leached from the aquifer. The findings from this test could be meaningful and could reduce expensive treatment/removal requirements for ASR systems that may be constructed by the SFWMD in the future.

If successful, the Bradenton technology demonstration project will provide an option that existing (and future) ASR operators can use to meet the FDEP's requirement that the drinking water standard for arsenic must be met at all times. This in turn could ensure the long-term performance of ASR as a water supply option to meet future demands. The project will involve development of a technical advisory committee to gather information and provide fact-finding, as well as to assist with the system design, test procedures, and interpretation of technical data. The system is anticipated to be constructed in 2008. Upon completion of the construction of the pre-treatment system, the ASR facility will undergo cycle testing for a period of approximately two years. The USACE and SFWMD are committed to using or developing technology and operational measures to minimize or eliminate potential risks associated with the implementation of CERP ASR.

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? FREQUENTLY ASKED QUESTIONS

Q What water treatment technologies are being tested and why?

A The pilot projects are testing a self-cleaning screen and pressure-media filtration process. These two processes were evaluated as being most cost-effective in treating the surface water that would be pumped into the ASR wells. A new filtration technology is expected to be evaluated at the Port Mayaca Pilot Project facility. The disinfection process is in-line ultraviolet radiation, which is clean, effective, and does not result in disinfection by-products that are commonly associated with chlorine additives.

Q How will the information from the pilot sites help in addressing the uncertainties identified by the CROGEE?

A When pilot systems are operated and monitored, the recovered water can be analyzed in greater detail to answer important questions about hydrogeologic impacts, geochemical reactions, and the effect of the water on the ecosystem. These issues have all been raised by the CROGEE. The information from the pilot projects will be fed into the groundwater and ecological models to extrapolate the potential effects that possibly hundreds of ASR wells will have on south Florida. This information will be useful in recommending how many ASR wells should be constructed and where they should be deployed, while minimizing or eliminating ecological risk.

Q How is the water quality altered in the subsurface during ASR storage?

A The treated fresh water pumped into the ASR well is generally higher in dissolved oxygen. When it is pumped into the ASR well and into the aquifer, the water loses its dissolved oxygen. The water is generally devoid of oxygen as it is returned to the surface. Other reactions between water and the aquifer matrix tend to increase the total dissolved solids concentration of stored water.

Q What technologies are being explored to reduce or avoid the release of chemicals from rocks into the recharged water?

A A technology designed to lower the amount of dissolved oxygen in treated fresh water prior to recharge into the aquifer is expected to be tested. The geochemical experts believe that by reducing the dissolved oxygen in the recharge water, the release of chemicals naturally present in the aquifer rocks can be avoided.

More questions? See Appendix A: Frequently Asked Questions.

7

Studies of Native Microorganisms in Aquifers

The ASR Issue Team recommended analyzing water-quality changes during recharge, storage, and recovery. Studies were conducted to investigate the presence of microorganisms in ambient groundwater within the Floridan aquifer system and the survival of surface water organisms that may be pumped underground. The effect of biological reactions on water quality within aquifers is complex, and these studies represent early attempts to document organisms that thrive naturally within the Floridan aquifer system and the life expectancy of microorganisms in surface water recharged and stored within the aquifer.

> **POINTS OF INTEREST**
>
> - Waters collected from Floridan aquifer system wells in south Florida contained small, naturally occurring populations of bacteria – the first baseline document-tation of abundance and diversity that will be monitored over time.
> - The SFWMD partnered with the SWFWMD to investigate the survival of microorganisms that are subjected to conditions within a deep confined aquifer. The laboratory study documented the rates at which various pathogens become "inactivated" while under these conditions. The next step would be to conduct similar experiments at actual systems in operation.

AMBIENT MICROBIAL POPULATIONS IN THE FLORIDAN AQUIFER SYSTEM

Bacteria that are native to aquifers are not necessarily of direct public-health concern, but they do bring about nutrient cycling and geomicro-biological processes (for example, karst geology dissolution, metal mobilization, and biofilm development), which may negatively affect the quality of water pumped into the aquifer. Studies have shown that microbial interactions with the aquifer rock matrix may enhance many naturally occurring geologic processes, such as metal mobilization, and under certain circumstances can produce by-products (such as methylated compounds) that may have public-health concerns. Additionally, changes in the water-quality and biofilm characteristics within an aquifer may enhance the survival of pathogenic and nonpathogenic bacteria and protozoans if they were present in the source water.

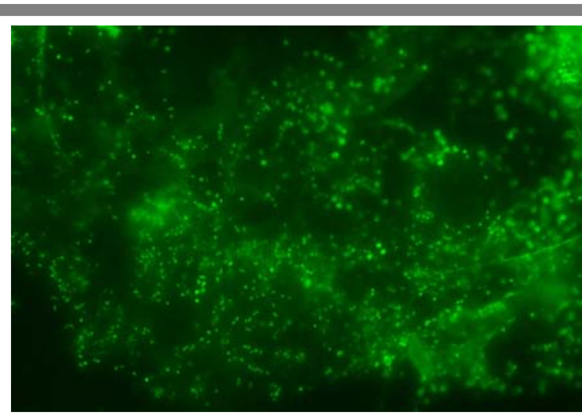
TERMINOLOGY

Biofilm
A complex aggregation of microorganisms held in place on surfaces by an exo-polysaccharide layer (protective and adhesive matrix) that is excreted by the microorganisms.
Methylation
A chemical process for introducing a methyl group into an organic compound. If a constituent of water is methylated, a methyl radical group is substituted into its chemical structure.
Assay
A procedure where a property of a system or object is measured.

A suite of culture- and nonculture-based methods was used to assess the abundance, viability, and productivity of bacterial communities in samples collected from the Floridan aquifer system at CERP ASR pilot projects located at Port Mayaca, the Kissimmee River and the Caloosahatchee River. The tests indicated that the native bacterial communities have extremely low productivity and growth rates similar to those in bacterial communities in extreme environments, such as Antarctica.

The "community-level physiological profile," a process of the Biolog EcoPlate™ (created specifically for community analysis and microbial ecological studies) indicated that the native bacterial populations are very similar to patterns of bacterial communities in brackish zones of the Floridan aquifer system in the Tampa Bay area.

This study provides the first baseline dataset for the abundance, viability, productivity, and genetic diversity of native bacterial populations in the Floridan aquifer system that have potential for ASR. These data and the assays described in this report can be used to monitor changes and assess the impact that ASR has on the native Floridan aquifer system bacterial communities over specific periods of time and operational regimes. These data, in conjunction with geochemical analyses, can be used as a tool to assist in the management and maintenance of ASR wells and in providing a better understanding of the potential impact of ASR on the ecology of aquifers used as storage zones. To

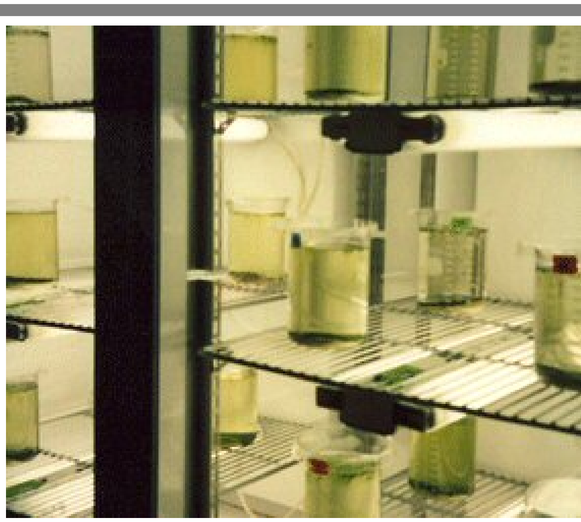

Water Sample Containing Microbial Organisms

access the full report of this study, see the References for Additional Information section at the end of this chapter.

FATE OF MICROORGANISMS IN AQUIFERS

The Fate of Microorganisms in Aquifers Study was jointly funded by the SFWMD and SWFWMD in 2001–2002 to investigate the survival of several groups of microorganisms used as public-health risk indicators in situations that may be encountered in the Floridan aquifer system, particularly through untreated surface water recharge into the aquifer, which is not envisioned for CERP ASR facilities.

The study has sought to fill data gaps in published literature on the survival and inactivation of a number of organism groups in the kind of conditions that might be encountered with ASR influence on the Floridan aquifer system. The study was limited to laboratory beaker-type (benchscale) experiments, simulating conditions that occur in the aquifer, although with some simplifications and assumptions. The next phase of work might involve conducting tests in the field, using diffusion chambers to test the survival of a group of test organisms in wells.



Benchscale Experiments of Microorganisms in Aquifers

Benchscale experiments provided a controlled set of situations to examine the behavior of these organism groups, with the intended purpose of both establishing actual survival rates in waters and conditions representative of the Florida environment, and to clarify some of the factors that may affect the length of survival of organisms. Results from these experiments were analyzed to describe some important factors influencing the variability of inactivation via statistical tests. Information about observed inactivation was used to estimate some possible persistence times under the conditions found in Florida groundwater or surface water that may be recharged underground. It is anticipated that the results of this report will provide a foundation for informed decision-making about the future direction of studies on public-health microorganism survival in subtropical groundwater environments, and ultimately, help clarify some of the unknown potential impacts of untreated surface water injection to aquifers. Some of the results of the study were:

- Total dissolved solids (TDS) were not a significant variable for survival of any organism group.
- Temperature in TDS-temperature experiments had a statistically significant effect on all microbial inactivation.
- Fecal coliform, enterococci, DNA coliphage, PRD-1 and *Cryptosporidium* all experienced greater inactivation in surface water than in groundwater. In contrast, RNA coliphage and *Giardia* experienced greater inactivation in groundwater than surface water.
- For fecal coliform, 2-log (99%) inactivation was predicted over periods of 2–6 weeks in groundwater and 1–2 weeks in surface water; enterococci predictions ranged from 1–5 weeks in groundwater and about 1 week in surface water sources.
- The parasites and the DNA coliphage were much more resistant than the fecal coliform or enterococci. It would take an estimated 7 months to achieve 99 percent reduction of *Giardia* cysts in surface waters, while 1–4 months would be required for DNA coliphage and *Cryptosporidium oocysts*.
- Bacterial or coliphage indicators are not adequate indicators of the risks potentially associated with the increased survival of the enteric protozoa.
- Site-specific monitoring of sites using water containing these organisms should be required until survival behavior in field conditions can be better defined.

TERMINOLOGY

Coliphage
A class of viruses that specifically infect bacteria living in the lower intestines of mammals.

PRD-1
A strain of virus that only infects bacteria and is routinely used in studies about how microorganisms are transported through a variety of groundwater environments.

Enterococci (group)
A group of bacteria that are commonly used to determine the probability of surface and groundwaters being contaminated from feces. This group of bacteria is relatively tolerant of salt concentrations making it the choice fecal indicator group when analyzing brackish and marine waters.

Cryptosporidium
A protozoan parasite that infects the intestinal tracts of humans and other vertebrates.

Cryptosporidium oocyst
A spore-like phase of the protozoan pathogen, which causes a diarrheal illness. In this state, the parasite can survive for lengthy periods outside a host and can resist many common disinfectants, notably chlorine-based disinfectants.

Giardia
A protozoan parasite that infects the gastrointestinal tracts of humans and other vertebrates.

Enteric protozoa
Single-celled microorganisms of, relating to or being within the intestines.

To access the full report of this study, see the References for Additional Information section at the end of this chapter.

SUMMARY

Samples from the Floridan aquifer system were collected at three CERP ASR pilot projects to assess the abundance, viability, productivity, and genetic diversity of the native bacterial populations in the Floridan aquifer system. In another study, benchscale experiments were performed to determine the potential fate of nonnative microorganisms in the Floridan aquifer system, especially through untreated surface water recharge into the aquifer. Both studies provide baseline data for further investigations, and were useful in documenting various biological components of interest during operation of an ASR system.

FUTURE DIRECTIONS

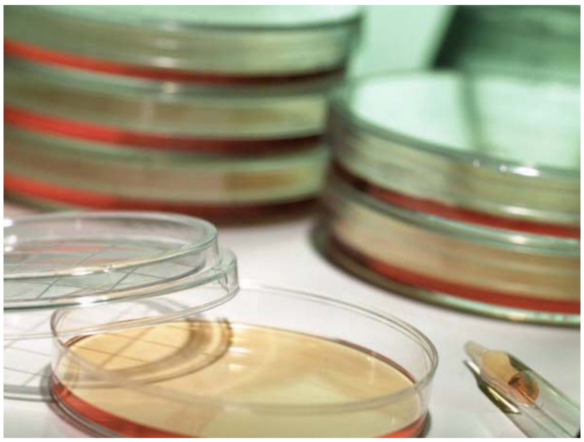
The CERP has made a commitment to fully disinfect the recharge water at all of the ASR pilot project sites. It remains to be seen what impact the recharge water will have on the ambient microbial population in the aquifer. Therefore, a comprehensive bio-geochemical monitoring and testing program has been developed for the cycle testing phase of the pilot projects when cycle testing begins at these ASR systems. These tests will "bridge the gap" between lab experiments that have been conducted and actual water subjected to geochemical reactions at the ASR pilot project sites. Cycle testing is described in the Future Directions section of **Chapter 2**.

REFERENCES FOR ADDITIONAL INFORMATION

* see enclosed CD

John, D.E., J.B. Rose and A. Kamarainen. 2004. *Survival of Fecal Indicator Bacteria, Bacteriophage and Protozoa in Florida's Surface and Ground Waters—Potential Implications for Aquifer Storage and Recovery*. University of South Florida, Tampa, FL, and Michigan State University, East Lansing, MI. Prepared for the SFWMD, West Palm Beach, FL, and SWFWMD, Brooksville, FL. (* chap7_asr_fate_of_microorganisms_study.pdf)

Lisle, J. 2005. *Characterization of the Native Microbial Communities in Floridan Aquifer Waters Targeted for Aquifer Storage and Recovery (ASR) Applications, South Central Florida.* USGS, Open File Report 2005-1036, pp.29, Tallahassee, FL.



ASR Requires Careful Research

"**What is good** for one part of the system may or may not be good for another, necessitating careful research on the unique needs of distinct ecosystems."

The Science of Restoring the Everglades, National Research Council, 2003.

8

Ecological Studies

POINTS OF INTEREST

- Several years of water quality, habitat, plant, sediment, insect, macroinvertebrate, mollusk, and arthropod data were collected at each of the pilot project locations. These data will serve as a baseline for future conditions as these systems are tested, setting a foundation for sound ecological impact prediction.
- Ecological studies of varying mixtures of Floridan aquifer water with surface water did not show toxic effects on organisms, and showed only minimal effects on reproduction or absorption of chemicals, except when the most extreme concentrations of solutions were used.
- Recovered water samples collected from an operational ASR system near the Hillsboro ASR Pilot Project showed no toxic effects on organisms and will provide a baseline for comparison as the Hillsboro site initiates cycle testing.
- A mobile bioconcentration laboratory was constructed that can be transported to a variety of ASR sites during cycle testing as recovered water is collected.
- An Ecological Risk Assessment is now under development, which will be used to evaluate the potential environmental impacts that could be associated with water recovered from CERP ASR systems, should they be constructed.
- A preliminary mercury assessment conducted by the USGS suggested that ASR recovered water will not likely result in added mercury to the ecosystem. Mercury will continue to be monitored as the pilot projects undergo cycle testing.

Based on the scale of the proposed CERP ASR Program, the potential exists for significant physical, chemical, and biological changes to the south Florida ecosystem. The ASR Issue Team identified two ecological issues associated with the implementation of regional-scale ASR facilities, which were re-phrased as questions by the Committee on the Restoration of the Greater Everglades Ecosystem (CROGEE) in their 2000 review of draft ASR plans for the Lake Okeechobee and the Western Hillsboro areas:

1. What water-quality changes will result from movement and storage in the aquifer, and will the quality of the recovered water pose environmental or health concerns?

2. What is the potential impact of recovered water on mercury in the south Florida surface environment?

To investigate the ecological impact of regional ASR implementation, study planners composed of biologists, chemists, environmental engineers, and ecologists developed a tiered approach involving the progressive integration and synthesis of monitoring, research, and modeling studies. While the majority of the planned investigations require operational (cycle testing) water-quality data from the ASR pilot projects, several tasks were completed prior to this Interim Report. This chapter discusses the ecological and water-quality tasks under way or completed to date. These tasks include baseline water-quality and ecological assessments, initial ecotoxicological studies, and a preliminary mercury methylation investigation.

TERMINOLOGY

Ecotoxicology The study of the pathways of exposure, uptake, and effects of chemical agents on organisms, populations, communities, and ecosystems.

Lake Okeechobee

BASELINE ECOLOGICAL ASSESSMENT AND MONITORING

One of the first tasks initiated as part of the ASR Regional Study was the development of a Baseline Environmental Monitoring Plan. This will make it possible to assess potential impacts from the pilot projects relative to baseline conditions when they become operational. Baseline monitoring and assessment took place at each pilot project location and consisted of the following:

- Quarterly collection of water-quality samples, including analysis for all basic water chemistry parameters and regulatory standards
- An initial (and annual) ecological/habitat assessment of each pilot project site, including development of a Florida Department of Environmental Protection Stream Condition Index and Vegetative Index of Wetland Condition

- Deployment of sensors to continuously record temperature, dissolved oxygen, conductivity, and pH in the canals adjacent to the pilot projects
- Quarterly collection of plants, sediments, and macroinvertebrates, including mollusks, insects, and arthropods
- Quarterly collection and assessment of fish community structure (conducted cooperatively with the Florida Fish and Wildlife Conservation Commission)

TERMINOLOGY

Macroinvertebrate
Aquatic invertebrates, including insects, crustaceans, mollusks, and worms, which inhabit a river channel, pond, lake, wetland or ocean.

The data from the baseline ecological assessment have been compiled and included in a report entitled *CERP ASR Baseline Environmental Monitoring Summary Report*.

ECOTOXICOLOGY INVESTIGATIONS

The CROGEE (2001 and 2002) recommended, "ecotoxicological studies, including long-term bioassays, be conducted at the field scale to evaluate the ecological impacts of water-quality changes" caused by the use of ASR technologies in south Florida. During 2004, the SFWMD initiated studies to evaluate ecotoxicological test methods and the following discussion summarizes the selection of screening tests, bioconcentration methods and subsequent data development using these screening tests at a public utility using ASR recovered water.

TERMINOLOGY

Bioassay
A method for quantitatively determining the concentration of a substance by its effect on a suitable animal, plant, or microorganism under controlled conditions.

Bioconcentration
The accumulation of a chemical in tissues of an organism to levels greater than that in the surrounding environment.

Phase I Screening-level Method Development

The objective of the Phase I study was to develop a set of tests to evaluate the toxicity and/or bioconcentration potential of ASR recovered waters that will be discharged into surface waters. The results of this study were used to determine the need for additional method development and to define screening-level testing of ASR pilot projects when the ASR wells become functional. Acute and chronic toxicity studies were performed using sensitive fish, frog, and invertebrate early-life stages. Bioconcentration methods using fish and freshwater mussels were also evaluated, tested, and selected.

TERMINOLOGY

Toxicology
The study of poisons, including their nature, effects, and detection, and methods of treatment.

The source of potential toxicity or bioconcentration could be from chemicals present in the recovered waters, and high ionic content and/or ionic imbalance of these waters (in particular, groundwater).

Phase I Aquatic Toxicity Studies

Aquatic Toxicity Testing

To evaluate the potential toxicity of ASR discharges, ASR recovered water was needed. Phase I of the ecotoxicological study was conducted prior to ASR pilot project cycle testing, therefore ASR recovered water was not available. To conduct the toxicity screening-level studies, groundwater and surface (source) water samples from an ASR pilot site were used. Groundwater samples from the Floridan aquifer system were collected from an exploratory well associated with the Caloosahatchee River ASR Pilot Project in Hendry County. Surface water samples were collected from a nearby canal (potential source water for the pilot). A benchscale treatment system designed to mimic the pre-treatment process prior to well recharge was used to generate "treated water" for testing. Screening toxicity tests were then performed on the following water mixtures:

- Laboratory control water
- Surface water, (no treatment)
- Treated surface water (sand filtration, pH adjustment, ultraviolet disinfection)
- 20% Floridan aquifer system groundwater with treated surface water
- 50% Floridan aquifer system groundwater with treated surface water
- 80% Floridan aquifer system groundwater with treated surface water
- 100% Floridan aquifer system groundwater

The following toxicity assays were used in the initial range-finding tests:

- 7-day Chronic Fathead Minnow, *Pimephales promelas*, Embryo-larval Survival and Teratogenicity (gross morphological deformities), USEPA Test Method 1001.0
- 7-day Chronic Daphnid, *Ceriodaphnia dubia*, Survival and Reproduction, USEPA Test Method 1002.0
- 21-day Daphnid, *Daphnia magna*, Life-cycle Toxicity Test, ASTM: E1193-97
- 96-hour Frog Embryo Teratogenesis Assay-*Xenopus* (FETAX), ASTM: E1439-98

TERMINOLOGY

Chronic Assay
A long-term study, usually to determine the potential effects of chemicals on particular organisms.
ASTM
Originally known as the American Society for Testing and Materials (ASTM), ASTM International is one of the largest voluntary standards development organizations in the world.

The aquatic toxicity tests were completed successfully. Overall, the benchscale full strength ASR treated surface water did not have any quantifiable toxic effect on survival, reproduction, or embryological development on any species or endpoint measured. However, full strength (100%) groundwater showed a statistically significant reduction in reproductive rate for *C. dubia*. Because it is not anticipated that 100 percent Floridan aquifer system groundwater is going to be discharged from an ASR well, the observation of full strength groundwater effect is not considered an ecological issue for ASR discharges. In all cases, once the groundwater was diluted with 50 percent treated surface water, no effect was quantifiable for any species tested. As all tests met the guidelines required by the cited methods and water quality of the surface and treated water did not result in a quantifiable effect on the species selected, no changes to the proposed battery of toxicity tests were recommended.

Phase I Bioconcentration Study

Freshwater mussel, *Elliptio buckleyi*
Standard Test Species

Trace metals and radium present in ASR recovered water released to the surface have the potential to bioconcentrate in aquatic organisms. A preliminary study was performed in Phase I to evaluate the uptake of metals by fish and mussels exposed to treatment solutions. The treatments were laboratory control water, untreated surface water, treated surface water, and Floridan aquifer groundwater.

TERMINOLOGY

Radium
A naturally occurring radioactive element that forms from the decay of uranium. The isotope ^{226}radium is the most abundant form.

The ASTM International method for conducting bioconcentration tests with fishes and saltwater bivalve mollusks was used for these tests. Twenty-eight day tests were conducted during the wet (March–April 2005) and dry (June–July 2005) seasons under continuous flow conditions in order to evaluate the applicability of the methods and develop initial data on bioconcentration potential of surface water and groundwater at the Caloosahatchee River ASR Pilot Project site.

The results showed that trace metals (arsenic, selenium, cadmium, and mercury) and radium (isotopes 226 and 228) concentrations in fish and mussel tissue were similar for all treatments at the end of the exposure (controls: full strength groundwater, full strength untreated surface water, and full strength treated surface water). These tissue concentrations were not statistically higher than the background tissues (prior to exposure). In other words, the trace metals and radium evaluated in these studies did not bioconcentrate in fish or mussel tissues during the 28-day exposure tests. It should be noted that the low background concentrations for these chemicals were found in the water samples tested.

The fish species bluegill (*Lepomis macrochirus*) used in this study proved to be a good choice given its ready adaptation to laboratory conditions, as well as its widespread existence within south Florida surface waters. The mussel species used in this study, *Elliptio buckleyi*, was also a good choice, as it adapted well to laboratory conditions, accepted an algal diet and was easy to handle. Given the desire to test not only standard laboratory species, but also species found in Florida habitats, the choice of *E. buckleyi* for the bioconcentration testing proved to be a robust approach. The study conclusion indicated that both of the species used in the development of the bioconcentration protocols are acceptable and recommended for use in future bioconcentration studies when the pilot projects start cycle testing.

Phase II Studies

Phase II of the ecotoxicology investigation focused on:

1. Application of the Phase I toxicity tests to water recovered from an operational ASR system
2. Design and construction of a mobile bioconcentration laboratory
3. Development of a preliminary conceptual ecological model of ASR discharges on aquatic systems

Toxicity Tests at Eastern Hillsboro ASR System

To better understand the potential effects of CERP ASR recovered waters, the Eastern Hillsboro ASR well system was selected for testing using the ecotoxicity test methods developed during Phase I. This ASR system, operated by Palm Beach County Water Utilities Department, was selected because of its proximity to the Hillsboro Canal ASR Pilot Project and the timing of its recovery cycle. The aquatic toxicity series of tests were conducted using recovered water from the Eastern Hillsboro ASR well. In addition, acute toxicity testing was performed using the following standard fish and invertebrate species tests required by the *Comprehensive Everglades Restoration Plan Regulation Act* (CERPRA) Permit for the ASR pilot projects:

1. Daphnid, *C. dubia*, Acute Toxicity USEPA Test Method 2002.0
2. Bannerfin shiner, *Cyprinella leedsi*, Acute Toxicity USEPA Test Method 2000.0

The results of the Phase II testing showed only limited effects on the organisms. The fathead minnow (*P. promelas*) test demonstrated 80 percent survival in the 80 percent recovered / 20 percent control water blend, which was statistically different from the controls (95% survival); but no statistical difference in survival was observed in the 100 percent recovered water. The effect observed in the 80 percent dilution, although statistically significant, may not be ecologically significant or directly related to the ASR technology based on the acceptable survival in 100 percent recovered water. Seventy-five percent survival was observed in the full strength source water (Biscayne aquifer). The FETAX (frog embryo) test showed a statistically significant reduction in growth for the 100 percent recovered water; the reduction in embryo length (5.4%) may not be biologically significant and will be investigated further through toxicity testing during CERP ASR cycle testing. The 7-day chronic bioassay with *C. dubia* showed no effect in comparison to the controls, and the 21-day *D. magna* life-cycle test showed no effects as compared to the controls. The results from testing required by the CERPRA permits showed no toxicity for any mixture of surface water or recovered water. Overall, the results of the Phase II testing confirmed that the aquatic toxicity methods developed in Phase I are appropriate to evaluate the toxicity of recovered water from the pilot projects during cycle testing.

Mobile Bioconcentration Laboratory

To perform the ASR source and recovered water bioconcentration tests, water needs to flow continuously through a series of exposure aquaria. The bioconcentration tests require hundreds of gallons of water for the planned 4-week test duration. Therefore, a mobile laboratory for on-site testing was designed and constructed to minimize logistics challenges, conduct onsite studies and provide testing flexibility for field studies.

Mobile Bioconcentration Laboratory

The mobile laboratory consists of a 20-foot trailer custom fit with a bench, sink and exposure aquaria. The water distribution system allows for the needed volume replacements per day, and provides controlled temperature conditions. Prior to a recovery event, the mobile laboratory will be transported to the site and set up to conduct bioconcentration studies using source water as it is being recharged into the well. When the pilot projects begin recovery of recharged water, the mobile laboratory will again be used to conduct bioconcentration studies of the recovered water. The source and the recovered water results will be compared as part of the evaluation of potential changes to water quality due to ASR technology.

Conceptual Ecological Model of the Ecological Risk Assessment

Conceptual ecological models can be used to help visualize potential ecological risks and benefits that could result from human activities, such as ASR use is south Florida. A preliminary conceptual ecological model (**Figure 21**) was developed to initiate the "ecological risk assessment" to be performed later as part of the ASR Regional Study. This conceptual ecological model has been developed to illustrate the relationships between biological components found in south Florida water bodies, such as Lake Okeechobee and the large canals used to manage the system.

> **TERMINOLOGY**
>
> **Conceptual Ecological Model**
> A set of relationships among certain factors that could impact or cause a certain result. Conceptual models present the working hypotheses that explain current ecological linkages between stressors and attributes in these systems.
>
> **Ecological Risk Assessment**
> An organized procedure to evaluate the likelihood that ecological effects will occur as a result of exposure to stressors related to human activities, such as release of ASR recovered water.
>
> **Stressor**
> Any physical, chemical, or biological entity that can induce an adverse response (synonymous with agent).
>
> **Receptor**
> The ecological entity exposed to the stressor.

The conceptual ecological model will be used to show the potential changes in water quality due to the use of ASR technologies. The model will also be used to evaluate how the stressors (constituents of concern) present in ASR recovered water can affect various components of the environment through various pathways (water, sediments, or organic reactions).

The conceptual ecological model is part of the problem formulation phase of the ecological risk assessment, a process to organize and analyze data, information, assumptions, and uncertainties to evaluate the likelihood of adverse ecological effects arising from ASR. The problem formulation is currently being developed as part of Phase III of the ecotoxicology study.

Though still in the development phase, the conceptual ecological model and problem formulation for the ecological risk assessment will be completed in time for initial pilot project testing.

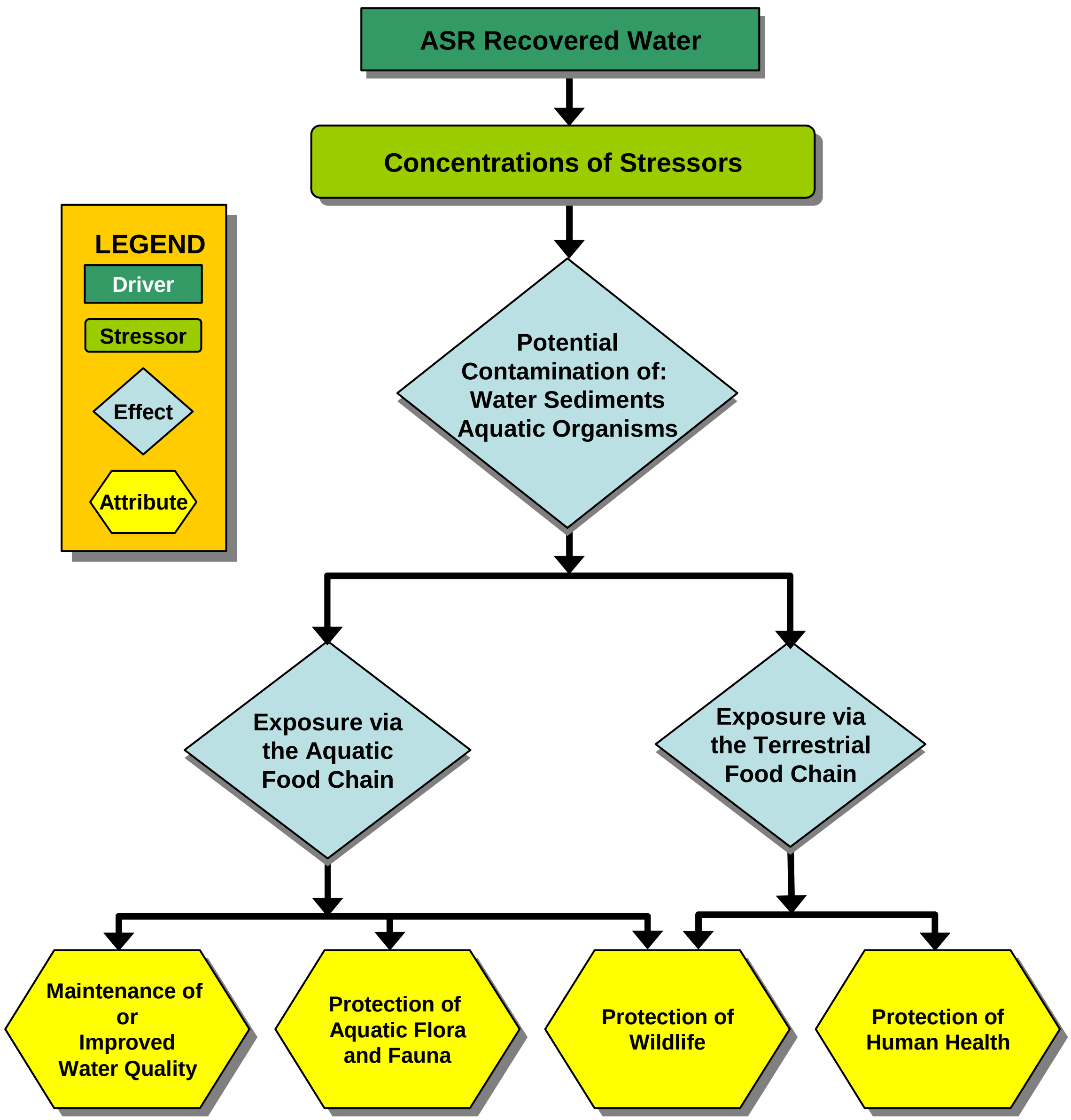


Figure 21. Preliminary Conceptual Model for Human Health and Ecological Risk Assessment.

PRELIMINARY METHYLMERCURY EVALUATION

TERMINOLOGY

Methylmercury
Short for "monomethylmercuri-cation," methylmercury is an organometallic (chemical compound containing bonds between carbon and a metal) cation. It is composed of a methyl group (CH_3-) bonded to a mercury atom; its chemical formula is CH_3Hg^+ (sometimes written as $MeHg^+$ or MeHG).

Cation
An ion with a positive charge.

Mercury contamination of aquatic ecosystems is a worldwide issue, and especially in some portions of the Everglades, where conditions appear optimal for mercury to accumulate in fish and wildlife to levels of concern. As the overall understanding of the sources of mercury contamination has progressed, scientists have found that many factors, which do not necessarily affect overall mercury concentrations, can have profound effects on mercury toxicity in some settings. Such is the case in south Florida, where researchers have demonstrated that hydrologic factors, like flooding and drying cycles or changes to carbon and sulfur cycling, can hasten the conversion of mercury to methylmercury, the most toxic form of mercury in the environment. Given that the CERP ASR Program will contribute to altering hydrologic patterns, as well as carbon and sulfur cycling patterns, the implementation of this technology could increase mercury availability within the Greater Everglades ecosystem, and therefore, carbon and sulfur cycling patterns need to be studied.

An initial methylmercury investigation was conducted by the U.S. Geological Survey (USGS) of the possible effects of the CERP ASR Program on mercury concentrations within the Greater Everglades ecosystem. The project used field sampling and controlled benchscale experiments. The field sampling survey gathered groundwater samples from ASR target aquifers to determine background levels of mercury and methylmercury and to find any spatial trends of these concentrations in the aquifers. Laboratory experiments were used to determine how the recharged surface water would react in the aquifer during storage.

Overall, concentrations of total mercury and methylmercury in both the Floridan and surficial aquifer systems are very low, with no apparent spatial trends in either aquifer. These results suggest that ASR recovered water would not represent a significant additional direct load of mercury and methylmercury to receiving waters. Because the Floridan aquifer system generally has elevated concentrations of sulfate, and surface waters near Lake Okeechobee are elevated in organic carbon and sulfate, some potential exists for increased methylmercury production from the release of ASR recovered water to areas in or near the Everglades.

Chemical results from samples collected from the Floridan aquifer system are significantly higher in conductivity, sodium, chloride, and sulfate concentrations as compared to the samples from the surficial aquifer system. Of these constituents, sulfate is of primary concern. Analytical results show that the native brackish (salty) Upper Floridan aquifer water is about five times higher in sulfate concentration than the surficial aquifer water or typical south Florida surface water. Recovered water from a functioning ASR facility in south Florida could likely contain sulfate concentrations, which when in contact with surface water having high total organic carbon concentration, could stimulate methylmercury production.

Laboratory experiments were conducted to assess whether net methylation and/or net changes in sulfate and total organic carbon might occur during storage periods. Test results suggest that mercury and methylmercury are removed in groundwater by sorption to the mineral surfaces. These results further suggest that although sulfate reduction occurred under experimental conditions, and is likely occurring in the surficial and Upper Floridan aquifers, natural methylmercury levels are quite low and net methylation was not observed.

Overall, the low levels of total mercury and methylmercury observed in field samples collected from shallow and deep aquifers in southeast Florida suggest that recovered water from the envisioned CERP ASR will not likely result in added mercury loads to receiving ecosystems. However, there is concern for elevated levels of sulfate in the recovered water, which if released to the Everglades and its adjoining ecosystems, could result in methylmercury production in excess of baseline conditions. Operational and technological measures need to be considered to avoid or minimize this potential condition. Follow-up mercury methylation studies will be conducted during the ASR pilot cycle testing to further address the impact of recovered water on methylation dynamics in the receiving water. These studies will be integrated into the final ecological risk assessment.

SUMMARY

A Baseline Environmental Monitoring Plan has been developed to assess potential impacts of the pilot projects when they become operational. In addition, a series of chronic toxicity studies were performed on sensitive fish, frog and invertebrate species to determine the potential toxicity of CERP ASR recovered waters that may be discharged into the surface ecosystem. Protocols to evaluate the potential bioconcentration of chemicals found in ASR recovered water were developed using a fish and a mussel species. To perform the bioconcentration tests on-site, a mobile laboratory was designed and built and is available for use when the pilot projects begin recovery cycles. Though still in the development stage, a conceptual ecological model is nearing completion as part of the ecological risk assessment of ASR technology use in south Florida. Additionally, the USGS has completed an initial methylmercury investigation of the possible effects of the ASR program on mercury concentrations and bioavailability within the Greater Everglades ecosystem. These results will also be integrated into the human health and ecological risk assessments to ensure that people and wildlife can have full use of the water resources supplied with ASR recovered water.

FUTURE DIRECTIONS

The three most fundamental questions yet to be answered as part of the ASR Regional Study ecological risk assessment are:

1. What are the critical stressors?
2. What are the critical receptors?
3. What is the extent of exposure?

In the context of this study, stressors are defined as those physical and chemical conditions that when altered as a result of ASR discharges, will affect the receptors (valued ecosystem components). The degree of environmental impact is directly related to the extent of receptor exposure to stressors. Originally, the ASR Regional Study was designed to use water-quality and ecological data from five ASR pilot sites. To date, only two of these sites have been constructed and are expected to be operated prior to the completion of the ASR Regional Study. Though there are fewer available ASR sites from which to gather data, the ASR Project Team will still evaluate the system-wide impacts that result from ASR implementation. To perform the system-wide evaluation, the team will integrate ecotoxicological and water-quality data collected at the two pilot sites with several numerical simulation models and other information from non-CERP ASR facilities to predict the potential ecological risk and benefits of CERP ASR.

Ecotoxicological Testing During Cycle Testing

TERMINOLOGY

Bioaccumulation
The process by which organisms absorb chemicals or elements directly from their environment.

During recovery at the pilot sites, samples from the recovered water will be collected on a routine basis in order to characterize the quality of the water as it is discharged to the environment. Acute/chronic toxicity tests, as well as bioaccumulation tests will be conducted using various blends of recovered water and surface water. Bioconcentration studies will be conducted onsite using the mobile bioconcentration laboratory.

Phase III Problem Formulation for the Ecological Risk Assessment

The problem formulation process for the ecological risk assessment will assist in the selection and development of additional experiments that will provide meaningful results when the pilot projects become operational. The ecological risk assessment will be used to analyze both positive and negative affects that ASR operations will have on the environment.

> **TERMINOLOGY**
>
> **Periphyton**
> The biological community of microscopic plants and animals attached to surfaces in aquatic environments. Algae are the primary component in these assemblages, which naturally reduce phosphorus levels in water and serve a key function in stormwater treatment areas.

As part of the ongoing problem formulation process for the ecological risk assessment, all studies are being re-evaluated based on additional water-quality data and ongoing exposure modeling (described in the following section). Additional plant and periphyton studies are being considered for the pilot projects to address longer-term water-quality changes, while recognizing that CERP ASR facilities are not envisioned to operate continuously, except perhaps during long-term droughts. The goal of all the ecotoxicological testing will be to derive site-specific information that relates stressor concentration with receptor effects.

Prediction of Receptor Exposure to Stressors

> **TERMINOLOGY**
>
> **Near Field**
> The habitat immediately downstream of ASR discharges.
> **Far Field**
> The receiving body downstream of the near field exposure area.
> **Far-Far Field**
> The third water body or habitat zone downstream of ASR discharges.

As part of the ecological risk assessment, exposure characteristics will be predicted for near field, far field, and far-far field. The most important far field water body is Lake Okeechobee. The most important far-far field habitat is the northern portion of the Everglades Protection Area. The following models are expected to be used:

1. **Density-Dependent Groundwater Flow Models** – Combine site-specific hydrogeologic conditions, water-quality data, and CERP ASR recharge and recovery flows to predict recovered water quality as a function of time. This modeling will be done using inset versions of the regional groundwater models.
2. **Near Field Mixing Models** – Combine flow and concentration output from the groundwater model with receiving water hydraulic conditions to predict nearfield exposure potential as a function of time.

3. **Far Field Mixing Models** – Used to predict dispersion and transport of ASR related stressors for Lake Okeechobee. Possible models include a simple mass balance simulation model or the Lake Okeechobee Environment Model that incorporates hydrodynamic processes.
4. **Far-Far Field Mixing Models** – Used to predict dispersion and transport of ASR related stressors from Lake Okeechobee to the northern Everglades Protection Area. Of particular interest to the study team is the prediction of far-far field sulfate concentrations given this stressor's role in mercury methylation dynamics.

Overall Study Plan

Figure 22 presents a flow chart of the ASR ecological studies envisioned for this project. The final human health and ecological risk assessment will integrate the numerical modeling efforts with the pilot site ecotoxicological testing and field results. Potential human health impacts will be integrated into the assessment using the results of the fish consumption study and the predicted exposure of fish to ASR stressors. The ecological impact of ASR water treatment technology resulting from sludge disposal, chemical transportation, and energy consumption will also be investigated as part of the final risk assessment.

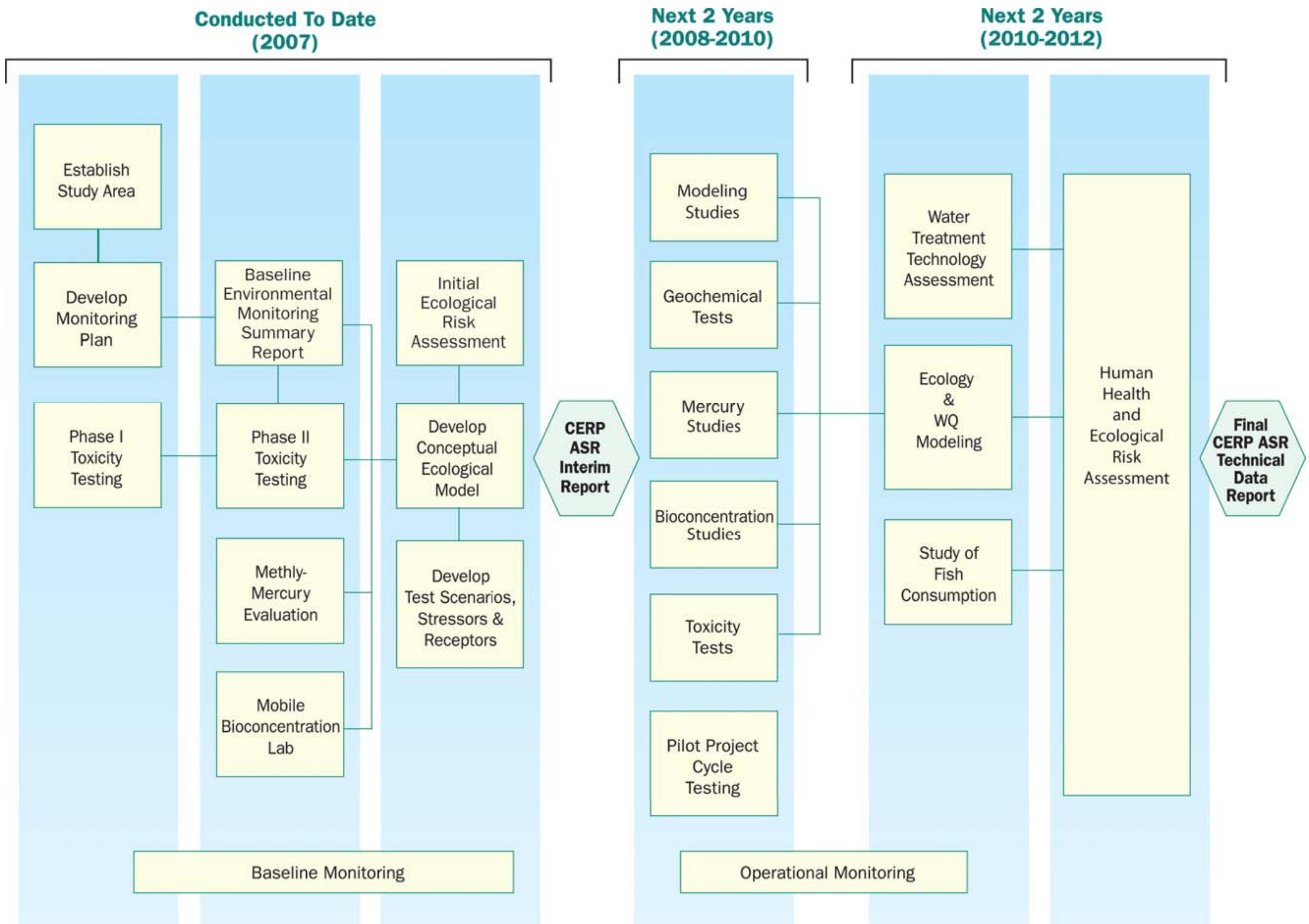


Figure 22. ASR Ecological Studies Plan Flow Chart.

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Alligators in the Everglades

The ecological restoration of the Everglades and the south Florida ecosystem is a challenging and significant environmental initiative. Essential to restoration is a way to capture and store water during wet periods, and then redistribute water to replenish ecosystems during dry periods. Through adaptive management, ASR is being studied to better understand how this technology can be implemented safely and successfully for Everglades restoration.

9

Plan Formulation

This Interim Report presents information that will be used, along with data collected from future studies, to assess the technical feasibilities of CERP ASR implementation. As additional investigations are performed and refinements made to the regional-scale groundwater model, the number of ASR wells to be considered may vary from the 333 wells envisioned in the CERP ASR Program. The results of these studies and regional model simulations may require the evaluation of other potential areas for ASR implementation, or alternatives, should the ASR program not perform on the regional scale envisioned in the CERP.

Hillsboro Canal ASR Pilot Project

This chapter discusses the development of ASR performance measures to evaluate the ASR program as new findings become available. Future efforts are also presented, including the ASR Optimization Study and the ASR Contingency Study, should CERP ASR implementation not be feasible as originally envisioned.

ASR PERFORMANCE MEASURE DEVELOPMENT

As stated in the ASR Regional Study Project Management Plan (ASR Regional Study PMP), one of the study objectives is to use a plan formulation process to "recommend a technically feasible or optimal ASR alternative with consideration and evaluation of well cluster alternatives, geographical alternatives within the CERP study area, alternative facility configurations, and implementation phasing and sequencing." The specific plan formulation tasks identified in the PMP include:

- Establish well siting
- Develop evaluation criteria
- Develop regional model

- Develop and simulate alternative ASR plans
- Evaluate performance of alternatives

The well siting and regional model development efforts are discussed in **Chapter 5** of this Interim Report. The remaining tasks—develop evaluation criteria, simulate alternative ASR plans, and evaluate performance of alternatives—are integral to the plan formulation process. These efforts are discussed in more detail following the Plan Formulation Process section. The technically feasible plan(s) recommended by the ASR Region Study will form the foundation for future project implementation report efforts.

Plan Formulation Process

The plan formulation process to be performed for the ASR Regional Study will generally follow the traditional federal six-step plan formulation process. The plan formulation process is the systematic development and evaluation of alternative plans based on study goals and objectives. This process is consistent with the CERP adaptive management approach described in **Chapter 1** of this document and as illustrated in the following diagram. The effects of alternative plans are evaluated based on objectives and constraints using study-specific evaluation criteria, leading to modifications to the plans followed by additional evaluation. The final iteration should produce cost-effective alternative plans with maximum benefits and minimum potential adverse impacts within the study constraints.

The USACE plan formulation process follows six-steps as follows:

1. Identify problems and opportunities.
2. Inventory and forecast resources.
3. Formulate alternative plans.
4. Evaluate plan effects.
5. Compare effects of alternative plans.
6. Select best plan (outside of the scope of the ASR Regional Study).

As more information is acquired during the study, some of the previous steps may need to be repeated. Iterations of steps are conducted as needed to formulate optimal, effective, complete, and acceptable plans.

The plan formulation process for the ASR Regional Study will essentially complete Steps 1–4 to assess risk factors. This information will be used to compare alternative plans and select project-specific plans in the individual ASR Project Implementation Reports (PIRs) that will follow the ASR Regional Study. These plans will be developed for the Caloosahatchee River Basin ASR PIR, the Hillsboro Canal ASR PIR, the Lake Okeechobee ASR PIR and the Palm Beach

County Agriculture Reserve ASR PIR using plan formulation processes tailored for each PIR.

The interagency ASR Project Team has identified a Plan Formulation and Evaluation Criteria Sub-Team to more fully define and perform the plan formulation tasks identified in the Project Management Plan. These efforts are largely focused on Steps 1-4 of the plan formulation process. The first task is to develop evaluation criteria.

Develop Evaluation Criteria

The Evaluation Criteria and Plan Formulation Sub-Team will develop criteria to evaluate the effects of the potential regional ASR implementation plans. The criteria will be used primarily to evaluate results from regional groundwater model simulation runs. The regional groundwater model is the repository for all of the hydrogeologic information gathered as part of the ASR Regional Study. The plan formulation process will be used to formulate alternative CERP ASR well configurations that will be simulated using the regional groundwater model. The model will provide data for parameters, such as hydraulic pressure and salinity. These effects will be evaluated using the criteria developed by the sub-team. The criteria may include target ranges that define feasible alternative plans for further evaluation and refinement during project implementation report efforts.

The regional groundwater model results may also be used with the ecological risk assessment model (see **Chapter 5**: Groundwater Modeling and **Chapter 8**: Ecological Studies) and possibly other surface water-quality modeling to evaluate the effects of the alternative CERP ASR well configurations on regional ecological resources and surface water quality. In addition to the models, other knowledge and information obtained from the ASR pilot projects (recharge and recovery rates, power consumption, etc.) and other ASR Regional Study efforts (such as mesocosms, mixing models, etc.) may be used in the evaluation of the alternative plans.

> TERMINOLOGY
>
> **Mesocosm**
> A partially enclosed experimental vessel designed to simulate the natural environment to help bridge the gap between laboratory studies and real-world impacts.

When applicable, CERP system-wide performance measures will be used to evaluate alternative plans. The performance measures are scientifically-based indicators of conditions that are characteristic of a healthy, restored ecosystem. The CERP system-wide performance measures were developed by the Restoration Coordination and Verification (RECOVER) group to predict system-wide performance of alternative plans and assess actual performance following implementation. RECOVER will assist the ASR Project Team with this effort.

Simulate Alternative ASR Plans

The evaluation criteria developed by the sub-team will be used with the results from the regional groundwater model. As previously discussed, the regional groundwater model will be used to simulate alternative ASR plans (well configuration and cycle operation scenarios). The Project Management Plan has identified the first alternative to be simulated and evaluated as 50 million gallons per day (MGD) ASR systems at each of the proposed CERP ASR sites. The 50-MGD increment was preliminarily selected because it is greater than that currently used at operational ASR facilities in Florida, yet significantly smaller than regional CERP ASR implementation. It represents a conservatively sized wellfield cluster (10, 5-MGD ASR wells) that could be serviced by a single water treatment facility. This approach bridges the significant gap between the size of the pilot projects and regional-scale CERP ASR, thereby encouraging economies of scale in water treatment facilities and allowing for a more desirable phased approach to CERP ASR implementation. Therefore, this first alternative would be the step increment for adding or subtracting wells to the regional groundwater model. Subsequent simulation runs will increase and/or reduce the number of wells at some or all of the sites. Additional sites for potential ASR implementation may also be evaluated, depending on simulation run results and more refined storage needs for other CERP components.

Evaluate Performance of Alternatives

The regional groundwater model simulation runs for the various alternative ASR plans will generate output data for parameters that will include hydraulic pressure and salinity. These results will be evaluated using the criteria developed by the sub-team. For example, the salinity data generated by a simulation run could be evaluated against a risk-based range of acceptable values. If the salinity is generally within the acceptable range defined by the evaluation criteria, the alternative might be considered feasible for salinity. Similar evaluations would be completed for other criteria, including perhaps extrapolations to CERP system-wide performance measures using the ecological risk assessment model or other surface water modeling. Alternatives that meet the targets established for the evaluation criteria/performance measures would be considered a feasible well configuration for CERP ASR implementation. Again, an iterative approach would be used to identify additional alternative plans.

SUMMARY

The ASR Regional Study is developing a comprehensive groundwater-modeling tool that will incorporate detailed information compiled for the regional aquifer system. Cycle testing data to be obtained at different pilot project sites will provide additional information to refine the model and be considered when developing alternative plans. Further, a system-wide analysis will be conducted by RECOVER to determine the potential effect of the alternative plans on the ecosystem.

Chapter 10 provides an assessment of the CERP ASR Program's progress in providing answers to the questions raised by the ASR Issue Team and the Committee on the Restoration of the Greater Everglades Ecosystem (CROGEE). The chapter also highlights the major accomplishments of the ASR program.

FUTURE DIRECTIONS

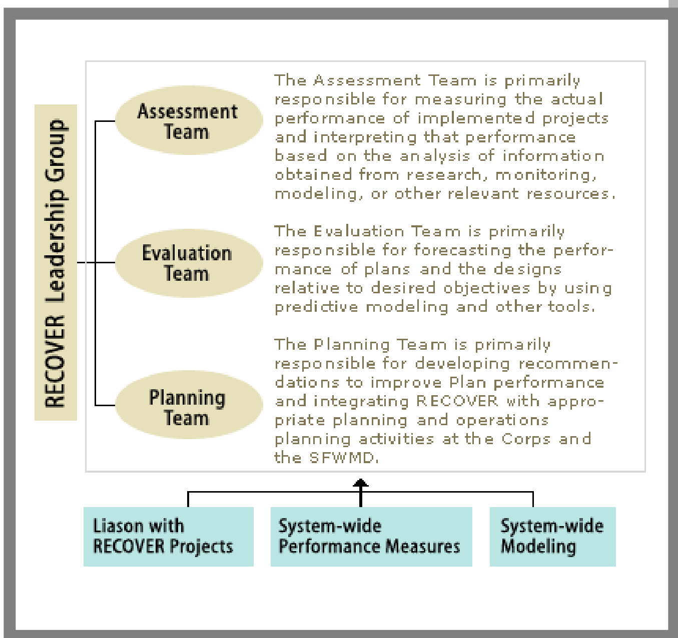
Modeling will continue to be performed to investigate the feasibility of various changes to the proposed CERP ASR Program should studies show that ASR is not feasible on the scale currently envisioned.

ASR Optimization Study

In the event that groundwater modeling results show that fewer ASR wells can be implemented, an optimization modeling effort will be conducted as part of the ASR Regional Study during the plan formulation process. For example, fewer wells could be operated for longer durations or wells could be operated at times that are more opportune to maximize operational efficiency. Future development and refinement of an optimization model may reveal a potential for significant cost savings.

ASR Contingency Study

Although the ASR Contingency Study is a separate project from the ASR Regional Study, it deals with the possibility that some or all 333 ASR wells might not be installed, and therefore, additional projects and technologies may need to be implemented to compensate for the desired benefits resulting from planned regional-scale ASR. It is believed that ASR will work almost anywhere in south Florida on some scale and with some degree of efficiency. However, ASR studies and pilot projects may reveal that the ASR program may not perform on the scale envisioned in the CERP. An ASR Contingency Study is being performed to investigate the mitigation of hydrologic effects on Everglades restoration if ASR is implemented at a level less than originally envisioned in the CERP.



The CERP system-wide performance measures, developed by RECOVER, are scientifically-based indicators of conditions that are characteristic of a healthy, restored ecosystem. These performance measures are used to predict system-wide performance of alternative plans and assess actual performance following implementation. RECOVER will assist the ASR Project Team with this prediction and assessment of ASR to formulate a plan that achieves the approved performance levels of the CERP.

10

The CERP ASR Program Report Card

In summary, numerous scientific investigations have taken place over the past five years as part of the CERP ASR pilot projects and ASR Regional Study. Accomplishments include the following:

- Exploratory wells were constructed and permitting and design of ASR pilot systems were initiated at five separate locations in south Florida. Two of these ASR pilot project systems have been constructed and are about to become operational.
- A large hydrogeologic database was completed and a hydrogeologic framework of the Floridan aquifer system in south Florida was developed. In doing so, data gap areas were identified where additional information was needed, and numerous geological and geophysical investigations were conducted to fill in the missing information.
- A deeper understanding was gained of the geochemical and biological reactions that can take place within the aquifer. Testing programs were developed to further evaluate how these reactions may impact the quality of water recovered from the CERP ASR systems.
- Phase I modeling was completed and development began on the Phase II transient groundwater flow model that will be used to predict the potential subsurface effects of the proposed CERP ASR Program on south Florida.
- A baseline source water-quality and environmental monitoring program was completed and several preliminary ecological tests were conducted to assess the environmental impacts of the implementation of CERP ASR.

HIGH POINTS

To date, no "fatal flaws" have been uncovered as a result of this study that might hinder the implementation of CERP ASR. The Hillsboro Canal and Kissimmee River ASR Pilot Projects sites have been designed, permitted, constructed, and are about to become operational. The information gained from cycle testing at these facilities will be critical in determining the local-scale effects of ASR operation, and water recovered from these systems will be subjected to a battery of experiments to evaluate the potential effects of ASR water on the environment. One concern, however, is that a drought may limit the duration and volume of the planned cycles, which could lengthen the time it takes to complete the testing.

A new, updated hydrogeologic understanding of the Floridan aquifer system has been developed and many data gap areas have been filled in using test wells and a variety of geophysical techniques. A preliminary fracturing study has indicated that ASR's potential for "breaking" the formations is low, as long as recharge pressures are kept reasonable. State-of-the-art groundwater models are now under development to forecast with precision the local and regional effects of simulated ASR systems.

An extensive water-quality and ecological monitoring program has been developed to document conditions prior to and during ASR pilot system testing. The ecological tests conducted to date have indicated that water to be used for and recovered by ASR wells is not inherently toxic to a variety of test organisms. A preliminary assessment has concluded that ASR systems are not likely to add mercury to the south Florida ecosystem.

LOW POINTS

The exploratory wells at the Caloosahatchee River ASR Pilot Project in Hendry County indicated that high-capacity ASR wells cannot be implemented at this site. Future opportunities to site an ASR system in the Caloosahatchee Basin will be assessed as new locations for additional storage are identified. In addition, funding for the Port Mayaca and Moore Haven ASR Pilot Project sites has been delayed; however, it is expected that construction of the Port Mayaca multi-well facility may be initiated in the near future. Future funding may be affected by other CERP priorities in the next few years.

Arsenic remains a potential challenge for existing and future ASR systems. Although there are technologies to treat the water before it is supplied, technologies are being researched to prevent arsenic from being leached within the aquifer. In addition, the ASR Project Team will work with regulators to demonstrate that reactions within the aquifer can be managed and that administrative or institutional controls can be put in place so the public and the environment can benefit from this important technology.

THE REPORT CARD

ASR Report Card

The ASR Project Team includes members of the South Florida Water Management District (SFWMD); the U.S. Army Corps of Engineers (USACE); the Florida Geological Survey (FGS); the U.S. Geological Survey (USGS); the U.S. Fish and Wildlife Service (USFWS); and others. During the past few years, the ASR Project Team has debated how far the ASR program has progressed in answering each question posed by the ASR Issue Team and implementing the recommendations of the CROGEE. The ASR Project Team's deliberation and consensus on the progress achieved for each item is reflected in the "CERP ASR Program Report Card," as shown in **Table 2**. The CERP ASR Program Report Card indicates that strong progress has been made on several items, while the progress of many items is dependent on data from three important data sources—cycle testing of the pilot projects, the groundwater model and the ecological risk assessment—which will be forthcoming in the next few years.

Table 2. The CERP ASR Program Report Card, February 2008.

Issue Team Items - 1999	% Progress Addressing Issue									
	10	20	30	40	50	60	70	80	90	100
Characterize the quality/suitability/variability of source waters										
Characterize the regional hydrogeology and water quality of the Floridan aquifer system										
Analysis of critical pressure for rock fracturing										
Analysis of site and regional changes in head and flow patterns										
Analysis of water-quality changes during movement and storage										
Potential effects on mercury bioaccumulation										
Relationship between storage zone properties, recovery rates, and recharge volume										
CROGEE Recommendations - 2001										
Compile available datasets for regional assessment										
Develop a regional-scale groundwater flow model										
Drill exploratory wells, including cores, geophysical logs, hydraulic tests, and water-quality sampling										
Seismic reflection surveys										
Develop a siting approach										
Bioassay and ecotoxicological studies										
Characterize organic carbon in water to anticipate biogeochemical reactions										
Laboratory studies to evaluate dissolution reactions in the aquifer matrix										
Studies designed to understand mixing within the aquifer										
CROGEE Recommendations - 2002										
Increase number of monitor wells at pilot sites and expanded cycle test duration										
Increased emphasis on geochemical reactions										
Community and ecosystem-level ecological effect analysis										
Extended duration of bioassay testing and biological impact monitoring										
Expanded ecosystem modeling										

THE PATH FORWARD

The next few years will be a challenging time for the CERP ASR Project Team as cycle testing begins at the Hillsboro Canal and Kissimmee River ASR Pilot Project sites. These tests will provide field data to augment scientific and engineering studies that have been conducted and will help to determine:

- Optimal operations to maximize storage and recovery
- The effectiveness of water treatment technologies prior to recharge
- Water-quality changes that take place during recharge, storage, and recovery
- The potential for mercury bioaccumulation from recovered water
- The relationship between storage zone properties and recovery efficiency
- An understanding of the water-rock mixing and geochemical reactions within the aquifer
- The impact of recovered water on the ecology through extended bioassay testing, monitoring, and ecosystem modeling

When the groundwater modeling results become available, they will be used to:

- Evaluate the potential groundwater impacts that a regional-scale ASR system, as envisioned in the CERP, may have on south Florida
- Analyze the local and regional-scale changes in groundwater heads and flow directions
- Determine the potential for effects due to pumping withdrawals or pressurizing the aquifer
- Predict regional water-quality changes within the aquifer
- Propose locations, the number of ASR wells, and facilities that optimize benefits and minimize or eliminate potential risks

The conceptual ecological model will provide insight to understanding the relationships between potential stressors and receptors on the environment resulting from CERP ASR. The model will be an important step toward performing an ecological risk assessment that will reveal the potential environmental benefits and risks that might occur from the proposed CERP ASR Program.

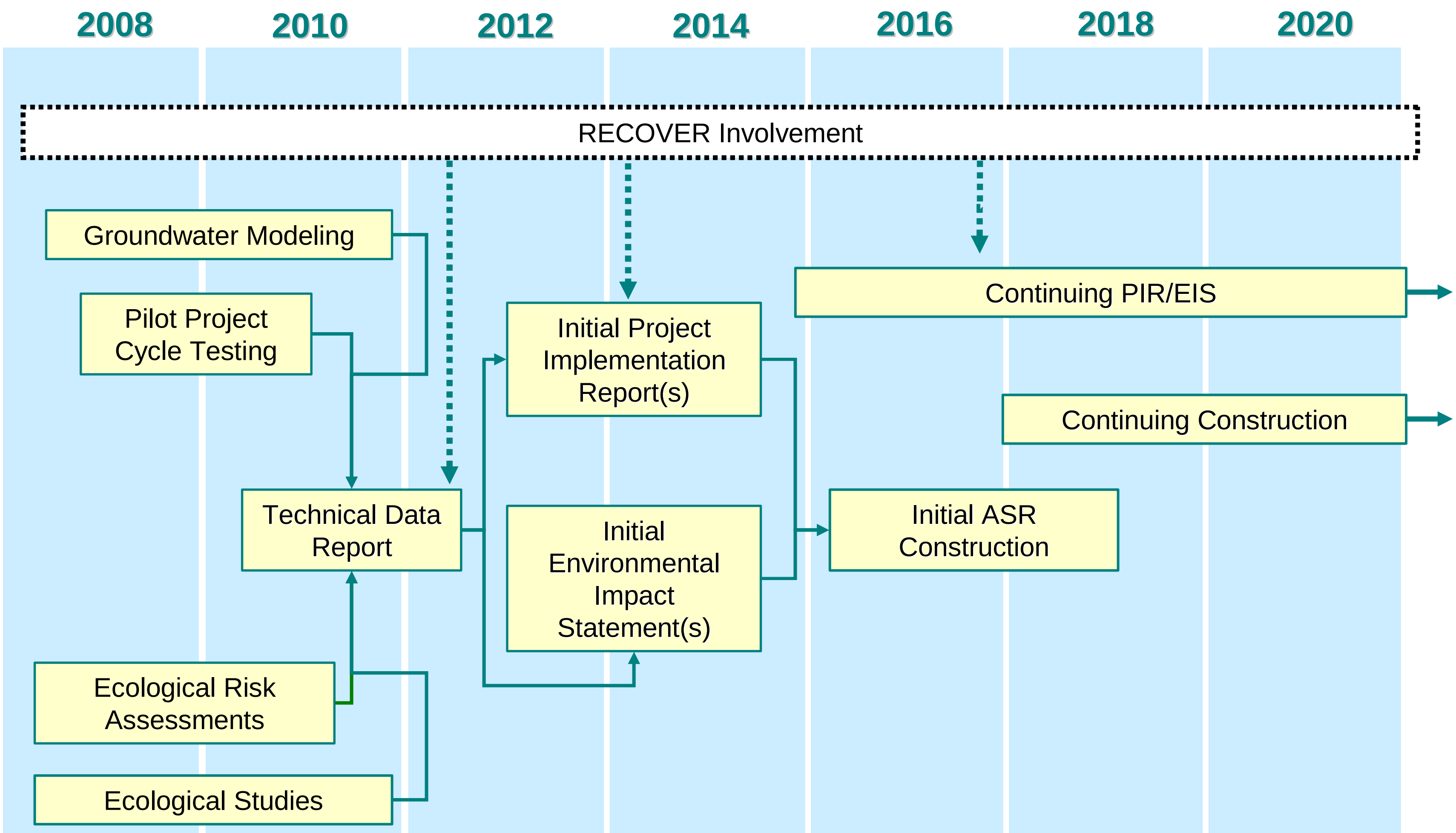


Figure 23. CERP ASR Program Schedule.

Glossary

Alkalinity Refers to the extent to which water or soils contain soluble mineral salts. Waters with a pH greater than 7.4 are considered alkaline.

American Society for Testing and Materials (ASTM) ASTM International is one of the largest voluntary standards development organizations in the world.

Anisotropy The condition under which one or more of the hydraulic properties of an aquifer vary unequally according to the direction of the flow.

Aquifer An underground body of porous materials, such as sand, gravel, or fractured rock, filled with water and capable of supplying useful quantities of water to a well or spring.

Arthropod An invertebrate having jointed limbs and a segmented body with an exoskeleton made of chitin.

Assay A procedure where a property of a system or object is measured.

Bacteriophage Any one of a number of virus-like agents that infect bacteria.

Bioaccumulation The process by which organisms absorb chemicals or elements directly from their environment.

Bioassay A method for quantitatively determining the concentration of a substance by its effect on a suitable animal, plant, or microorganism under controlled conditions.

Bioconcentration The accumulation of a chemical in tissues of an organism to levels greater than that in the surrounding environment.

Biofilm A complex aggregation of microorganisms held in place on surfaces by an exo-polysaccharide layer (protective and adhesive matrix) that is excreted by the microorganisms.

Biolog EcoPlate™ A community-level physiological profile created specifically for community analysis and microbial ecological studies.

Borehole A hole bored or drilled into the earth, as an exploratory well; a small-diameter well drilled especially to obtain water.

Cation An ion with a positive charge.

Chronic Assay A long-term study, usually to determine the potential effects of chemicals on particular organisms.

Coliform bacteria Colon bacilli, a commonly-used bacterial indicator of sanitary quality of foods and water.

Coliphage A class of viruses that specifically infect bacteria living in the lower intestines of mammals.

Conceptual Ecological Model A set of relationships among certain factors that could impact or cause a certain result. Conceptual models present the working hypotheses that explain current ecological linkages between stressors and attributes in these systems.

Confining unit A relatively low permeability geologic unit that impedes the vertical movement of water.

Core Sample/Corehole A core sample is a cylindrical section of rock or sediment obtained by drilling into the medium with a hollow steel tube called a corer. The hole made for the core sample is called a corehole.

Cryptosporidium A protozoan parasite that infects the intestinal tracts of humans and other vertebrates

Cryptosporidium oocyst A spore-like phase of the protozoan pathogen, which causes a diarrheal illness. In this state, the parasite can survive for lengthy periods outside a host and can resist many common disinfectants, notably chlorine-based disinfectants.

Ecological Risk Assessment An organized procedure to evaluate the likelihood that ecological effects will occur as a result of exposure to stressors related to human activities, such as release of ASR recovered water.

Ecotoxicology The study of the pathways of exposure, uptake, and effects of chemical agents on organisms, populations, communities, and ecosystems.

Embryological/Embryology The study of the development of an organism from the zygote, or fertilized egg.

Enteric protozoa Single-celled microorganisms of, relating to or being within the intestines.

Enterococci (group) A group of bacteria that are commonly used to determine the probability of surface and ground waters being contaminated from feces. This group of bacteria is relatively tolerant of salt concentrations making it the choice fecal indicator group when analyzing brackish and marine waters.

Framboid/Framboidal A microscopic aggregate of pyrite grains, often occurring in spheroidal clusters.

Geologic unit A geologic unit is a volume of rock or ice of identifiable origin and age range, which is defined by the distinctive and dominant, easily mapped and recognizable petrographic, lithologic, or paleontologic features that characterize it.

Geophysical Log A record of the structure and composition of the earth with depth encountered when drilling a well or similar type of test or boring hole.

Giardia A protozoan parasite that infects the gastrointestinal tracts of humans and other vertebrates.

Hydrogeologic unit Any rock unit or zone that, because of its hydraulic properties has a distinct influence on the storage or movement of groundwater.

Hydrophone A device attached to a seismic cable (streamer) used to record sound signals that are reflected back from structures within rock.

Hydrostratigraphic unit Bodies of rock with considerable lateral extent that act as a reasonably distinct hydrologic system.

Hydrostratigraphy A geologic framework consisting of a body or rock having considerable lateral extent and composing a reasonably distinct hydrologic system.

In Situ An environmental measurement taken in the field, without removal of a sample to the laboratory.

Ion An atom or group of atoms that have lost or gained one or more electrons, making them negatively or positively charged.

Isotope One of two or more atoms with the same atomic number, but with different numbers of neutrons.

Landsat Program The Landsat Program is a series of Earth-observing satellite missions jointly managed by the National Aeronautics and Space Administration (NASA) and the U.S. Geological Survey (USGS). Since 1972, Landsat satellites have collected information about Earth from space. This science, known as remote sensing, has matured with the Landsat Program.

Land Subsidence The sinking or settling of land to a lower level in response to various natural and man-caused factors, such as earth movements; lowering of fluid pressure (or lowering of groundwater level); removal of underlying supporting materials by mining or solution of solids, either artificially or from natural causes; compaction caused by wetting (Hydrocompaction); oxidation of organic matter in soils; or added load on the land surface. With respect to groundwater, subsidence most frequently results from overdrafts of the underlying water table or aquifer and its inability to fully recharge.

Lineament A linear topographic feature that might result from a subsurface fault or zone of fractures.

Lithology The scientific study and description of rocks, usually with the unaided eye or with little magnification; the structure and composition of a rock formation.

Macroalgae Large-celled, photosynthetic algae that act as a natural water filter by reducing the available levels of phosphate and nitrogenous waste.

Macroinvertebrate Aquatic invertebrates including insects, crustaceans, mollusks, and worms, which inhabit a river channel, pond, lake, wetland, or ocean.

Mesocosm A partially enclosed experimental vessel designed to simulate the natural environment to help bridge the gap between laboratory studies and real-world impacts.

Methylate/Methylation A chemical process for introducing a methyl group into an organic compound. If a constituent of water is methylated, a methyl radical group is substituted into its chemical structure.

Methylmercury Short for monomethylmercury, more correctly "monomethylmercuric cation," is an organometallic (chemical compound containing bonds between carbon and a metal) cation. It is composed of a methyl group (CH_3-) bonded to a mercury atom; its chemical formula is CH_3Hg^+ (sometimes written as $MeHg^+$ or MeHG).

MODFLOW A modular, three-dimensional, finite-difference groundwater modeling code created by the USGS, which is used to simulate the flow of groundwater through aquifers. The SFWMD uses it for subregional groundwater modeling.

Mole The mass in grams of this amount of a substance, numerically equal to the molecular weight of the substance.

MT3DMS A modular, three-dimensional multispecies transport model for simulating advection, dispersion, and chemical reactions of contaminants in groundwater systems.

Oxyhydroxide Commonly known as rust**,** the oxide that is formed by open-air oxidation of iron.

Paleontologic/Paleontology The study of the forms of life existing in prehistoric or geologic times, as represented by the fossils of plants, animals, and other organisms.

Periphyton The biological community of microscopic plants and animals attached to surfaces in aquatic environments. Algae are the primary component in these assemblages, which naturally reduce phosphorus levels in water and serve a key function in Stormwater Treatment Areas.

Permeability The capacity of a porous rock, sediment, or soil for transmitting a fluid.

Petrographic/Petrography The description and classification of rocks.

pH A measure of the acidity or alkalinity of a solution, numerically equal to 7 for neutral solutions, increasing with increasing alkalinity and decreasing with increasing acidity. The pH scale commonly in use ranges from 0 to 14.

Phosphorite A sedimentary rock composed chiefly of phosphate minerals.

Plug flow A type of flow that occurs in tanks, basins, or reactors when a slug of water moves through without ever dispersing or mixing with the rest of the water flowing through.

Porosity A measure of the void spaces in a material as a fraction, between 0–1, or as a percentage between 0–100 percent. In rock, the porosity, or space, can be between grains or within cracks or cavities of the rock.

PRD-1 A strain of virus that only infects bacteria and is routinely used in studies about how microorganisms are transported through a variety of groundwater environments.

Radium A naturally occurring radioactive element that forms from the decay of uranium. The isotope ^{226}radium is the most abundant form.

RECOVER REstoration, COordination and VERification. RECOVER is an interagency, interdisciplinary team designed to comprehensively monitor, assess, and coordinate CERP activities relative to CERP goals.

Redox Shorthand for reduction/oxidation reaction; describes all chemical reactions in which atoms have their oxidation state change.

SEAWAT A program developed to simulate three-dimensional, variable-density, transient groundwater flow in porous media. The source code for SEAWAT was developed by combining MODFLOW and MT3DMS into a single program that solves the coupled flow and solute-transport equations.

Sea Water Intrusion (SWI) Package A code for modeling regional seawater intrusion with MODFLOW. Its main advantage is that each aquifer can be modeled with a single layer of cells.

Seismic Tomography The process whereby a computer first synthesizes data on the velocities of seismic waves from thousands of recent earthquakes to make a series of images depicting successive planes within the Earth, and then uses these images to construct a representation of the Earth's interior.

Specific Conductance A measure of the ability of water to conduct an electrical current.

Stratigraphy The branch of geology that deals with the definition and description of major and minor natural divisions of rocks, and the interpretation of these divisions in terms of origin, occurrence, environment, thickness, lithology, composition, fossil content, age, history, paleogeographic conditions, relation to organic evolution, and relation to other geological concepts.

Teratogenesis Related to biological deformities, congenital malformations, or grossly deformed individuals.

Tomography Geophysical imaging by sections or sectioning. A device used in tomography is called a "tomograph," while the image produced is a "tomogram."

Toxicology/Toxicological The study of poisons, including their nature, effects, and detection, and methods of treatment.

Transmissivity The ability of an aquifer to transmit water.

Trihalomethane Any of several synthetic organic compounds formed when chlorine combines with organic materials in water during the disinfection process.

Turbidity The measure of suspended material in a liquid.

Unconformity An unconformity forms the boundary between rock masses of two different ages.

WASH123D A three-dimensional, finite-element, variable-density computer code that simulates water flow and contaminant and sediment transport in coupled surface water and groundwater systems.

Appendix A

FREQUENTLY ASKED QUESTIONS

What is Aquifer Storage and Recovery?

Q How does ASR work?

A Aquifer storage and recovery (ASR) is the practice of managed recharge using a dual-purpose well for both recharge (pumping water into an aquifer) and recovery (pumping water out of the aquifer). In south Florida, most ASR systems store treated drinking water in the Floridan aquifer system, which contains brackish (salty) water. The water is pumped through a well casing, down into the Floridan aquifer system, causing the water to be pushed into the holes of the rock around the well. The fresh water pumped into the well displaces the brackish water naturally surrounding the well.

The brackish water in the aquifer radiates away from the well as fresh water is pumped into the formation. Generally speaking, the water in the aquifer will radially spread away from the well to a distance of less than one mile.

Q Is ASR a new technology?

A No. Artificial recharge of aquifers has been used in the United States since the 1940s. The first ASR system in the United States was constructed in 1968 in Wildwood, New Jersey. The states of California, Florida, Nevada, New Jersey, and Texas now have multiple ASR systems. On a global scale, ASR systems have been or are currently under construction in Canada, England, The Netherlands, Israel, and Australia.

Q How deep are ASR wells?

A The total depth of ASR wells in the South Florida Water Management District (SFWMD or District) generally ranges between 700 and 1,300 feet below land surface. The depth depends on several factors, including the location of the well. Typically, ASR wells are shallower in the northern sections of the SFWMD and get deeper toward the south.

Q At what rate can water be stored in and pumped out of an ASR well?

A Within the SFWMD, existing ASR wells can store water at a rate ranging from less than 1 million gallons per day (MGD) to about 10 MGD, depending on availability of excess surface water. Generally speaking, an ASR well is designed to pump out water at the same rate the water was pumped into the well, depending on water needs. However, in some cases, the well operator may choose to pump out at a lower rate.

Q How much water can an ASR well store?

A Theoretically, there is no limit to the amount of water that can be stored by an ASR well. One of the benefits of ASR is that water can be recharged and stored in wells over multiple seasons and multiple years during periods of excess water and recovered during periods of water need, such as during droughts. Therefore, the storage capacity available from ASR is nearly infinite as compared to reservoirs, which are limited in size because of land acquisition costs and design considerations; and moreover, the stored water will not be subject to evaporation.

The limitation of ASR lies with the amount of water that can be recovered at the location where it was recharged. In other words, as more water is pumped into the well, the water migrates farther away from the well. The water that travels the farthest from the well may not be recoverable.

Q How long can water be stored before it moves away from the well?

A The answer depends on many factors. The principal factors involve artificial groundwater movement (how the well is operated) and the natural gradient in the aquifer. As water is pumped into the ASR well, the stored water is pushed away from the well. The more water that is pumped and the faster the water is pumped, the farther the water moves away from the well. Even without pumping, natural conditions within the aquifer affect groundwater movement. These natural conditions include hydraulic gradient and permeability. When the natural gradient and permeability are high, the stored water will more readily move away from the well. Conversely, low gradients and permeabilities result in slower movement.

Q What is a cycle?

A The process of recharge, storage, and recovery is called a cycle. Cycle tests serve as the primary means to analyze the feasibility of ASR on a pilot scale.

Q How much water can be recovered from an ASR well?

A The amount of water recovered from an ASR well depends on many factors, including the water quality of the recharged water, the ambient quality of water in the aquifer, and the hydrogeologic characteristics of the storage zone and confining zones. The most common method of computing the amount of water recovered is called the "recovery efficiency," which is the percentage of water stored in an operating cycle that is subsequently recovered in the same cycle, while meeting a target water-quality criterion in the recovered water. Recovery efficiency tends to improve with successive cycles when the same volume of water is stored in each cycle. This is because the residual water not recovered in one cycle becomes a transition, or buffer zone, of marginal quality surrounding the stored water in the next cycle.

The USGS recently concluded that several ASR systems in south Florida had attained recovery efficiencies between 10 percent and 90 percent. The systems with the highest recovery efficiencies were those that employed a "target storage volume" or water banking approach. This method involves recharging a large volume of water in an initial cycle, which flushes out the aquifer around the well and builds up a buffer zone that can maintain high recovery efficiencies in the following cycles using much lower recharge volumes.

Q What are the differences between ASR and deep injection wells?

A The differences are primarily in terms of purpose and depth. ASR wells are intended to store high-quality water for later retrieval. Deep injection wells are intended to dispose of unwanted water – never to be retrieved. The storage zones of ASR wells within the SFWMD are generally 500 to 1,300 feet below land surface. This is in contrast to the deep injection wells that generally dispose of water between 2,500 and 3,500 feet below land surface.

Q Is it difficult to permit ASR wells?

A Yes. Federal and state regulatory requirements are very stringent for ASR wells and several permits are needed to construct and operate ASR systems. These permits regulate the water pumped into and out of the well, as well as the discharge into the local water body. The permitting process generally takes more than one year for construction, and a permit for long-term operation depends on the results of the ASR cycle testing period.

The Comprehensive Everglades Restoration Plan and ASR

Q Why is ASR considered part of Everglades restoration?

A Aquifer storage and recovery is proposed in the Comprehensive Everglades Restoration Plan (CERP) as a significant storage and distribution component to improve quantity, quality, timing, and distribution of flows to the Everglades system. The Floridan aquifer system would act as a large underground reservoir. The potential advantages of using ASR technology for these objectives include:

- Reduces costs as compared to surface storage facilities
- Allows for continuous, multiseasonal/multiyear operation
- Eliminates water losses due to evapotranspiration and seepage
- Reduces water distribution costs by locating wells in areas of greatest need
- Minimizes land acquisition
- Provides the ability to recover large volumes of water during severe droughts, presumably when reservoir levels would be low

These advantages are particularly important in south Florida where land acquisition costs are high, the availability of water is seasonal, and the underlying Floridan aquifer system is geographically extensive.

Q How will ASR help restore the environment?

A ASR is intended to work in combination with the other CERP features to better manage the level of Lake Okeechobee, reduce harmful discharges to the St. Lucie and Caloosahatchee River estuaries, and restore the quality and timing of water deliveries to the Everglades, which should benefit the flora and fauna of south Florida.

Additionally, ASR offers the ability to store large quantities of water (similar to a large reservoir) for prolonged recovery periods. During times of severe drought, water recovered from ASR systems can provide supply and base flow to natural systems when there might otherwise be none.

Q How many ASR wells are proposed in the CERP?

A In the CERP ASR Program, 333 ASR wells are proposed, each with a target capacity of 5 MGD. The capacity of each well, however, will be dependent on several factors, including the hydrogeology of the site and the purpose of the well.

The number of wells in the CERP is based on a broad assumption that if each well can recharge and recover 5 MGD of water, then 1.7 billion gallons of water per day (BGD) can be captured, which otherwise would be discharged to tide, along with associated potential adverse impacts to the estuaries.

Q What will determine the actual number of wells in the CERP?

A The groundwater model and ecological risk assessment, described in **Chapters 5** and **8**, respectively of this Interim Report, will be used to evaluate the number of wells determined to be physically or environmentally beneficial. The results of these analyses will be used to develop the recommended number of ASR wells to be constructed under the CERP. The groundwater model will also be used to predict the cumulative effects on groundwater flow directions when all of the ASR wells are in operation.

Q Where are CERP ASR wells anticipated to be built and why?

A The CERP anticipates building the ASR wells near water bodies that can be withdrawn from during times of high discharge and flow – namely Lake Okeechobee, the Kissimmee River, the major canals in the SFWMD, and the reservoirs that will be constructed as part of the CERP and other environmental initiatives. Most of the ASR wells are located near Lake Okeechobee because the lake captures and retains the vast quantity of water that flows through the SFWMD, and it is essentially a large reservoir to supply the ASR component of the CERP, which otherwise would be discharged to tide. Other locations, such as the Caloosahatchee, Hillsboro, L-8 and C-51 basins, and central Palm Beach County have been found to have regional potential for ASR.

Q Will the CERP ASR wells impact existing wells?

A Perhaps. The CERP ASR wells will be designed and operated so as minimally impact existing wells. Any potential impact depends on the depth of the wells. The wells in close proximity to ASR wells and drilled to the same, or similar, depths as the ASR wells are expected to be most influenced. However, it is the intent not to locate or operate ASR wells that would cause significant impacts.

Q Can CERP ASR wells create sinkholes?

A No, not in south Florida. The ASR wells are not expected to create sinkholes at the proposed locations in the CERP. Sinkholes, where present in Florida, are relatively shallow surface features that form where there is direct connection between the surface and the Floridan aquifer system. In contrast, ASR wells will store water between 500 and 1,000 feet below land surface. In addition, throughout most of the SFWMD, hundreds of feet of silt and clay separate the deeper ASR zones from potential surface sinkhole features, eliminating direct connection between the surface and the Floridan aquifer system.

Q Will the water pumped into the CERP ASR wells cause the aquifer to burst?

A No. The existing ASR wells in Florida and throughout the world have indicated that this is not a concern. However, studies conducted and presented in this Interim Report have addressed this concern because of the large number of ASR wells that have been proposed in the CERP. These evaluations have shown that the higher pressures created by the ASR wells are not capable of bursting the aquifer or fracturing the layers above it.

The ASR Regional Study and CERP Pilot Projects

Q What is the ASR Regional Study?

A The ASR Regional Study has been developed to answer regional questions dealing with the effects of CERP ASR throughout south Florida.

Q What are the ASR pilot projects and their purpose?

A Five ASR pilot projects were initially planned for the CERP ASR Program – three at Lake Okeechobee (Kissimmee, Port Mayaca, and Moore Haven), one in the Caloosahatchee Basin, and one on the Hillsboro Canal in the Lower East Coast. The cost estimates for the three pilot projects at Lake Okeechobee indicated that the available budget authorized by Congress would be exceeded, so the Moore Haven site was deferred and construction of the Port Mayaca site was delayed. Later, the exploratory well at the Caloosahatchee Pilot Project site indicated that ASR was not feasible at that location.

The pilot facilities were formulated to answer many of the basic questions about how to design, permit, build, and test the high-capacity ASR systems envisioned in the CERP. Data gathered from the pilot systems will be used to determine whether larger, more efficient and cost-effective multi-well systems can be built. The pilot facilities will also serve as platforms for the ASR Project Team to conduct several scientific and engineering studies intended to answer uncertainties about the use of ASR technology as part of the CERP.

Q How does the ASR Regional Study tie into the pilot projects?

A The pilot projects serve as a basis for the ASR Regional Study by providing scientific and engineering information in the form of site-specific and nearby data for development of the groundwater model. The pilot projects will also provide recovered water to conduct many of the ecological and environmental tests needed for developing the ecological risk assessment, samples collection and groundwater measurements, which are part of the ASR Regional Study.

Q Why is it taking so long to complete the CERP ASR pilot projects?

A The project management plans for the ASR pilot projects and Regional Study took time to develop. The plans involved a multiagency team of scientists and engineers who collectively provided input to the programs that have been deployed and implemented. Numerous exploratory wells have been constructed, pilot projects have been designed, two of the pilot projects have been permitted and constructed, and many studies have been documented in response to the reviews by the Committee on the Restoration of the Greater Everglades Ecosystem (CROGEE). Studies to help determine the feasibility of implementing CERP ASR are proceeding in a logical, scientific, and objective manner. Project tasks still need to be performed for several years before conclusive findings and recommendations can be presented. Moreover, funding constraints affected the initial planned construction schedule.

Q Which pilot projects are scheduled for testing/operation?

A At this time, the Hillsboro Canal and Kissimmee River Pilot Projects sites will be ready for operation beginning in 2008. The cycle testing will take about two years, so it is anticipated that these projects will be complete by 2010. Annual funding from the U.S. Army Corps of Engineers (USACE) may be available in the near future to initiate construction of the pilot system at Port Mayaca.

Q Multi-well ASR facilities are being considered for the CERP, so why are the USACE and SFWMD constructing facilities with just one ASR well?

A When developing the project management plans for the pilot projects, the ASR Project Team determined that it was more important to test ASR over a broad area of south Florida to ascertain if ASR was feasible throughout the area of the CERP. As a result, the team decided to deploy several one-well systems as opposed to constructing fewer multi-well systems. Port Mayaca will be the only multi-well pilot facility to be constructed.

Q What water treatment technologies are being tested and why?

A The pilot projects are testing a self-cleaning screen and pressure-media filtration process. These two processes were evaluated as being most cost-effective in treating the surface water that would be pumped into the ASR wells. A new filtration technology is expected to be evaluated at the Port Mayaca Pilot Project facility. The disinfection process is in-line ultraviolet radiation, which is clean, effective, and does not result in disinfection by-products that are commonly associated with chlorine additives.

Q How will the information from the pilot sites help in addressing the uncertainties identified by the CROGEE?

A When pilot systems are operated and monitored, the recovered water can be analyzed in greater detail to answer important questions about hydrogeologic impacts, geochemical reactions, and the effect of the water on the ecosystem. These issues have all been raised by the CROGEE. The information from the pilot projects will be fed into the groundwater and ecological models to extrapolate the potential effects that possibly hundreds of ASR wells will have on south Florida. This information will be useful in recommending how many ASR wells should be constructed and where they should be deployed, while minimizing or eliminating ecological risk.

Q How long will it be before the CERP ASR wells are ready?

A It is estimated that most of the pilot projects will be complete in 2010 and that the final CERP ASR Program Technical Data Report will be complete by 2012. The Technical Data Report will provide information to be considered when developing Project Implementation Reports (PIRs), which would recommend the locations and numbers of wells to be constructed. The PIR may take up to three years to develop. The construction of the wells would be phased and would last until approximately 2020. Once constructed, the ASR wells will be ready for operation. The ASR Regional Study is expected to continue conducting scientific and engineering studies through 2020 to help ensure the safe operation of ASR facilities for environmental water supply.

ASR Costs

Q How much does ASR cost?

A The one-well pilot facilities constructed to date have cost between $4 million and $6 million per facility, which includes the ASR wells, associated monitoring wells and the water treatment systems. In addition to the capital costs to construct the systems, costs need to be determined to operate and maintain the systems. These costs will be determined over the two-year period of cycle testing that is about to begin at the Hillsboro Canal and Kissimmee ASR Pilot Project sites.

Q What size reservoir would be needed to replace an ASR facility?

A The ASR Contingency Study, described in **Chapter 9** of the Interim Report, will evaluate ASR alternatives, such as reservoirs. These alternatives will be highly dependent on location and other features that will be constructed and operated as part of Everglades restoration.

Q How much does ASR cost relative to other water supply options?

A A recent evaluation of the cost of various storage and supply alternatives by the USACE determined that CERP ASR will provide water at a cost of about $1–$2 per 1,000 gallons. This compares favorably with other options, such as desalination and surface reservoirs.

Q Is ASR too expensive to work effectively?

A No. Since ASR systems can provide for multiyear storage and recovery, they offer a solution that surface reservoirs cannot. ASR systems do not require the purchase of extensive tracts of land; therefore, the upfront capital outlays are not nearly as large as those required for surface reservoirs. In addition, CERP ASR would only recharge when there is excess water, such as during high flow events, and recover when there is water need, such as during water shortages. As a result, the per-gallon cost of water supplied by ASR compares very favorably with other storage technologies considered in the CERP.

ASR Water Quality

Q Will polluted water be pumped into the aquifer?

A No. The water that will be pumped into the ASR wells will come from Lake Okeechobee and the major canals within the SFWMD. The water will be treated through filtration and disinfection before being pumped into the wells to meet federal and state regulatory standards, which include Primary Drinking Water standards before being pumped into the aquifer. The treated recharge water will be cleaner than the water in its original state.

Q Will the water pumped into ASR wells contaminate the drinking water aquifers?

A No. The brackish water naturally found within the Floridan aquifer system is considered drinking water although it does not taste very good and requires extensive treatment before it can be acceptable for consumption. The water pumped into the ASR wells will be fresh water treated to federal drinking water standards, so it will be of higher quality than the water naturally found within the aquifer.

Q What is the quality of the water pumped out of the ASR well?

A The water pumped out of the well will be the treated fresh water most recently pumped into the well. The water will be extensively monitored to determine if any harmful or unanticipated chemicals have formed within the water while it was stored underground.

Q Where does the water go when it is pumped out of the ASR well?

A When the water is recovered, it will flow back into the same canal, reservoir, or lake from which it came. The state has rigid permitting requirements for discharging water into the surface waters, and the recovered water will be filtered or treated to meet those standards.

Q How is the water quality altered in the subsurface during ASR storage?

A The treated fresh water pumped into the ASR well is generally higher in dissolved oxygen. When it is pumped into the ASR well and into the aquifer, the water loses its dissolved oxygen. The water is generally devoid of oxygen as it is returned to the surface. Other reactions between water and the aquifer matrix tend to increase the total dissolved solids concentration of stored water.

Q How will ASR affect drinking water?

A The water pumped into ASR wells meets drinking water standards, so it is not anticipated to have any impact on existing drinking water supplies.

Q Is arsenic in ASR wells a problem?

A Yes. When the federal drinking water standard for arsenic was lowered from 50 parts per billion to 10 parts per billion in January 2006, arsenic became the primary concern that could affect the success of ASR technology in Florida. The Florida Department of Environmental Protection (FDEP) recently determined that the arsenic standard at ASR sites must be met at all times, including in the aquifer. Most ASR systems in Florida could meet the previous standard, but are having difficulty meeting the new standard at all times.

This poses a significant challenge to the long-term sustainability of ASR as an alternative water supply option in the state. If arsenic is mobilized within the aquifer, then it causes a violation of the permit to operate the ASR system.

Q Are there technologies to remove arsenic from recovered water?

A Yes. There are technologies to remove arsenic that might be in water recovered from an ASR system before it is released into the environment, or before it is supplied for drinking water purposes. Our efforts to date have been to try to understand the mechanisms that cause the arsenic mobilization within the aquifer in an effort to find possible ways to minimize mobilization and avoid additional expense for treatment technology. One such study is taking place at an ASR system in the City of Bradenton, which is discussed in **Chapter 6** of this Interim Report.

Q Will there be any public drinking water benefits from the CERP ASR Program?

A Perhaps. The ASR systems being constructed under the CERP are intended to be used primarily for environmental restoration. There may be surplus water beyond what is required for the environment, which may be available for other uses, such as public drinking supply or agriculture.

Q What technologies are being explored to reduce or avoid the release of chemicals from rocks into the recharged water?

A A technology designed to lower the amount of dissolved oxygen in treated fresh water prior to recharge into the aquifer is expected to be tested. The geochemical experts believe that by reducing the dissolved oxygen in the recharge water, the release of chemicals naturally present in the aquifer rocks can be avoided.

General Information

Q Are there any public safety issues associated with ASR?

A No. Because ASR systems are underground features and public access is typically not warranted or desired, they do not have public safety issues associated with aboveground reservoirs and impoundments, such as flooding due to dike failure.

Q What has been learned so far?

A This report documents the many tests that have been conducted to answer the questions posed by the experts in the scientific community. As the ASR pilot projects and Regional Study proceed, each new question will be responded to objectively in order to provide a technically sound, defensible recommendation for the implementation of the CERP ASR.

Q Can I attend and participate in ASR meetings?

A Yes. The public is invited to our project team meetings. During these meetings, time is set aside for the public to make comments about the project. Meeting schedules are available from: http://www.evergladesplan.org.

Q Where can I read about the ASR Regional Study and pilot projects?

A The project documents, including meeting minutes, the calendar of events, and other useful information are available on the CERP Web site available from: http://www.evergladesplan.org.

Q If CERP ASR is not feasible, what then?

A The ASR Contingency Study is being conducted to determine what alternatives could provide the same benefits as ASR. Most of the alternatives under consideration involve construction of surface water impoundments and reservoirs. As with all CERP projects, the final report for this study will be available to the public.

Q Why are the effects of recovered water on biological communities in surface waters being studied?

A The ASR Regional Study includes comprehensive ecological and water-quality monitoring to evaluate any potential effects. Experts are conducting scientific studies to address the uncertainties of the effect of ASR recovered water on biological communities and humans. Initially, a comprehensive study was conducted of the existing conditions where ASR pilot facilities were constructed. During cycle testing, additional studies at the pilot facilities will be conducted.

Q Are findings being shared and discussed with others investigating ASR technology?

A Yes. Many of the interagency scientists, engineers, and project managers on the ASR Project Team have been actively participating in statewide, national, and international conferences, as well as giving presentations and participating in workshops. Conferences include the Biennial International Symposium on Managed Aquifer Recharge and the Annual Aquifer Storage Recovery of the American Groundwater Trust. A recent National Academies of Science report of Managed Underground Storage recommended many activities that the CERP ASR Project Team is already conducting.

The enclosed CD contains this CERP ASR Program Interim Report, as well as supporting technical memos and reports, as noted by the asterisked references in the References for Additional Information sections of each chapter.

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.

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