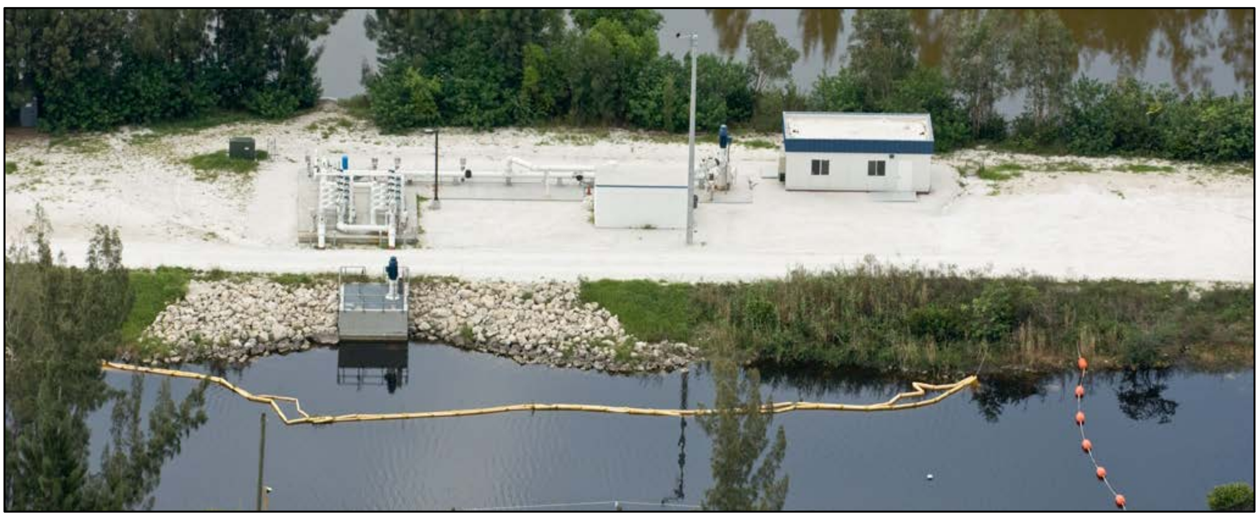
CENTRAL AND SOUTHERN FLORIDA PROJECT

COMPREHENSIVE EVERGLADES RESTORATION PLAN



FINAL TECHNICAL DATA REPORT

COMPREHENSIVE EVERGLADES RESTORATION PLAN AQUIFER STORAGE AND RECOVERY PILOT PROJECT

Kissimmee River ASR System

Hillsboro ASR System

December 2013

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AQUIFER STORAGE AND RECOVERY PILOT PROJECTS

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List of Acronyms

ACH	Aluminum Chlorhydrate
APPZ	Avon Park Permeable Zone
APT	Aquifer Performance Test
AO	Administrative Order
ASR	Aquifer Storage and Recovery
BLS	Below Land Surface
BTEX	Benzene, Toluene, Ethylbenzene, and Xylenes
C&SF	Central & South Florida
CERP	Comprehensive Everglades Restoration Plan
CERPRA	Comprehensive Everglades Restoration Program Regulatory Act
CROGEE	Committee on Restoration of the Greater Everglades Ecosystem
CTD	Conductivity – Temperature - Depth
CWA	Clean Water Act
DDR	Design Documentation Report
DMR	Discharge Monitoring Report
DO	Dissolved Oxygen
DOC	Dissolved Organic Carbon
DSL	Digital Subscriber Line
EDC	Engineering During Construction
EIS	Environmental Impact Statement
FAS	Floridan Aquifer System
FDEP	Florida Department of Environmental Protection
FETAX	Frog Embryo Teratogenesis Assay - *Xenopus*
FFWCC	Florida Fish and Wildlife Conservation Commission
FONS	Fiber Optic Network Solution
HASR	Hillsboro ASR Pilot System
HMI	Human Machine Interface
HDPE	High Density Polyethylene
HP	Horsepower
HPC	Heterotrophic Plate Count
HRT	Hydraulic Residence Time
HVAC	Heating, Ventilation, and Air Conditioning
I&C	Instrumentation and Control
IC_{25}	Inhibitory concentration to 25 percent of individuals tested
ICU	Intermediate Confining Unit
IEX	Ion Exchange Treated Water
KRASR	Kissimmee River ASR Pilot System
LAE	Limited Aquifer Exemption
LC50	Lethal concentration to half of the individuals exposed
LFA	Lower Floridan Aquifer

LNWR	Loxahatchee National Wildlife Refuge
LWDD	Lake Worth Drainage District
MC1	Middle Confining Unit 1
MC2	Middle Confining Unit 2
MCL	Maximum Contaminant Level
MDL	Method Detection Limit
MF	Microfiltration
MOR	Monthly Operating Report
NFPA	National Fire Protection Agency
NGVD29	National Geodetic Vertical Datum 1929
NOEC	No Observable Effect Concentration
NPDES	National Pollutant Discharge Elimination System
NTP	Notice to Proceed
ORP	Oxidation Reduction Potential
O&M	Operation and Maintenance
PBCWUD	Palm Beach County Water Utility Department
PDT	Project Delivery Team
PLC	Programmable Logic Controller
PMP	Project Management Plan
POD	Point of Discharge
PPDR	Pilot Project Design Report
PQL	Practical Quantitation Limit
RFI	Request for Information
RFP	Request for Proposal
RTU	Remote Terminal Unit
RW	Raw Water
SAS	Surficial Aquifer System
SCADA	Supervisory Control and Data Acquisition
SDWA	Safe Drinking Water Act
SF	Serial Filtration
SFWMD	South Florida Water Management District
SOP	Standard Operating Procedure
SZMW	Storage Zone Monitor Well
TCLP	Toxicity Characteristics Leaching Procedure
TDH	Total Dynamic Head
TDS	Total Dissolved Solids
TKN	Total Kjeldahl Nitrogen
TMDL	Total Maximum Daily Load
TN	Total Nitrogen
TOC	Total Organic Carbon
TP	Total Phosphorus
TSS	Total Suspended Solids

TSV	Target Storage Volume
UFA	Upper Floridan Aquifer
UIC	Underground Injection Control
UPS	Uninterruptable Power Supply
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
USDW	Underground Source of Drinking Water
UV	Ultraviolet
UVT	Ultraviolet Transmittance
VE	Value Engineering
VFD	Variable Frequency Drive
VOC	Volatile Organic Compound
VPN	Virtual Private Network
WCA	Water Conservation Area
WHO	World Health Organization
WQ	Water Quality
WQCE	Water Quality Criteria Exemption
WRDA	Water Resources Development Act

UNITS

ACFM	actual cubic feet per minute
ac-ft	acre-feet
CFU/100 mL	colony forming units per 100 mL
cfs	cubic feet per second
ft	foot, feet
ft^2/day, ft/day	foot-squared per day, foot/day
ft/sec	feet per second
gal	gallons
GPM	gallons per minute
gpm/ft	gallons per minute per foot
HP	horsepower
in	inches
kWh	kilowatt-hours
L	liter
lb	pound
µm	micron or micrometer
µg/L	micrograms per liter
µS/cm	microsiemens per centimeter
m	meter
mA	milliamp
mJ/cm^2	millijoules per square centimeter
MGD	million gallons per day
mg/L	milligrams per liter
m, m^2	meter, square meter
min	minute, minutes
mL	milliliter
mm	millimeter
MPN/100 mL	most probable number per 100 mL
mV	millivolts
ng/L	nanograms per liter
NTU	nephelometric turbidity units
pCi/L	picocuries per liter
PCU	Platinum Cobalt Units
psi	pounds per square inch
psig	pounds per square inch gauge
RPM	rotations per minute
scfm	standard cubic feet per minute
W	watts
w/v	weight/volume (liquid solids concentration)

1. Preface

1.1 Foreward

This document presents and summarizes all activities conducted at two aquifer storage and recovery (ASR) systems that were designed, permitted, constructed, and operationally tested to fulfill requirements of the Lake Okeechobee ASR Pilot Project located on the Kissimmee River (also known as the Kissimmee River ASR system), and the Hillsboro ASR project. The Kissimmee River ASR (KRASR) system was designed, constructed, and operationally tested by the United States Army Corps of Engineers (USACE) – Jacksonville District. The Hillsboro ASR system was designed, constructed, and operationally tested by the South Florida Water Management District (SFWMD) who also served as the local sponsor. These two ASR projects collectively are known as Comprehensive Everglades Restoration Plan (CERP) Aquifer Storage and Recovery (ASR) Pilot Projects. This document should be of interest to water resource scientists and engineers in the fields of groundwater hydrogeology and hydraulics, groundwater and surface water quality, permitting, facility operations, and cost evaluations of an ASR surface facility and wellfield.

The U.S. Army Corp of Engineers and the South Florida Water Management District are proud to present the CERP ASR Pilot Project Technical Data Report. 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.

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 Program, which includes the ASR Regional Study in addition to the ASR pilot projects. The Technical Data Report summarizing the results of the ASR Regional Study will be forthcoming within the next year.

This publication - documenting the results of the ASR pilot projects - continues our commitment to communicate with the public as work progresses toward restoration of the south Florida ecosystem.

1.2 How to Read this Document

Certain practitioners will be more interested in some sections than others, so the following lists sections of interest by sub-discipline. All readers should consult Section 2, Executive Summary; Section 3, Introduction; Section 12, ASR Pilot Projects Address Stakeholder Concerns, and Section 14, Conclusions and Recommendations.

Planning and Permitting an ASR System - Please consult Section 3, Introduction; Section 7, Permitting; and

ASR System Design and Construction - Please consult Section 4, ASR Feasibility Studies; Section 6, Surface Facility Engineering Design; Section 8, Construction of ASR Pilot Systems; and Section 13, Value Engineering Studies.

Groundwater Hydrogeology and Aquifer Testing - Please consult Section 5, Hydrogeologic Setting and Hydraulics.

Regulatory Compliance of the ASR Systems - Please consult Section 7, Permitting; Section 9, Cycle Testing Results; and Section 10, Ecotoxicology and Ecological Studies.

Surface Water and Groundwater Quality During Cycle Testing - Please consult Section 9, Cycle Testing Results.

Ecotoxicological and Ecological Effects of Recovered Water on Aquatic Systems – Please consult Section 10, Ecotoxicology and Ecological Studies.

ASR System Costs - Please consult Section 11, ASR System Operation and Monitoring Costs; and Section 13, Value Engineering Studies.

2. Executive Summary

2.1 Synopsis

- The feasibility of large capacity (5 million gallons per day, MGD) ASR system operation has been confirmed at two CERP pilot facilities in south Florida – the Kissimmee River and Hillsboro ASR systems.
- Hydrogeologic characteristics of the upper Floridan Aquifer at these two locations show sufficient permeability and transmissivity for subsurface storage. The aquifer will accept 5 MGD during long (6-month) recharge phases. Significant volumes of water (40 to 100 percent) were recovered after 3 to 12 months in storage. Lower percent recovery occurred where the native Floridan Aquifer water is brackish.
- The integrity of the overlying Hawthorn confining unit was not compromised during system operations. No pressure or water-quality effects were observed in the surficial aquifer at either ASR system throughout the cycle testing program. This is consistent with geotechnical analysis, which indicates that operating pressures would have been insufficient to fracture confining unit lithologies.
- Recharge (surface) water quality consistently challenged the UV disinfection system, resulting in frequent detections of coliform bacteria. High color in recharge water limited UV transmittance with a subsequent reduction in performance. A more robust disinfection system, possibly coupled with new filtration technology, will be required for complete regulatory compliance in the future. It is also likely that coliforms will not survive under aquifer conditions. Total coliform concentrations decline to less than the regulatory standard after a minimum of 3 months in storage.
- Regulatory relief mechanisms were required for operational testing of both ASR systems. The Underground Injection Control permit required administrative orders for arsenic and total coliforms, and water-quality criteria exemptions for color. The National Pollution Discharge Elimination System permit required a mixing zone exemption for discharge into the Kissimmee River. These permit exemptions likely will be required for future ASR systems.
- Arsenic mobilization at concentrations above the regulatory criterion occurred in the aquifer during recharge, resulting from reaction of oxygenated recharge water with storage zone lithologies. However, cycle testing results at the Kissimmee River system demonstrate that this condition is temporary, because arsenic apparently precipitated as a stable solid during storage. At the Kissimmee River ASR system, all recovered water samples during cycle tests 2 through 4 showed arsenic concentrations below the 10 parts per billion regulatory criterion. Molybdenum also is mobilized during recharge, occasionally above the World Health Organization drinking water guideline of 70 parts per billion.
- Mercury and methyl mercury concentrations declined during the storage phase of ASR cycle testing to the minimum detection limit, well below regulatory criteria. There is no evidence of increased mercury methylation during ASR cycle testing. Phosphorus concentrations also declined, to generally below 15 parts per billion.

- Extensive ecotoxicological testing using selected aquatic organisms was performed at the Kissimmee River ASR system. Rare instances of chronic toxicity to *Ceriodaphnia dubia* were observed during two separate recovery events. The effects of ASR recovered water on aquatic organisms will be considered in greater detail in the ASR Regional Study technical data report.
- Several "best practices" were identified regarding maintenance tasks, which could be applied to similar ASR systems. During recharge, piping from the surface water intake to the ASR wellhead was chlorinated once a month. This reduced detections of total coliforms. ASR wells at both systems required acidization of the wellbore once every few years to prevent wellbore clogging.
- Operational testing costs at the Kissimmee River ASR system were high compared to potable ASR systems for two reasons. First, the surface and groundwater monitoring program exceeded regulatory requirements, and second, efforts for operating system optimization were performed continuously to ensure limited down-time. Detailed cost breakdowns are provided, but these costs probably represent maximum costs that might be expected at ASR systems. The existing CERP ASR pilot systems do not benefit from economy of scale.
- Cost-effectiveness of ASR system operations can be improved by the use of the following: 1) variable frequency drive pumps, to achieve greater flow rate; 2) removal of a pump stage on the existing pump; and 3) use of artesian pressure for recovery. A more effective UV system also would improve system cost-effectiveness.

2.2 Narrative

The Central & South Florida Project Comprehensive Review Study (USACE, 1999) was developed jointly by the USACE and SFWMD to present a framework for Everglades Restoration. This framework is now known as the Comprehensive Everglades Restoration Plan (CERP). CERP consists of 68 project components, many of which focus on the need for increased storage. One of the primary storage technologies proposed is Aquifer Storage and Recovery (ASR). ASR involves the recharge of excess surface water through wells into permeable zones (typically the Floridan Aquifer System, in the case of South Florida). Water is stored for some time, then subsequently recovered and distributed for purposes such as potable water supply or ecosystem restoration. Typically, ASR is implemented on an annual cycle in which recharge of excess wet season flows are stored, then recovered for distribution during the dry season. More complex ASR systems can recharge larger volumes through well clusters for multi-year storage, then recover as needed to augment water supplies during drought. In CERP, ASR technology would be implemented at many locations surrounding Lake Okeechobee and the Lower East Coast of Florida to capture up to 1.66 billion gallons per day of excess surface water currently lost to tide. New ASR storage would be developed primarily around the northern portion of Lake Okeechobee from Moore Haven to Port Mayaca, through a network of ASR wells having a pumping capacity of 5 million gallons per day per well. Additional ASR systems would be constructed in the Caloosahatchee, L-8, C-51, central Palm Beach, and Hillsboro Basins of south Florida.

ASR technology has served as a storage component at many drinking water systems in Florida since the 1980s, when operations began at the Peace River-Manasota Regional Water Supply Authority and the City of Cocoa Public Works ASR systems. However, operations of ASR systems that recharge potable (drinking) water differ fundamentally from those of CERP ASR systems. The level of pre-treatment at CERP ASR systems would be less than that at a drinking water system, generally consisting of filtration and disinfection prior to recharge. CERP ASR systems are unique in that "lightly treated" surface water is recharged, while still maintaining compliance with the same regulatory criteria as potable water ASR systems. Regulatory compliance became more difficult for ASR systems in 2005 when the Safe Drinking Water Act criterion for arsenic was decreased from 50 to 10 micrograms per liter (μg/L).

Implementing CERP ASR required that many uncertainties be resolved prior to expansion of this technology. Stakeholders voiced many concerns that are summarized as follows: 1) the suitability of surface water quality and quantity for recharge; 2) hydrogeologic and hydraulic suitability of the upper Floridan Aquifer for ASR; 3) rock deformation (and especially fracturing) in lithologies that include the Floridan Aquifer or the overlying confining unit from high pressures during recharge; 4) site and regional changes in groundwater flows and levels that might result from recharging and recovering large volumes of water; 5) deleterious effects on groundwater quality that result from the introduction of surface water into an aquifer; 6) the potential for mercury methylation to occur during storage; and 7) poor overall performance of proposed ASR facilities regarding recharge capacity and/or recovery efficiencies.

The CERP ASR Pilot Project was initiated to resolve some of these uncertainties. Two ASR systems (Kissimmee River and Hillsboro) were constructed and tested to evaluate ASR feasibility at two locations where ASR storage could be expanded in the future.

The Kissimmee River ASR (KRASR) system surface facility construction and endurance tests were completed in late 2007, at a cost of $6,138,253 (contract award plus modifications). Four storage zone monitor wells plus a surficial aquifer well were constructed at a cost of $1,741,171. Post-construction system upgrades and testing of the UV disinfection system were required to ensure continuous operation and regulatory compliance. This delayed the initiation of operational cycle testing until January 2009. Four operational cycle tests that consisted of recharge, storage, and recovery were completed at the KRASR system by July 2013. Successive cycle tests increased in volume of surface water recharged, and duration of storage in the Floridan Aquifer. Cycle test 4 at KRASR is the largest single-well recharge event conducted to date in Florida, and most closely resembles typical operation intended in the CERP for Lake Okeechobee. Percent recovery of recharged water from the Floridan Aquifer was approximately 100 percent by volume for each cycle test, which exceeds the maximum percent recovery estimated for the CERP (70 percent). High percent recoveries are expected at KRASR because the native groundwater is fresh.

The Hillsboro ASR (HASR) system was constructed around pre-existing exploratory and Floridan Aquifer monitor wells. Surface facility construction and endurance testing was completed in late 2008 at a cost of $2,277,598 (construction award plus modifications). A drought in late 2008 and early 2009, along with completion of required system upgrades, delayed the initiation of operational cycle testing until January 2010. Three operational cycle tests were completed at the HASR system by June 2012. HASR operations were designed to test the feasibility of wet-season recharge and dry-season recovery during an annual cycle test. Percent recovery improved from 21 percent during cycle test 2, to 41 percent by volume during cycle test 3. Lower percent recovery is expected at HASR (compared to KRASR) due to mixing with native brackish groundwater during each cycle test. The percent recovery during cycle test 3 exceeds the minimum estimated percent recovery estimated for the CERP (35 percent).

The surface facilities at both ASR systems were designed to “lightly” treat and recover surface water in regulatory compliance, but at a lower cost compared to a drinking water treatment plant. Ideally, these facilities can be operated remotely with minimal on-site personnel. The ASR system components are (in series): an intake pump, a filtration component, an ultraviolet (UV) disinfection system, a pump to recover water through the ASR well, a feature to hold or divert small volumes of recovered water, and a component for aeration of recovered water prior to discharge. The cost of ASR operations is the sum of three components: labor, power, and supplies and services. These component costs vary during each phase of the cycle test. A detailed cost evaluation is presented for KRASR, which has the most cost information available.

Labor cost is the greatest cost component in all cycle test phases at KRASR. Because these are “pilot facilities” that require an intensive data collection effort, labor costs are higher compared to that of a typical ASR system, particularly at KRASR. The KRASR facility is manned full-time on weekdays, which can be reduced with remote monitoring by SCADA. Power costs are the second greatest cost component, and are highest during recharge because the intake pump and all treatment components are operational. Supplies and services are the least costly component. Total cost (labor, power, supplies and services) per month for recharge at KRASR is $57,000 ($148/acre-ft; $454/million gallons recharged). Total cost per month for storage is $26,100. Total cost per month for recovery is $35,400 ($79/acre-ft; $242/million gallons recovered). This cost summary does not include water quality monitoring costs.

Water quality monitoring costs include labor plus cost of analyses, sample shipment, supplies, and mileage. A robust water quality monitoring program was implemented at KRASR, which far exceeded permit requirements for groundwater monitoring. Therefore, monitoring costs at KRASR are greater than would be expected during typical ASR system operation. The total cost for groundwater and surface water quality monitoring during a complete cycle test lasting approximately 1.5 to 2 years ranges between $200,000 and $270,000. This total cost includes monitoring for permit compliance, and for applied research on ASR system geochemistry.

As summarized above, during the ASR planning process, stakeholders identified many technical uncertainties surrounding ASR system implementation and operation. These uncertainties were formalized in a 1999 document authored for the South Florida Ecosystem Restoration Task Force entitled “ASR Issue Team Assessment Report and Comprehensive Strategy”. A major objective of the CERP ASR Pilot Projects was to address these uncertainties using site-specific data and interpretations. Four of the seven issues mentioned above required characterization of water quality changes in the aquifer storage zone during cycle testing, and also in the surface water body that receives recovered water. The robust monitoring data acquisition program implemented at KRASR shows that many favorable water quality changes occur during ASR cycle testing. The major conclusions from the large water quality data set pertain to arsenic and molybdenum mobilization, mercury methylation, phosphorus attenuation, and coliform inactivation.

Arsenic mobilization during cycle testing was identified as a potential challenge to ASR implementation as early as 1999. Arsenic is released from pyrite (iron sulfide) minerals in the aquifer matrix when exposed to dissolved oxygen in recharge water. Resultant arsenic concentrations can exceed the Federal maximum contaminant level (MCL; 10 µg/L) in the aquifer, in violation of permits and state and Federal law. Data acquired at KRASR shows that arsenic MCL exceedances are temporary. Arsenic is released during recharge, but the geochemical environment of the KRASR storage zone causes arsenic to co-precipitate as a solid iron sulfide phase. As a result, arsenic concentrations decline in the aquifer during storage, and recovered water quality is in compliance with the Safe Drinking Water Act and Clean Water Act criteria. Molybdenum also is mobilized during cycle testing, most likely by the same mechanism as arsenic.

High concentrations of the nutrient phosphorus—typically on the order of 100 to 200 µg/L—characterize Kissimmee River surface water. Phosphorus concentrations declined during the storage phase at KRASR due to microbiological uptake or precipitation of the mineral apatite (calcium phosphate). Phosphorus concentrations in recovered water typically are below 15 µg/L, and often are below the detection limit of 4.4 µg/L. Thus, with regard to phosphorus, water is returned to the Kissimmee River having better quality after cycle testing than before.

Methyl mercury is a powerful neurotoxin, and bioaccumulation of this contaminant is known to occur in Everglades food webs. Inorganic mercury is methylated by sulfate-reducing microbes in wetlands sediments, and subsequently released into surface water where it can be ingested by aquatic organisms. Because the Floridan Aquifer also is characterized by sulfate-reducing redox conditions, many stakeholders were concerned about the potential for mercury methylation by aquifer microbes during storage. At KRASR, inorganic mercury and methyl mercury concentrations in recovered water were lower, and often below their respective detection limits, compared to surface water concentrations. The difference between median surface water recharge and recovered water concentrations was statistically significant, and consistent through four successive cycle tests. Mercury methylation does not occur during storage at KRASR. More data are needed to confirm this conclusion at HASR.

The Safe Drinking Water Act requires source water disinfection if recharging to an aquifer having a total dissolved solids concentration less than 10,000 milligrams per liter (mg/L). During the ASR planning phase, many disinfection methods were evaluated for cost and performance. The disinfection technology applied at both ASR systems consists of flow-through UV reactors to attenuate coliform and other bacteria and viruses in the source water. UV disinfection technology was preferred over chemical methods, which have higher operations costs, have residuals from the treatment process, and often produce undesirable disinfection by-products such as trihalomethanes. Unfortunately, high color in surface water reduced UV disinfection system performance, particularly at the onset of the wet season. UV disinfection system performance at KRASR and HASR was insufficient and inconsistent for coliform inactivation, as demonstrated by frequent positive detections in weekly samples obtained from all wells during the recharge phase. Detection of surface water microorganisms during recharge is a permit violation. Fortunately, it is unlikely that these microorganisms will survive for long in the Floridan Aquifer. Survival studies at other ASR systems suggest that microbes and pathogens are inactivated after 3 to 6 months of storage in an aquifer. Future application of UV disinfection technology at ASR systems will require a more robust design than that used at KRASR and HASR.

Site-specific groundwater flow and solute transport models were developed and calibrated for KRASR. A more limited groundwater flow model was developed to simulate ASR operations and well spacing options at HASR. These models are useful for simulating drawdown, recovery efficiency, well spacing, and well-to-well interactions. These models also will be useful for planning expansion at KRASR and HASR, if desired.

Rock fracturing of the Floridan Aquifer storage zone limestones, or sediments in the overlying confining unit during recharge was another stakeholder concern. Typical wellhead pressures during the ASR recharge phase are far below those used for hydrofracking to release natural gas. However, there are no existing data to quantify minimum pressures that will induce rock fracturing in typical south Florida ASR systems. Geotechnical analyses were performed on core samples from the storage zone and confining unit lithologies at KRASR, HASR, and other potential CERP ASR locations. At KRASR, the lowest pressure threshold to induce microfracturing is 89 psi, which includes a 10 percent factor of safety. In comparison, ASR wellhead pressures never exceeded 66 psi during cycle testing at KRASR. At HASR, the lowest pressure threshold to induce microfracturing is 149 psi, which includes a 10 percent factor of safety. ASR wellhead pressures never exceeded 99 psi during ASR cycle testing at HASR. It is very unlikely that microfractures will propagate into the overlying confining unit, and typical ASR operating pressures during recharge do not induce macrofracturing or other structural disruption of storage zone lithologies. At KRASR, there was no evidence of changing pressure in a well open to the overlying Hawthorn confining unit during recharge and recovery pumping stresses. Typical operational pressures in the storage zone do not exert a measureable effect on the overlying confining unit.

Several value engineering studies were conducted at KRASR to improve existing operations and provide input to future ASR system designs. These studies focused on three areas: 1) recharge water treatability for better UV disinfection performance; 2) use of artesian flow during recovery; and 3) revisions to the existing pressure filter, intake pump, and power supply for more cost-effective operations. Use of artesian flow for recovery, and modifications to the intake pump for more efficient power consumption, were modifications that would provide the greatest increase in cost-effectiveness at KRASR.

In conclusion, successful completion of cycle tests at KRASR and HASR confirm that ASR technology is a feasible storage alternative for excess surface water flows at these geographic locations, if disinfection challenges are overcome. Overall design of surface facilities at KRASR and HASR enabled successful cycle testing. Percent recoveries were nearly 100 percent recovery at KRASR. At HASR, cycle test 3 showed a percent recovery of 41 percent, which was higher than expected. Value engineering studies conclude that the intake pump and UV disinfection system performance can be optimized or improved at KRASR, particularly for cost-effectiveness. Nearly four years of cycle testing at two locations have resolved several technical challenges to ASR application, particularly related to water quality changes and the potential for rock fracturing in the Floridan Aquifer System. Recovered water quality is improved during ASR cycle testing with regard to phosphorus, mercury, and methyl mercury compared to Kissimmee River surface water. Insufficient inactivation of total coliforms in recharge water by the existing UV disinfection system remains as a technical challenge. Groundwater flow and solute transport models completed for each ASR system will be useful for evaluating options for expansion of these facilities. Operational costs will decrease if the KRASR system is used as a base for operation of additional remote well clusters.

3. Introduction

The framework for Everglades restoration was defined by the USACE and SFWMD in the "Yellow Book", the colloquial name for the Central and Southern Florida (C&SF) Project Comprehensive Review Study (USACE, 1999). The Yellow Book defined the Comprehensive Everglades Restoration Plan (CERP), which consists of 68 water resource management project components. When completed, these components will improve the quantity, quality, and timing of water deliveries throughout south Florida and promote ecosystem restoration. The water resource management goal is achieved by capture and storage of 1.66 billion gallons of water per day currently lost to tide through the C&SF Flood Control System. Stored water is recovered later and distributed for ecosystem restoration and water supply.

Successful implementation of CERP requires optimizing currently available storage components, and developing new storage facilities (Committee on Restoration of the Greater Everglades Ecosystem [CROGEE], National Research Council, 2005). Additional storage will provide flexibility for water distribution during wet and dry seasons, and to satisfy multiple demands, sometimes simultaneously. Lake Okeechobee is the major regional reservoir that links mainly upland ecosystems of the Kissimmee River and Chain of Lakes with wetlands ecosystems to the south. Water conservation areas located south of Lake Okeechobee primarily detain excess surface water, but also serve in flood control, augmentation of water supply, aquifer recharge, and seepage management. Lake Okeechobee and the water conservation areas are the primary existing surface water storage features of South Florida.

3.1 ASR Background

Aquifer storage and recovery (ASR) was envisioned as the largest component of new storage in the CERP. ASR simulations indicated that more than 500,000 ac-ft (1.66 billion gallons per day) of storage each year could be provided by as many as 333 ASR wells. ASR technology could provide a cumulative storage capacity of more than 4 million ac-ft (USACE, 1999; National Research Council, 2005). CERP ASR applications involve capture and partial treatment of excess surface water (usually during the wet season) for storage in subsurface permeable zones (aquifers), through one or more production wells. Water is recovered through the same well then returned to a surface water body for distribution. In the CERP, water would be stored using a large number of ASR wells built around northern Lake Okeechobee, in Palm Beach County, and the Caloosahatchee Basin **(Figure 3-1)**.

Due to the expansive nature of ASR implementation proposed in the CERP, and because some regulatory and operational issues persist, three projects were developed to evaluate the feasibility of ASR technology for ecosystem restoration. These three projects are the Lake Okeechobee ASR Pilot Project, the Hillsboro ASR Pilot Project, and the ASR Regional Study.

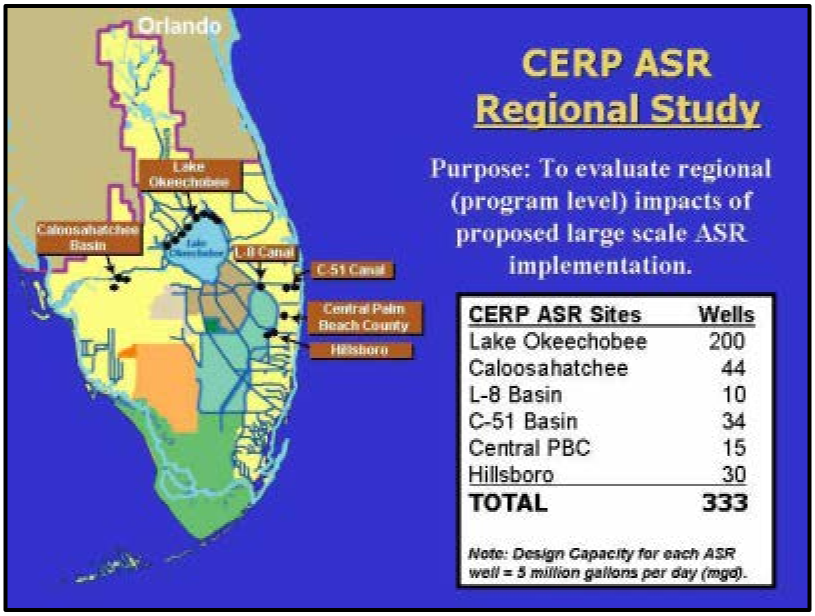


Figure 3-1 -- Image showing distribution of proposed ASR systems by basin, as defined in the CERP. Figure from USACE (2003).

Briefly, the goals of the CERP ASR Pilot Projects are: 1) to evaluate ASR feasibility at two locations having different surface water quality characteristics, hydrogeologic conditions, and surface water distribution configurations; 2) to reduce technical and regulatory uncertainties associated with ASR system operation; and 3) quantify cost of operation (USACE, 2001a, b; National Research Council, 2001). Specific objectives for operational testing at each ASR system are summarized in **Table 3-1.** The overall goal of the ASR Regional Study is to reduce uncertainties about regional-scale implementation of ASR across south Florida (USACE, 2003; National Research Council, 2002). In particular, the ASR Regional Study addresses the changes that may occur to ground and surface water quality, aquifer hydrology and hydraulics, and aquifer rock integrity during the operation of a large number of ASR wells.

During the planning process, additional hydrological and geotechnical objectives were identified by the ASR Issue Team (1999), the CROGEE (National Research Council, 2001), and in public workshops. These issues were incorporated into project objectives listed in the Pilot Project Design Report (PPDR; USACE, 2004). All issues identified by the ASR Issue Team (1999) and the CROGEE were incorporated, but some objectives will be achieved by completion of the CERP ASR Pilot Projects, while others will be achieved in the ASR Regional Study. The task breakdown between the ASR pilot projects and the ASR Regional Study is summarized in **Table 3-2.**

Issues identified by the CROGEE (National Research Council, 2001) focused primarily on hydrogeologic factors that can potentially affect ASR operation effectiveness. CROGEE encouraged evaluation of ASR well design (short versus long open intervals), variations in recharge and recovery rates, and implementing expanded number and sampling frequency in monitor wells at the ASR pilot systems. Completion of a rock fracturing study also was suggested.

Table 3-1 -- CERP ASR Pilot Project Objectives

PROJECT OBJECTIVES	Kissimmee River ASR Pilot System	Hillsboro ASR Pilot System
1. Evaluate the ability to construct and operate an ASR facility with a target capacity of 5 million gallons of water per day and determine a range of feasible recharge and recovery capacities	✓	✓
2. Identify and initiate evaluation of relevant geochemical and ambient groundwater quality changes during ASR cycle testing	✓	✓
3. Identify an appropriate treatment facility for recharge and recovered water. Determine lifecycle costs	✓	✓
4. Evaluate the inter-relationships of recharge and recovery rates, storage volumes and recoverability	✓	✓
5. In coordination with the ASR Regional Study, evaluate the effect of ASR on the affected ecosystem	✓	✓
6. Evaluate the extent of pressure changes and the cone of influence during recharge and recovery operations	✓	✓
7. Identify and evaluate the effects of ASR on existing Floridan Aquifer users	✓	✓
8. Design, construct, and test a three-well cluster to assist in future, large-scale ASR system design involving optimum well spacing, evaluating pressure effects, etc.		
9. Evaluate ASR system performance from a geographic perspective around Lake Okeechobee	✓	✓
10.Operate project in accordance with Adaptive Management guidance developed by RECOVER for CERP	✓	✓

Table 3-2 -- "ASR Issue Team" Objectives		
PROJECT OBJECTIVES	**CERP ASR Pilot Projects**	**ASR Regional Study**
1. Characterization of prospective sources waters, spatial and temporal variability	✓	✓
2. Characterization of regional hydrogeology of the upper Floridan Aquifer: hydraulic properties and water quality		✓
3. Analysis of critical pressure for rock fracturing	✓	✓
4. Analysis of site and regional changes in head and patterns of flow	✓	✓
5. Analysis of water quality changes during movement and storage in the aquifer	✓	✓
6. ASR potential effects on mercury bioaccumulation for ecosystem restoration projects	✓	✓
7. Relationship between ASR storage interval properties and recovery rates and recharge volume	✓	✓

3.2 Project Authority and Authorization

The Lake Okeechobee ASR Pilot Project and the Hillsboro ASR Pilot Project were authorized by Congress in section 101(a) (16) of the Water Resources Development Act (WRDA) of 1999 (113 Stat. 276). Three ASR systems were planned under the Lake Okeechobee Pilot Project. These systems would be located around Lake Okeechobee, at the Kissimmee River (Okeechobee County), Port Mayaca (Martin County), and Moore Haven (Glades County). The Hillsboro ASR Pilot Project was the fourth system to be developed, and was authorized simultaneously with the Lake Okeechobee ASR Pilot Project. The WRDA 1999 authorization was modified in section 101 (b) (2) (B) (i) of the WRDA 2000 (114 Stat. 2681) to authorize a fifth ASR pilot system on the Caloosahatchee River (Hendry County). The Lake Okeechobee and Hillsboro ASR Pilot Projects authorization was modified further in section 6001 (a) of the WRDA 2007 (121 Stat. 1041) to increase the total cost of the project from $27,000,000 (WRDA 1999) to $42,500,000. Further definition of the ASR pilot projects was provided in section 6001 (b) (1) of the WRDA 2007, which stated "…that operation and maintenance costs of the Lake Okeechobee and Hillsboro ASR projects shall remain a non-Federal responsibility".

3.3 Historical Development of the CERP ASR Pilot Systems

Management of the Lake Okeechobee, Hillsboro, and Caloosahatchee ASR Pilot Projects was defined in three separate project management plans (PMPs; USACE and SFWMD, 2001a, b; 2002). As the PMPs developed, SFWMD and USACE agreed to divide the lead responsibilities for permit acquisition, design, construction, and operational testing of the ASR systems. The SFWMD would serve as the lead agency on the Hillsboro, Moore Haven, and Caloosahatchee ASR pilot systems. The USACE would serve as lead agency on the two larger systems at the Kissimmee River and Port Mayaca. Studies to evaluate water pretreatment alternatives, background surface and groundwater quality characterization, exploratory well construction, and development of the Pilot Project Design Reports (PPDR) were conducted from 2003 to 2004. The Record of Decision for the PPDR and Final Environmental Impact Statement was signed on 21 October 2005.

The reality of cost constraints in an environment of rapidly increasing drilling and construction costs prompted revisions to the original cost estimates for ASR systems at the 30 percent and 60 percent design phases. At the March 22-23, 2004 ASR project delivery team (PDT) meeting, the decision was made to eliminate the Moore Haven ASR system from further consideration in the Lake Okeechobee ASR Pilot Project (P. Kwiatkowski, personal communication dated 12 May 2004). Eliminating the Moore Haven ASR system was the preferred cost-saving option, compared to scope reductions at the multi-well ASR system at Port Mayaca. Thus, only four pilot ASR systems were advanced for further development.

Geotechnical testing and exploratory well construction at the Caloosahatchee River ASR system was initiated in 2004, and completed in 2005 by the SFWMD (Water Resource Solutions, Inc., 2004, 2005). During well construction, significant drilling difficulties were encountered between 650 and 900-ft depth due to the presence of unconsolidated sands that caved into the borehole. Subsequently, the total depth of the well was 650-ft, which was not sufficient for development of an ASR storage zone at that site. USACE and SFWMD recommended in 2005 that the Caloosahatchee ASR system be re-located elsewhere on the Berry Groves property, but costs associated with additional geotechnical exploration and surface facility design changes threatened to exceed the authorized funding amount (also known as “the 902 limit”). The project was put on hold during 2006, and re-activated in 2007. Ultimately, the decision was made to plug and abandon well EXBRY-1 (Boyle, 2008) and to postpone indefinitely further development of the Caloosahatchee River ASR Pilot system at the Berry Groves site. Thus, only three pilot ASR systems were advanced for further development.

Exploratory well construction at the Port Mayaca ASR system was initiated in May 2003 and completed in January 2004 by the SFWMD (EXPM-1; Bennett et al., 2004). A storage zone monitor well (SZMW; MF-37) was constructed in 2001-2002, and converted to a dual-zone well in 2007 (Mactec Engineering and Consulting, Inc., 2007). A surficial aquifer monitor well also was constructed in 2007 (Challenge Engineering & Testing, Inc., 2007). Conceptualization and design of the surface facility began in 2004, culminating in a design documentation report (DDR; CH2M Hill, 2005). Plans and specifications were completed for the surface facility, and a request for proposals (RFP; W912EP-07-R-0015) for construction of the surface facility was issued on 3 July 2007. On 16 August 2007, management decided not to award the surface facility construction contract, so the request for proposal (RFP) was cancelled (Ramos-Gines, personal communication, 2007). The Port Mayaca ASR system was unique among the CERP ASR systems because it was designed as a multi-well cluster to have three ASR (recharge/recovery) wells. Without this system, objective 8 **(Table 3-1)** could not be achieved. Thus, only two pilot ASR systems were advanced for further development.

Exploratory well construction at the Hillsboro ASR system was initiated in 1999 and completed in 2001 by the SFWMD (EXW-1, now PBF-13; Bennett et al., 2001). A proximal storage zone monitor well (SZMW) (PBF-10R) was constructed during this same period. A distal SZMW (PBF-14) and surficial aquifer well were completed in 2007 (CH2M Hill, 2007). Conceptualization and design of the surface facility began in 2004, culminating in a design memorandum (PBS&J, 2005). Plans and specifications were completed shortly thereafter, and a construction contract was awarded with a notice to proceed by the SFWMD on 5 December 2005. Construction of all wells and the surface facility was completed by November 2008. There were several factors that delayed initiation of cycle testing at the Hillsboro ASR facility. Recharge was not permitted due to low water levels in L-29 (Hillsboro Canal) during late 2008 and 2009. Centralizers were added to the vertical turbine pump in the ASR well for better operation. These issues were resolved and cycle testing was initiated in January 2010. The third and final cycle test was completed on 26 June 2012.

Exploratory well construction at the Kissimmee River ASR system was initiated in 2003 and completed in 2004 by the SFWMD (EXKR-1; now the ASR well; CH2M Hill, 2004). The Kissimmee River ASR system would incorporate several monitor wells that had been constructed previously by the SFWMD for the Regional Floridan Aquifer Monitoring program. The dual-zone SZMW OKF-100 would serve as a distal monitoring well. OKH-100 serves to monitor water levels in the overlying Hawthorn Group confining unit. Well OKS-100 serves to monitor water levels in the surficial aquifer. The surface facility footprint was designed to take advantage of these existing features for cost savings. Conceptualization and design of the surface facility began in 2004, culminating in a design documentation report (DDR) (CH2M Hill, 2005). Plans and specifications were completed for the surface facility, and an RFP (W912EP-05-R-0031) for construction of the surface facility was issued on 13 January 2006. The construction contract was awarded with a notice to proceed on 7 June 2006. The surface facility was accepted after performance testing was completed on 7 December 2007. During performance testing, it became clear that the original two-unit ultraviolet disinfection (UV) system was insufficient for coliform inactivation. After consultation with the Florida Department of Environmental Protection (FDEP), the construction contract was modified on 7 March 2008 to add a third UV unit and by-pass piping so that the UV system could be tested without recharging the Floridan Aquifer. ASR system modifications and additional operational tests were completed, and a revised ASR system performance submittal was accepted by FDEP in December 2008. Cycle testing was initiated on 12 January 2009. The ASR wellfield was expanded with the addition of two distal SZMWs between cycle test 2 and 3 (Entrix, Inc., 2010 a, b). The fourth and final cycle test was completed in July 2013. Results obtained at the KRASR system are appropriate for further application to other planned ASR systems located north of Lake Okeechobee.

3.4 Pilot System Locations and Descriptions

The ASR pilot projects are located in southern Florida within SFWMD boundaries **(Figure 3-2)**. The pilot project sites were selected based on their broad spatial coverage around Lake Okeechobee and proximity to proposed CERP impoundments. The Hillsboro ASR system is located south of the Arthur R. Marshall Loxahatchee National Wildlife Refuge (also known as WCA-1) along the Hillsboro Canal. The Kissimmee River ASR system is located north of Lake Okeechobee near the confluence of the Kissimmee

River with the Lake. All of the sites are linked either directly or indirectly via waterways to Lake Okeechobee, which is the source of much of the water available for future storage via ASR systems.

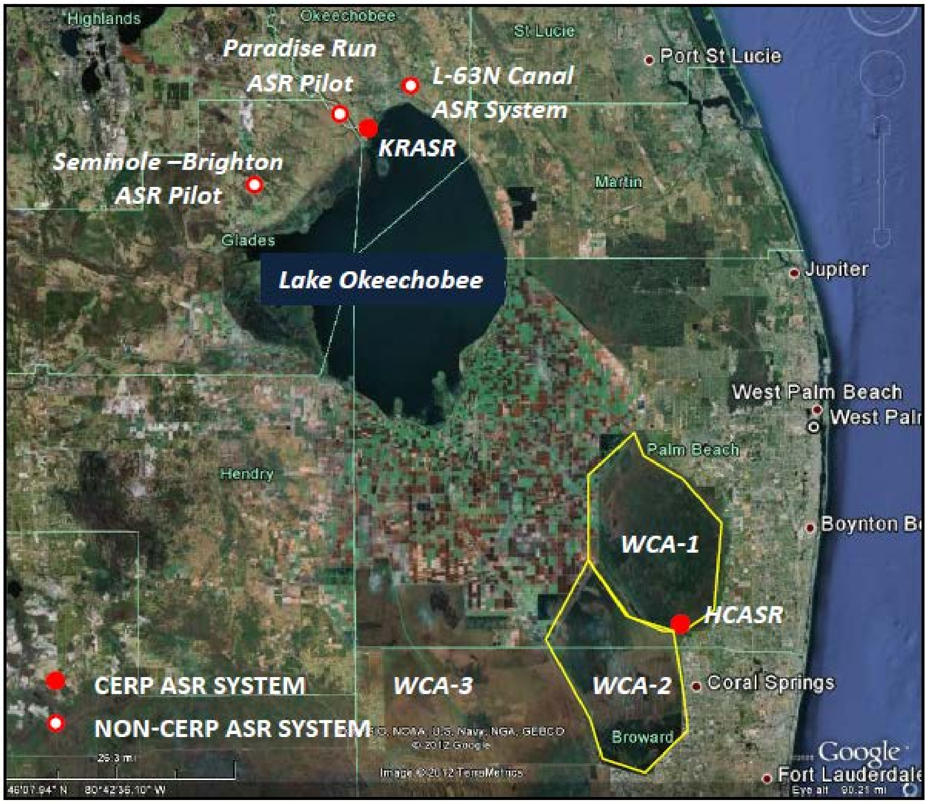


Figure 3-2 -- Locations of CERP ASR systems at Kissimmee River (KRASR) and Hillsboro (HASR). Locations of other non-CERP ASR systems with SFWMD involvement also are shown.

3.4.1 Kissimmee River ASR System

The Kissimmee River ASR system is located in the northwest corner of Section 19, Township 38 South, Range 35 East, (latitude N 27° 09’ 18.7”, longitude W 80° 52’ 29.7”) near the confluence of the Kissimmee River and Lake Okeechobee near Okeechobee, Florida **(Figure 3-3)**. The site is located on SFWMD-owned land on the Kissimmee River, which serves as source water for recharge, and receiving water body for recovery. The site is approximately 8,000 feet upstream from the river’s confluence to Lake Okeechobee, and north of Route 78. The area is bordered on all sides except the east by SFWMD lands. The east boundary is a paved road with a residence on the east side of road. Observed soil conditions appeared as highly disturbed, sandy dredged material, presumed to be from Kissimmee River channelization projects.

Figure 3-3 -- Location of the Kissimmee River ASR (KRASR) system. Inset is an aerial view of the ASR system.

3.4.2 Hillsboro ASR System

The Hillsboro ASR System is located at the southwestern corner of Section 19, Township 47 South, Range 41 East (Latitude/Longitude 26°21'07"N/80°17'42"W) along the Hillsboro Canal in southern Palm Beach County **(Figure 3-4)**. The Hillsboro Canal serves as source water and receiving water body for the ASR system. The facility was constructed on SFWMD property at the southern end of the Loxahatchee National Wildlife Reserve (LNWR) also known as Water Conservation Area (WCA)-1. The surface facility occupies a small peripheral area of the proposed Site 1 Impoundment footprint, which is a separate water management feature of the Hillsboro Basin in CERP. The site is bordered on the north and west by SFWMD-owned lands of WCA-1 and the Site 1 Impoundment. South of the site, across Hillsboro Canal, are commercial and agricultural facilities. Directly north of the ASR facility is a former rock quarry, which serves as an additional receiving basin.

Figure 3-4 -- Location of the Hillsboro ASR (HASR) system. Inset is a panoramic view of the ASR system.

3.5 Projects Related to the CERP ASR Pilot Projects

There are several CERP and non-CERP ASR projects in development in the Lake Okeechobee region. Each project is summarized and its relevance to the CERP ASR Pilot Project is discussed. Locations of these non-CERP ASR systems are shown on **Figure 3-2**.

3.5.1 The CERP ASR Regional Study

The ASR Regional Study was not one of the original projects proposed in the Yellow Book. There were significant concerns among stakeholders, the ASR Issue Team (ASR Issue Team, 1999) and CROGEE. The overarching goal of the ASR Regional Study is to reduce uncertainties about regional implementation (333 wells) of ASR technology in south Florida. (National Research Council, 2002). Uncertainties about ASR feasibility would be reduced by conducting scientific studies to address concerns listed in **Table 3-1** and **Table 3-2,** and also through the development of a regional groundwater flow and solute transport model that will simulate groundwater level and water quality changes resulting from recharge and recovery through 333 ASR wells. These tasks were executed and will be described in a separate technical data report that will be completed in 2014. An interim progress report highlighting many of the tasks in the ASR Regional Study was published in June 2008 (USACE and SFWMD, 2008).

3.5.2 The CERP Site 1 Impoundment

The proposed Site 1 Impoundment will be a 13,280 acre-ft above-ground storage reservoir located on a 1,660 acre footprint that is bounded on the south by the Hillsboro Canal, on the north and west by the L-40 canal, and on the east by a header canal **(Figure 3-4)**. This project is divided into two phases: Phase I will reinforce the L-40 levee that separates the LNWR from the impoundment; Phase II will complete the impoundment levee reinforcement, add two pump stations, and incorporate the HASR system into impoundment operations. Phase I is approximately 50 percent complete as of November 2013. When completed, this project will integrate 30 ASR wells with Site 1 Impoundment operation. This combined facility would be one of the few conjunctive ASR-reservoir operations in Florida.

3.5.3 Paradise Run ASR System

The Paradise Run project site is located seven miles northwest of KRASR, on the west bank of the Kissimmee River south of its confluence with C-41A and spillway and lock structure S65E in Glades County. The project site is within a former alluvial plain wetland and meander belt of the Kissimmee River. Exploratory well construction was completed by the SFWMD (HIF-42; CH2M Hill, 2008) to evaluate hydrogeological conditions for a 10-well ASR system that would recharge and recover water from "stacked" aquifers of the Floridan Aquifer System (FAS). This project defined the thickness and hydrologic characteristics of potential storage zones in the upper Floridan aquifer (UFA) and the Avon Park Permeable Zone (APPZ). A conceptual design for the ASR system also was proposed. The ASR system would use surface water from the Kissimmee River to recharge the stacked aquifers through 5 well pairs open to the UFA and APPZ. Stored water could be recovered using existing artesian pressure, then discharged into the former meander system, rehydrating the wetland. The conceptual design of this ASR system incorporates several novel features such as passive (artesian) recovery to reduce energy consumption, incorporation of a pipeline subsurface crossing of a canal, a flow-way to reduce total suspended solids prior to recharge, and use of wetlands for rehydration and ecosystem restoration. In addition, due to advances in Supervisory Control and Data Acquisition (SCADA) and telemetry, this site could be operated remotely from KRASR. As of August 2013, the Paradise Run ASR system project is inactive.

3.5.4 Seminole-Brighton ASR Exploratory Well Program

The Seminole-Brighton project site is located sixteen miles west-southwest of KRASR, on the north bank of the C-41 Canal in Glades County. Access to the site is along the north bank right-of-way, 0.44 miles northwest of the Harney Pond Road bridge crossing C-41. The project site is on agricultural lands of the Brighton Reservation of the Seminole Tribe. Exploratory well construction was completed on behalf of the Seminole Tribe (BREX-1; Missimer Groundwater Science, 2007) to evaluate the ASR feasibility and hydrologic characteristics of storage zones in the UFA and APPZ. Aquifer performance testing results indicated that the hydrologic characteristics of the UFA and APPZ were suitable for ASR. A third, shallower aquifer was characterized above the UFA, between 250 and 340 ft below land surface (bls). This unnamed aquifer is included in a coarse-grained quartz sand unit. If wells in this unit are suitably productive and have fresh water quality characteristics, this aquifer could serve as a new potable water source. Subsequently, alternatives for the design of the surface facility were developed (Entrix Water Solutions, 2008) for pre-treatment and disinfection of source water prior to recharge. As of August 2013, the Seminole-Brighton ASR program is inactive.

3.5.5 L-63N (Taylor Creek) ASR System Reactivation

The L-63N ASR system is located on the south bank of the L-63N Canal, on SFWMD lands west of the town of Okeechobee, in Okeechobee County. Access to the site is from State Rd 710 (The Beeline) just south of the bridge over the L-63N Canal. This system was one of the first ASR systems in the region, with construction of an exploratory borehole and a dual-zone monitor well completed for the SFWMD in 1989 (CH2M Hill, 1989). This ASR system was envisioned as a large-capacity (10 million gallons per day, MGD) ASR system with a large storage interval (1,275 ft to 1,700 ft below land surface, bls) in the APPZ. Four short cycle tests were conducted (CH2M Hill, 1989), all showing zero percent recovery (cycle tests 1 through 3), and 6 percent (cycle test 4). Poor ASR system performance probably occurred because cycle tests were of short duration (16 to 60 days), with small recharge volumes (25 to 100 million gallons, MG), in a highly transmissive aquifer (APPZ). Longer recharge phases and larger recharge volumes could result in improved percent recovery at this ASR system.

The L-63N ASR system remained largely inactive except for the water quality monitoring by the SFWMD until 2008, when the ASR system was re-examined as a technology to divert and store phosphorus-enriched surface water from L-63N canal in the APPZ. This application would reduce phosphorus loads from the L-63N canal into Lake Okeechobee, and thus would improve total maximum daily load (TMDL) compliance for this canal. To support ASR system reactivation, the SFWMD constructed a new SZMW (OKF-106; McMillan and Verrastro, 2008) located 140-ft from the ASR well. A new underground injection control (UIC) permit was required to resume cycle testing at this ASR system. As part of the UIC permit application process, the SFWMD also submitted a request for a limited aquifer exemption (LAE) for total coliforms in 2009. This LAE would legally remove the compliance requirements for total coliforms in the aquifer. The LAE is still pending, and no further cycle testing has been performed at this ASR system.

4. ASR Pilot System Feasibility Studies

To design each ASR system, it was necessary to collect source water quality and availability data at the proposed sites and then test treatment technologies for feasibility and regulatory compliance. The results of these studies provided guidance and design parameters for the pilot ASR systems. This section presents a summary of source water quality and availability data for the Kissimmee River ASR (KRASR) and the Hillsboro ASR (HASR) systems, and summaries of the feasibility studies **(Table 4-1)** which were conducted for the design of each system. Additional characterization of source water quality is described in **Sections 9.2.1.1** (KRASR) and **9.3.1.1** (HASR).

Table 4-1 -- Feasibility Studies Evaluated for KRASR and HASR

Study	Conducted By	Dates of Study	Location
Simulated Bank Filtration	Carollo Engineers	Aug 18 to Sept 29, 2002	Port Mayaca Lock, FL
UV Disinfection	Carollo Engineers	Aug 18 to Sept 29, 2002	Port Mayaca Lock, FL
Ozonation	Carollo Engineers	Aug 18 to Sept 29, 2002	Port Mayaca Lock, FL
Serial Filtration	HSA	Aug 14 to Sept 20, 2002	Port Mayaca Lock, FL
Microfiltration	HSA	Aug 14 to Sept 20, 2002	Port Mayaca Lock, FL
Disc Filtration	Kruger/CH2M Hill	August 2004	Port Mayaca Lock, FL
TeKleen Filtration	PBS&J/CH2M Hill	June 2004	Port Mayaca Lock, FL
TeKleen Filtration	PBS&J	June 2004	Hillsboro Canal, Florida

4.1 Kissimmee River ASR System

Source water characterization and potential best treatment alternatives were identified to properly design the pre-treatment components of the ASR system. However, existing surface water and groundwater quality data were limited. Surface water quality and availability were characterized in several basins along the northern and eastern portions of Lake Okeechobee to support the design effort. Feasibility studies were conducted to determine appropriate surface water treatment technologies. These feasibility studies are discussed in the following sections of this report.

4.1.1 Source Water Quality

The Lake Okeechobee watershed is predominantly agricultural, with cattle ranching and dairy farming to the north, and sugar cane cultivation to the south. The Kissimmee River and Lake Okeechobee waters have high, variable color and organic carbon concentrations, and are characterized by dissolved oxygen concentrations that often are near saturation. The soils within these basins are rich in phosphorus and nitrogen, which contribute to the eutrophic condition of the lake (Carollo, 2003). Surface water quality data were analyzed to determine the appropriate pre-treatment processes to be both cost-effective and in regulatory compliance. The historical water quality data at KRASR that were interpreted for ASR system design are shown in **Table 4-2** (USACE, 2004).

For the Kissimmee River Basin, historical surface water data indicate slightly turbid water with relatively high total dissolved solids (TDS). Average concentrations for some constituents (turbidity, chloride, iron, and TDS) exceeded primary or secondary drinking water criteria. Average concentrations for other constituents (specific conductance, chloride, and iron) exceeded Class I and/or Class III Surface Water criteria (USACE, 2004). At present the surface water quality criterion for phosphorus is estimated from Lake Okeechobee Total Minimum Daily Load (TMDL) calculations as 40 μg/L. Most phosphorus analyses tabulated in **Table 4-2** would now be considered as exceedances.

Table 4-2 -- Kissimmee River Source Water Quality Data (USACE, 2004)

Constituents	Unit	Min.	Max.	Avg.	SD	Number of Exceedances	Class I SW Std	Class III SW Std
Spec. Conduct.	μmhos/cm	124	8,614	1,816	1,900	354	1,275	1,275
Turbidity	NTU	0.40	265	7.20	13.2	300>5	29 (1)	NA
Total Ammonia	mg/L	0.009	3.850	0.155	0.270			
Chloride	mg/L	15	2,796	402	501	429	250	250
Iron	μg/L	27	4,410	821	889	64>300, 40>1,000	300	1,000
Phosphorus	mg/L	0.02	2.97	0.54	0.404			0.040 (2)
Nitrate	mg/L	0.01	0.93	0.05	0.07	0	10	NA
TDS	mg/L	10	4,592	935	1,010	61	NA	NA

Notes:
NA – No Standard available.
SW Std = Surface Water Standard based on FAC Class I and III surface water regulatory exceedance criteria; Rule 62-302.530.
SD = Standard Deviation
(1) Class I surface water standard for turbidity is less than or equal to 29 NTU above background
(2) Phosphorus criterion currently (2013) is estimated from TMDL loading into Lake Okeechobee

Water quality data also were collected as part of another water characterization effort for the period of 1989-2002. Selected constituents from the 1989-2002 and 2001-2012 datasets are compared in **Table 4-3**. Over time, there has been a significant decrease in total suspended solids (TSS), turbidity, alkalinity and iron in the source water while color values have significantly increased (SFWMD, 2012 b, c). Source water quality was also measured throughout ASR system operation, as discussed in **Section 9.2.1.1 (Tables 9-2** through **9-6).**

Table 4-3 -- Comparison of Selected Characteristics from Two Historical Kissimmee River Data Water Quality Data Sets

Constituent	Unit	2001-2012 Data Set				1989-2002 Data Set				Percent Change in Mean
		Mean	Median	Max	Min	Mean	Median	Max	Min	
TSS	mg/L	3.1	1.5	79	0.5	12.7	9.0	218	2.0	-76
Color	PCU	127	110	467	29.0	50.6	39.0	7.00	2.0	+150
Turbidity	NTU	3.3	3.0	27	0.8	7.2	4.2	265	0.4	-54
Alkalinity	mg/L	37	36	68	14	90	95	219	0.67	-56
Iron	mg/L	0.39	0.34	1.04	0.09	0.82	0.42	4.41	0.03	-53

4.1.2 Source Water Availability

Source water availability and demand analysis defines the volume and timing of water that can be diverted into storage at each ASR system. The KRASR system recharges water from the Kissimmee River downstream of water control structure S65E. There are no intervening water control structures downstream between the KRASR intake and Lake Okeechobee. When S65E is closed, surface water can flow either upstream or downstream depending on wind direction. The KRASR system is designed for Lake Okeechobee/Kissimmee River water level of 14-ft NGVD29 (National Geodetic Vertical Datum 1929). However, recharge can occur with water level as low as 8-ft NGVD29. The intake screen is close to the water surface at depths below 8-ft NGVD29, which could induce cavitation in the pump.

KRASR withdrawal demands on the river are low relative to flow. There is no minimum flow requirement in the Kissimmee River to constrain recharge duration and timing, as the pilot system demand during recharge is small (7.5 cfs) compared to flow **(Table 4-4)**. However, it was necessary to compare this demand to flow frequency data to estimate seasonal variation in flow. **Table 4-4** lists the historic average monthly flows for structure S65E.

Figure 4-1 depicts flows through structure S65E on the Kissimmee River from 1958 to 2012 gathered for two different periods of record, 1958 to 2001 and 2001 to 2012. The older, longer period of record typically is used for surface water model development. The younger, shorter period of record captures more extreme weather events in south Florida – a historic drought and two years of multiple hurricanes. Mean monthly flow rates generally are at or above 1,000 cubic feet per second (cfs). In the more recent period of record, flows are approximately 2,000-cfs or greater approximately 40 percent of the time. These higher flows are due in part to a greater storm and hurricane frequency within the more recent period of record (E. Brown, personal communication, 2012). In comparison, the KRASR facility withdrawal demands on the river are approximately 7.7 cfs, or less than one percent of the historical flow rate.

Table 4-4 -- Historic Monthly Flow Data from Structure S65E, in cfs. Period of record from 1965 to 2000. Data from USACE (1999).

Month	Minimum	Mean	Maximum	Std. Deviation
Jan	0	1,348	9,490	1,808
Feb	0	1,530	12,200	1,786
Mar	0	1,634	12,200	2,119
Apr	0	1,592	7,610	1,718
May	0	1,006	5,350	1,090
Jun	0	938	11,400	1,594
Jul	0	1,575	14,000	2,203
Aug	0	2,318	12,200	2,490
Sep	0	2,313	14,900	2,493
Oct	0	1,920	23,500	2,940
Nov	0	982	9,710	1,939
Dec	0	909	10,400	1,664

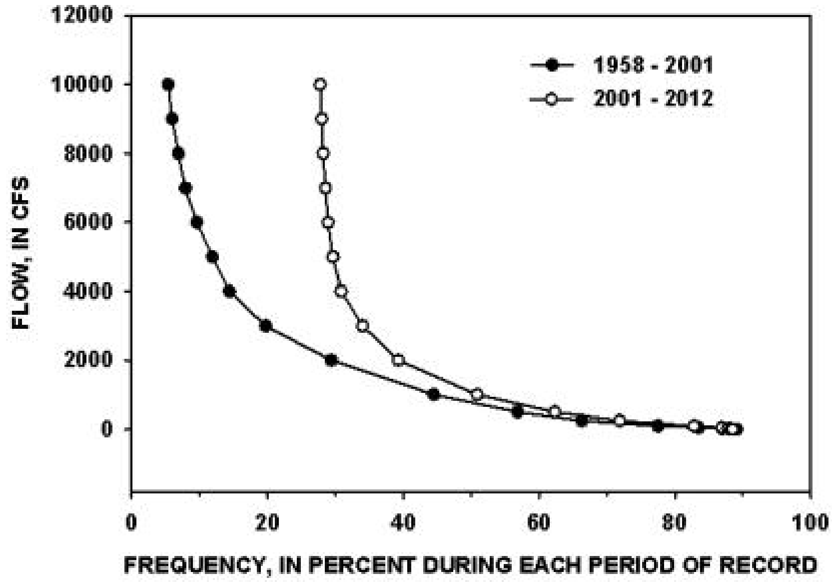


Figure 4-1 -- Plot showing average flows at the S65E water control structure on the Kissimmee River. Two periods of record are shown: 1958 through 2001, and 2001 through 2012**.** Data from the SFWMD DBHydro database.

4.2 Hillsboro ASR System

The single-well Hillsboro ASR (HASR) Pilot system was planned at the proposed Site 1 Impoundment location in Palm Beach County. In order to select the appropriate pre-treatment components for the HASR surface facility, it was necessary to analyze surface water quality, availability, as well as conduct a filtration pilot study for feasible application at the full design scale. These studies are discussed in the following sections.

4.2.1 Source Water Quality

Historically the surface water quality in the Hillsboro Canal is characterized as treatable for potability, with low turbidity, moderate dissolved oxygen concentrations, and high color. The HASR design memorandum (PBS&J, 2005) characterized source water quality, and these results are summarized in **Table 4-5**. Source water quality was also measured throughout HASR system operation, as discussed in **Section 9.3.1.1.**

High flows through S39 can disturb sediment within the canal and increase turbidity values, which could clog HASR filters. The HASR surface water intake is located approximately 900 feet downstream from S-39 structure to allow larger suspended particles to settle upstream of the ASR system. The particle size range is approximately 1 µm or less in size (PBS&J, 2004; **Section 4.5**).

Table 4-5 -- Hillsboro Canal Source Water Quality Data Data from PBS&J (2005).			
Parameter	**Units**	**Avg. Value**	**No. of Samples**
Water Temp	° C (° F)	25 (77)	N/A
Dissolved Oxygen	mg/L	3 - 4	N/A
pH	Standard units	7	N/A
Turbidity	NTU	3	280
TSS Concentration	mg/L	3 - 4	90
Particle Diameter	µm	< 1	N/A

4.2.2 Source Water Availability

The purpose of the source water availability and demand analysis at the Hillsboro ASR system was to estimate the volume and timing of water that could be diverted into storage. Using data compiled by the USACE (2004), the Hillsboro Canal can provide sufficient recharge water supply to the ASR system during the wet season of June through October. In the unlikely event that reduced LNWR regulatory releases and/or drought lowers the water level in the Hillsboro Canal, it was recommended (USACE, 2004) that water from Lake Okeechobee or other locations upstream of water control structure S39 could be rerouted to the Hillsboro Canal. Rerouting would allow continuous operation of the HASR system during periods of low source water availability without affecting downstream users. The stage in the Hillsboro Canal is defined in the WCA-1 regulation schedule. Discharges at the (upstream) S39 structure are managed for a maximum tailwater elevation of 9.0-ft NGVD29. Water levels at the downstream G56 structure are managed to maintain a headwater of 7.0- to 8.0-ft NGVD29. The Hillsboro Canal water surface elevation at the HASR site has not exceeded 9.0-ft NGVD29 during cycle testing operations. The canal elevation at this location typically is above 6.0-ft under normal conditions but is susceptible to falling below 6.0-ft due to water supply pumping and drought conditions (SFWMD, 2002).

Surface water flow from LNWR is controlled by structure S39 upstream of HASR, and water control structure G56 downstream. After water supply demands have been met, G56 discharges excess Hillsboro Canal water to tide. As such, G56 discharge volume provides the best indication of water availability for the HASR system. The average daily discharge at G56 for any single day varies from approximately 500-cfs in January to 9-cfs in May. G56 headwater flow data from February 1986 to December 2001 are shown in **Figure 4-2**. Demand flow was analyzed at various canal flow elevations and it was determined to have enough source water at this location for three separate 5-MGD facilities. It was concluded that the estimated water volume available was clearly sufficient, except during a severe drought (USACE, 2004).

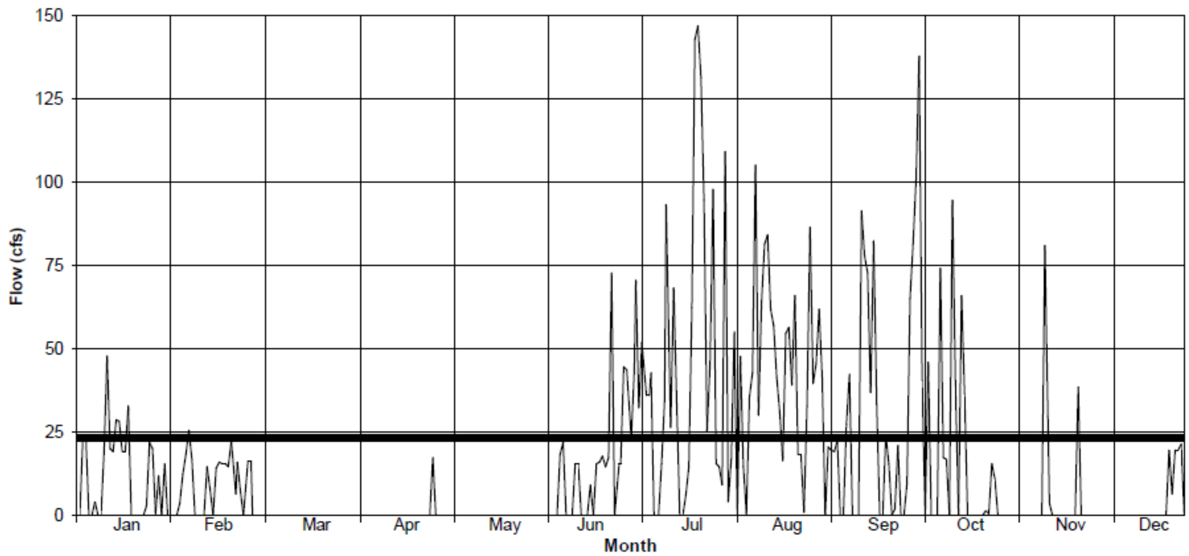


Figure 4-2 -- Flow statistics at the G-56 structure by month. Light line shows average daily flow 90 percent exceedance record, dark line is 25 MGD demand at HASR. Period of record is February 1986 to December 2001. Figure from SFWMD (2001).

4.3 Filtration and Disinfection Feasibility Study

Once surface water quality characterization was completed, the optimum treatment technologies were evaluated during pre-treatment feasibility studies. Pre-treatment feasibility studies were conducted for the KRASR surface facility design from August to September of 2002, to coincide with wet season releases from Lake Okeechobee (Carollo, 2003). Four different filtration and disinfection technologies were considered. The following combinations of components were tested as potential "treatment trains":

- Simulated bank filtration, ozonation
- Simulated bank filtration, UV disinfection
- Simple mechanical separation, ozonation
- Simple mechanical separation, UV disinfection

4.3.1 Simulated Bank Filtration

This treatment train consisted of source water pumped from an intake pipe through a centrifugal pump into the simulated bank filtration treatment unit for subsequent disinfection. Simulated bank filtration consisted of a mechanical separation unit either a wedge-wire filter or cyclone separator, followed by a gravity sand filter operated at a very low loading rate. The flow rate through the sand filter ranged between 14 and 30 gallons per minute (GPM), with an average value of 22.3 GPM (Carollo, 2003). **Figure 4-3** shows the measured loading rates compared to the loading rates typical of a rapid sand filter and a bank filter. Bank filtration loads were approximately one-fifth of those capable of being handled through a rapid sand filter.

The simulated bank filtration treatment yielded promising results, with attenuation of some constituents. Color was reduced by approximately 55 percent to 120 Platinum-Cobalt Units (PCU). Turbidity was reduced 78 percent to 3.38 NTU. Coliforms were reduced 93 percent to 59 colony forming units (CFU)/100 mL. However, this value exceeded the Florida groundwater criterion of 4 CFU/ 100 mL (FAC 62.520.420). The sand filter effluent also showed consistently removed, which would reduce the potential for well clogging but would require more maintenance of the filter bed. Summaries of each of the individual treatment scenario implemented within simulated bank filtration are included in the following subsections of **4.3.1**.

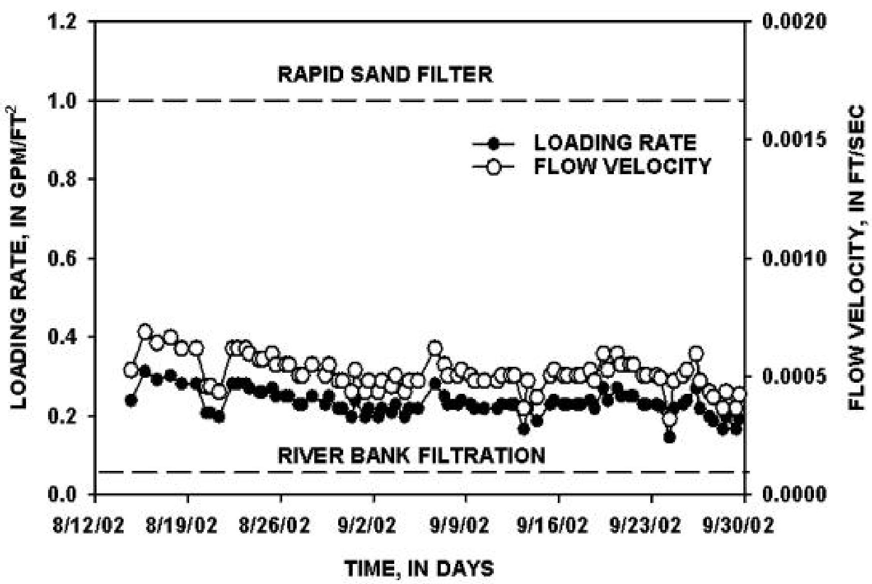


Figure 4-3 -- Plot showing trends in loading rate and flow velocity measured during the filtration feasibility tests. Data are compared to values for rapid sand filter and riverbank filtration systems. Data from Carollo Engineers (2003).

4.3.1.1 Wedge-Wire Filter

A wedge-wire filter served as the initial mechanical separation unit for the simulated bank filtration feasibility test. Wedge-wire screen sizes of 25-µm, 50-µm, and 75-µm were evaluated. The filter typically was operated with a cleaning assembly in constant operation at a rotation rate of 9 rotations per minute (rpm). "Blow down" of the accumulated solids typically was done once per day independent of pressure drop across the unit. The typical range of differential pressure across the unit was 3 to 10 pounds per square inch (psi). As expected, the pressure differential increased with time between blow downs. In addition, a smaller screen size generally resulted in higher operational pressure differentials. Because of this differential and its impact on process flow, the majority of the sampling was performed with the 75-µm screen size. In general, the water quality downstream of the wedge-wire filter was virtually indistinguishable from the influent source water quality over the duration of the study, regardless of the screen size used. Even the 25-µm screen assembly consistently showed only marginal reductions in particle counts. Similar to particle count data, the turbidity, color, algal count, and ultraviolet (UV) absorbance measurements did not differ significantly from the source water influent measurements, regardless of the size of the wire mesh. Only microbiological constituents were removed by the wedge-wire filter effluent, and this improvement was observed for all screen sizes (Carollo, 2003).

4.3.1.2 Cyclone Separator

The cyclone separator was operated with a continuous injection of the solids slurry, which emptied to an overflow trough, mixed with filtered water, and was then pumped to the lake. During this time, the cyclone separator was not operated under the design flow conditions (35-55 GPM) because the flow rate through the sand filters following the cyclone separator was limited to 10-20 GPM. Even at lower flow rates, the cyclone separator performed at least as well as, if not better than the wedge-wire filter, with the exception of particle counts. Particle counts of the cyclone effluent were similar to those of the influent source water. Turbidity, color, and UV absorbance values of the cyclone effluent were slightly lower than those observed in the source water. Microbial results were highly variable - some cyclone effluent samples showed reduced microbial concentrations while others showed an apparent increase in the same microbe counts. Therefore, no consistent conclusions could be drawn about the microbial removal efficiency of this unit process (Carollo, 2003).

4.3.1.3 Mechanical Separation Conclusions

The wedge-wire filter and cyclone separator tested here provided marginal improvement of source water quality, at best (**Table 4-6**). Due to the lack of benefits obtained from these components, their use could not be justified as a stand-alone treatment system. Particle size distribution measurements of the source water verified that screen sizes above 15-µm had little effect on turbidity, and particle counts and screen sizes below 15-µm are not feasible for this technology (Carollo, 2003).

Table 4-6 -- Summary of Mechanical Separator Pre- and Post-Treatment Water Quality (Carollo, 2003)

Parameter	Unit	Average	Min	Max	Avg. Percent Reduction*
Particle Count (Total)	no. / mL	7,863	1,143	9,152	4
Turbidity	NTU	15.4	5.1	55.4	< 1
Algae	no. / mL	17,092	15,016	19,168	< 1
TSS	mg/L	15.5	5.4	42	4
Color (apparent/true)	PCU†	261/94	192/29	435/192	< 1 / < 0
UV Absorbance (unfiltered/filtered)	cm^{-1}	0.75/0.65	0.54/0.42	0.98/0.90	< 0 / < 0

*Average Percent Reduction based on difference between source water and sand filter effluent

†Referenced report designates these as color units which are most commonly measured on the platinum-cobalt scale and referred to as Pt-Co units or PCU.

4.3.1.4 Sand Filter

The sand filter (Miami Filter Company, Ft. Pierce, Florida) consisted of a circular steel vessel with 36-in thickness of 0.45- to 0.55-mm diameter sand filter pack. The sand filter was operated downstream of the wedge-wire filter or cyclone separator components to simulate the bank filtration process. The filter was plumbed with an inlet float valve to maintain constant water level on top of the media. During the first week of operation, decreased flow was noted and a pump was installed at the effluent port to maintain a constant filter outflow rate. Additionally, approximately 2-in of filter medium was removed to minimize head loss through the filter. The system operated effectively for approximately 2 weeks before a series of “reverse flow” procedures were performed to purge air from the system. At no time during the “reverse flow” procedure was the filter medium fluidized or the filter waste wash water removed. An additional 2-in of filter medium was removed near the end of the study to maintain effluent flow (Carollo, 2003).

4.3.1.5 Sand Filtration Conclusions

The sand filter improved a number of the water quality characteristics when compared to the source water, or effluent from the mechanical separation process **(Table 4-6)**. These data suggest significant reduction in particulates, iron, and turbidity concentrations by the sand filtration process. Microbe concentrations were reduced significantly, typically by one to two orders of magnitude. A small reduction of particulate carbon and UV absorbance was observed in sand filter effluent, although no reduction in total organic carbon (TOC) and filtered UV absorbance was observed. The lack of TOC removal or reduction of filtered UV absorbance probably resulted from the lack of biological activity on the sand media. The hydraulic residence time (HRT) through the sand filter was on the order of one to three hours (Carollo, 2003).

The feasibility test results indicate that simulated bank filtration, and in particular the sand media component, is effective for removing a percentage of turbidity, particulates, and microbes. It was proposed that by increasing the HRT through a sand media filter to that of a full-scale bank filtration system, the particulate and microbe attenuation would be enhanced to a level to meet state and Federal groundwater and drinking water standards. The addition of UV and/or ozonation to a treatment train using bank filtration will likely ensure compliance with primary and secondary drinking water standards, and could potentially reduce the required bank filtration HRT (Carollo, 2003).

4.3.2 Ultraviolet (UV) Disinfection

Two disinfection processes were tested following filtration: UV disinfection and ozonation. Additional testing was performed to determine if a simple particulate removal process (the mechanical separation units) could be employed in lieu of bank filtration. During this phase of the testing, effluent from the mechanical separation unit bypassed the sand filtration unit and was fed directly to the ozonation or UV disinfection units.

The UV disinfection feasibility test was conducted using an Aquionics Berson In-Line 125 reactor, containing four, 400-watt medium pressure UV lamps inside a 316-L stainless steel pipe spool. UV disinfection is rated by the dose of energy applied, in millijoules of energy per square centimeter (mJ/cm^2). During the feasibility tests, dosages were applied from 40 mJ/cm^2 to 140 mJ/cm^2 and flow rates ranged from 10- to 50-GPM. Treated water was discharged to a collection basin and then returned to the lake (Carollo, 2003)

During operation, cleaning was performed to ensure the optimal function of the UV units. The reactor and associated piping were taken off-line and cleaned with a dilute chlorine solution and brush. During this cleaning, substantial algae growth was removed. In each case, the cleaning was initiated when the UV intensity decreased to 90 percent. The UV intensity returned to 100 percent after one cleaning cycle. During the test, the UV disinfection process did not significantly change non-microbial water quality constituents at the applied doses. These non-biological water quality constituents are shown in **Table 4-7.**

Table 4-7 -- Non-Biological UV Disinfected Water Quality

Constituent	Unit	Average	Min	Max
Dissolved Oxygen	mg/L	5.9	3.6	7.4
Dissolved Organic Carbon	mg/L	20.6	16.9	33.4
UV Absorbance (Unfiltered)	cm^{-1}	0.660	0.429	0.895
UV Absorbance (Filtered)	cm^{-1}	0.620	0.413	0.870
Alkalinity	mg/L as $CaCO_3$	103	65	134

Ultraviolet Transmittance (UVT) is a critical characteristic of source water to evaluate the treatment and cost effectiveness of a UV disinfection system. The efficacy of the UV disinfection system was tested using two water types: effluent from the mechanical separation process, and effluent from the sand filtration process. Initial UVT values for both data sets were approximately 12 and 14 percent for the mechanical separation and sand filter effluent, respectively **(Figure 4-4)**. UVT values showed some variation in both effluents through the feasibility tests. Final UVT values of both data sets were approximately 17 and 27 percent for the mechanical separation and sand filter effluent respectively. This coincided with the last day in a series during which no water was pulsed into the canal. Pulsing seemed to increase and improve the UVT values (Carollo, 2003).

4.3.2.1 UV Disinfection Conclusions

Although the UV disinfection equipment was sized and operated to deliver a maximum dose of 140 mJ/cm^2, microbes were detected in the disinfected effluent. Two potential reasons for detections in effluent samples were hypothesized. First, while the utmost care was taken to follow industry accepted sampling procedures in the field, the location and conditions of the test may have contributed to contamination of the effluent during sampling. Coliform bacteria are common in untreated water and soil, and it is difficult to maintain sterile surfaces in the field. Second, the UV effluent was hydraulically short-circuiting within the reactor. Because of the extremely low UVT of the water, the chosen reactor was oversized compared to the reactor size for typical water applications. This resulted in very small flows travelling through the reactor, potentially causing undesired hydraulic conditions (e.g. hydraulic short circuiting) that minimized the applied dose. Full-scale reactors are not as susceptible to this type of phenomenon because they must be validated as part of the procurement process. During validation testing, hydraulic inefficiencies affecting performance would be recognized. In addition, full-scale designs can incorporate smaller reactors in series, exposing the water to more UV lamps while maintaining flow velocities through the reactors at acceptable rates (Carollo, 2003).

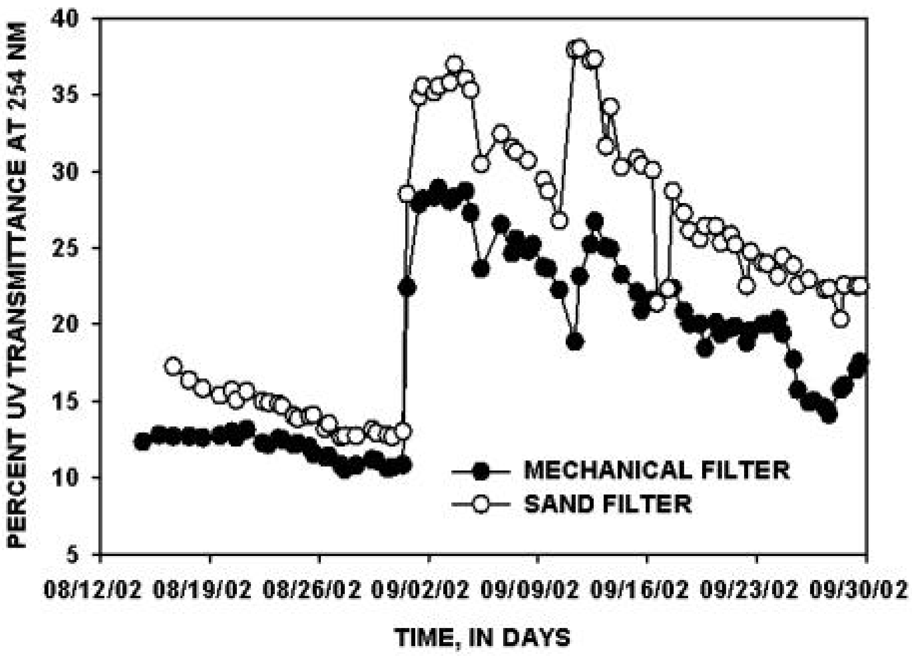


Figure 4-4 -- Plot showing percent UV Transmittance (UVT) in effluents from the mechanical and sand filters. Data from Carollo Engineers (2003).

In terms of overall water quality, UV disinfection did not reduce coliform counts to meet drinking water standards. Average total coliform measurements were 23 CFU/100 mL. Transmittance during the operational test averaged 23 percent, which was near the maximum performance level of the UV unit. The average color value of effluent from the sand filter was 89 PCU (Carollo, 2003), suggesting that the coupling of sand filtration with a single UV disinfection unit will be insufficient for regulatory compliance.

4.3.3 Ozonation Study

The ozonation study was conducted using an ozone generator and contactors, and controls on two skids. One skid contained the programmable logic controller (PLC) and the human machine interface (HMI) as well as a power distribution panel to supply power to the instrumentation and ozone generator. The second skid contained the ozone generator and ozone contactors (three flow-through

8-in clear PVC pipes with diffusers at the bottom for gas introduction). Sample taps were installed after each contactor as well as downstream of the skid (Carollo, 2003).

Feed water quality was evaluated during three separate time periods to characterize variability. Initially, effluent from the sand filtration process was used as feed water for the ozonation process (August 23-31). Two sets of ozone demand and decay tests were performed during this period to evaluate the required dose and the decay constants. Additional ozone demand testing was conducted from September 1-23 due to changes in source water quality resulting from the pulsing of water from Lake Okeechobee through the St. Lucie Canal. As expected, this change in source water quality altered the sand filter effluent quality, resulting in different ozone effluent quality. After the additional testing related to the pulsing events was completed, one last alteration of the ozone feed water quality occurred during the study extension from September 24-29. The ozone feed water was then switched from sand filter effluent to mechanical separation effluent. Additional details of the ozonation study are discussed in the following subsections (Carollo, 2003).

4.3.3.1 Ozonation for Disinfection

To evaluate the effectiveness of ozone as a disinfectant, the concentration and reaction relationships of aqueous ozone as it passes through a series of contact columns was required. The concentrations and reaction relationships were characterized during a series of demand and decay tests using oxygen as the feed gas to maintain a measurable ozone residual. Achieving a measurable ozone residual during feasibility testing was difficult without an extremely high applied ozone dose.

The primary disinfection byproduct of ozonation in the presence of bromide ion is bromate, BrO_3^-. Since bromate is a regulated potential human carcinogen (Maximum Contaminant Level, MCL = 10 μg/L), it is an important analyte for maximum ozone dose determination. At low ozone doses, no bromate formed because most of the ozone was rapidly consumed by the oxidation of organic material. In fact, no bromate formed until the ozone dose reached 9.6 mg/L. Further, the study showed that an ozone dose of approximately 14 mg/L produced 10 μg/L of bromate, equal to the drinking water MCL. It was concluded that a balance between achieving a desired residual for disinfection requirements and limiting bromate formation should be incorporated into the design of an ozone disinfection system (Carollo, 2003).

As a result of the high ozone demand required by the feed water and the potential for disinfection byproduct formation, a moderate ozone dose was used for the test. The moderate dose yielded satisfactory UV absorbance and color removal but produced no measurable ozone residual.

4.3.3.2 Long-Term Testing of Ozonation

This section summarizes overall water quality of the ozonated effluent during long-term testing. For the initial testing phase, an average ozone dose was 5.2 mg/L, but ranged from 1.6 to 32.2 mg/L. During the normal operation phase the dose was maintained at an average of 5.2 mg/L ± 2 mg/L. After the sand filter bypass was installed and the mechanical separation effluent became the ozone feed water, the applied dose was increased to an average of nearly 12 mg/L. This increase was achieved by decreasing the process water flow rate to between 5 and 6.5 GPM. The higher dose during this phase helped to compensate for the increase in UV absorbance attributed to the bypass scenario, and yielded ozonated effluent with UV absorbance values similar to those before the bypass (Carollo, 2003).

Average ozonated water quality is shown in **Table 4-8**. The averages were calculated for the overall study period as well as subdivided to show water quality changes that resulted after disinfection of sand filter versus mechanical separation effluent. Selected water quality constituents also were measured in ozonated sand filter effluent during the pulsing event. Effluent turbidity depended on the influent feed water turbidity. The effluent color was much higher when the mechanical separation effluent was fed directly to the ozone system. The UV absorbance and true color for ozonated, mechanical separation effluent was similar to that of the sand filter effluent during the pulsing event due to an increased applied ozone dose. The iron concentration increased and the pH dropped when mechanical separation effluent was fed to the ozone system, compared to values observed with sand filter effluent. Additionally, microbial constituents increased when mechanical separation effluent was fed to the ozone skid as opposed to sand filter effluent despite increased applied ozone doses. This increase demonstrated that the the sand filter served as a barrier of protection from pathogens. In addition, coliform counts using this method of treatment were higher than those resulting from use of UV treatment and also did not meet the drinking water criteria (Carollo 2003; USACE, 2004).

Table 4-8 -- Summary of Ozonated Water Quality

Constituent	Unit	Overall Avg.	Avg. SFE[1]	Avg. MSE[2]	Min	Max
Turbidity	NTU	5.6	2.8	19.8	1	32.7
Dissolved Oxygen	mg/L	7.5	7.6	7	4.9	16.3
Color (Apparent)	PCU	108	86 (62)[3]	227	16	366
Color (True)	PCU	56	59 (32)[3]	39	6	136
TOC	mg/L	24.9	24.7 (23)[3]	28	18.6	46.5
DOC	mg/L	20.8	20.8 (18)[3]	21	11.4	36
UV Absorbance (Unfilter)	cm^{-1}	0.509	0.509 (0.391)[3]	0.510	0.156	0.824
UV Absorbance(Filtered)	cm^{-1}	0.476	0.491 (0.371)[3]	0.393	0.148	0.793
Alkalinity	mg/L as $CaCO_3$	103	108	76.0	60.0	147
Bromate	µg/L	6.7	6.7	-	0	20
Iron	mg/L	0.094	0.074	0.191	0.025	0.219
pH	standard units	7.65	7.7	7.5	7.2	8
Fecal Coliform	no./100 mL	3.5	2.7	8.2	1.0	26
HPC	CFU/100 mL	1270	765	3800	3.00	5600
Total Coliform	no./100 mL	116	19	550	1.0	1000
Enterococci	no./100 mL	1	1	1	1	1
Bacillus Spores	no./100 mL	1243	916	2550	5.00	2550

[1] SFE – average with sand filter effluent as ozone feed water.
[2] MSE – average with mechanical separation as ozone feed water.
[3] ( ) indicate the SFE average for September 1 – 23 during the pulsing event.
Data summarized from Carollo (2003), Table 4.14

4.3.3.3 Ozonation Conclusions

Lake Okeechobee water required a very high ozone dose due to the concentration and nature of the dissolved organic carbon. Ozone decay rates were high, making it difficult to maintain a residual for any significant amount of time (Carollo, 2003). Average ozone doses during the study were insufficient for meeting the water-quality criteria for total and fecal coliforms. As the overall ozone dosage is limited by the 10 µg/L bromate MCL, tests indicate that this system is not sufficient for compliance with drinking water standards. Ozone alone may not be effective for disinfection due to high required doses and measureable source water bromide concentrations. However, the use of ozone was found to reduce UV absorbance and color and thereby improve UV transmittance.

It was determined that ozone could potentially be an effective treatment option in terms of improving the performance of a downstream UV disinfection unit. By increasing the UV transmittance of the water, the size of a UV reactor could be reduced. Additionally, if an ozone system does not have to be sized for disinfection but rather color, taste and odor compound removal, its size would also be reduced. It was suggested by Carollo (2003) that the combined use of a smaller ozone system and smaller UV system might be more effective in terms of both capital and operating costs while still meeting water treatment goals.

4.3.4 Feasibility Study Conclusions

Throughout the feasibility studies, source water quality varied dramatically as a result of the "pulsing" of lake water through the St. Lucie Canal. In general, pulsing improved the overall water quality entering the treatment system. Source water quality is characterized by high TOC, DOC, UV absorbance, and color values. Particle counts and diameters in the source water indicate microparticulates having typical size distributions ranging between 3- to 15-µm. The microbial testing results indicated that the fecal contamination was also high given the number of indicator organisms observed. Although no protozoa were found during the study, the levels of indicator organisms suggested the likely presence of protozoa. Limited water quality testing at alternate locations suggested no significant differences among locations tested when compared to the present intake location (Carollo, 2003).

Water quality testing of the effluent from the mechanical separation equipment (wedge-wire filter or cyclone separator) indicated that this process had limited effectiveness due to the small particle diameters in source water. Particle counts suggested that most of the particulate matter was less than 15-µm, smaller than all filter mesh sizes tested. In addition, source water organic component characteristics likely limited the effectiveness of the cyclone separator and wedge-wire filter, respectively (Carollo, 2003).

Sand filter effluent results suggested that this component was effective at reducing concentrations of turbidity, particulate material, iron, and microbes. In contrast, sand filter effluent showed only limited reductions in organic constituent concentrations (TOC, filtered UV absorbance). One potential reason for less effective organic attenuation is that the travel times through the sand filter were not long enough for significant microbial degradation. The high level of organic material present in the sand filter effluent (or mechanical separator bypass) resulted in the water having a very high oxygen demand (Carollo, 2003).

During the UV disinfection study, the UV reactor was operated to deliver dosages up to 140 mJ/cm^2, equal to the required dose for microbe inactivation. Effluent sampling indicated that some microbes had survived passage through the system, probably due to short-circuiting through the system or environmental contamination of the effluent samples. Fouling of the reactor lamp was observed once during operation when the system was fed with sand filtration effluent, and three times when the system was fed mechanically separated effluent. This fouling was remedied by implementation of the UV unit cleaning system, indicating that most automatic cleaning systems provided with full-scale UV reactors should keep lamp sleeves free from fouling and scaling (Carollo, 2003).

Ozonation treatment testing indicated that the levels of ozone required to overcome the demand of the water and provide a residual may be cost-prohibitive, due in part to the bromate concentrations present in the disinfected effluent. The use of comparatively low levels of ozone resulted in improvements to water quality, making ozone an attractive potential pretreatment step for a UV disinfection system. The use of ozone in this capacity would not yield effluent bromate concentrations that exceed the MCL. Lower dose treatment also would improve taste and odor, color, and UV absorbance without the requirement of a large contactor necessary to achieve adequate disinfection (Carollo, 2003).

4.4 Microfiltration Feasibility Study

Two different microfiltration technologies were tested as a component of the overall water treatment: a microfiltration unit (MF), and a serial filtration unit (SF; HSA, 2003). Source water was drawn from the St. Lucie Canal, using a 0.75-HP pump at an average rate of 20 GPM, then delivered to an equalization tank for use as feed water. After coarse filtration using a mechanical wedge-wire filter, the water was discharged into a 500-gallon high density polyethylene (HDPE) feed equalization tank located within the test facility. Two separate feed pumps transported the post-equalization feed water into the MF and SF units, set-up in parallel. The filtrate from both units emptied into the effluent holding tank and was then pumped to Lake Okeechobee (HSA, 2003). The schematic diagram for this process is shown in **Figure 4-5**.

Backwash from both the SF (the 20-µm multimedia filter) and microfiltration (MF) units was discharged into the same backwash equalization tank. From here, the backwash was pumped into a 2,000-gallon HDPE tank. The backwash interval of the MF unit was varied, but each interval was maintained for 20 minutes. The SF unit was backwashed manually each day throughout the test. All accumulated solids collected in this manner were removed offsite at the end of the test by a licensed waste hauler.

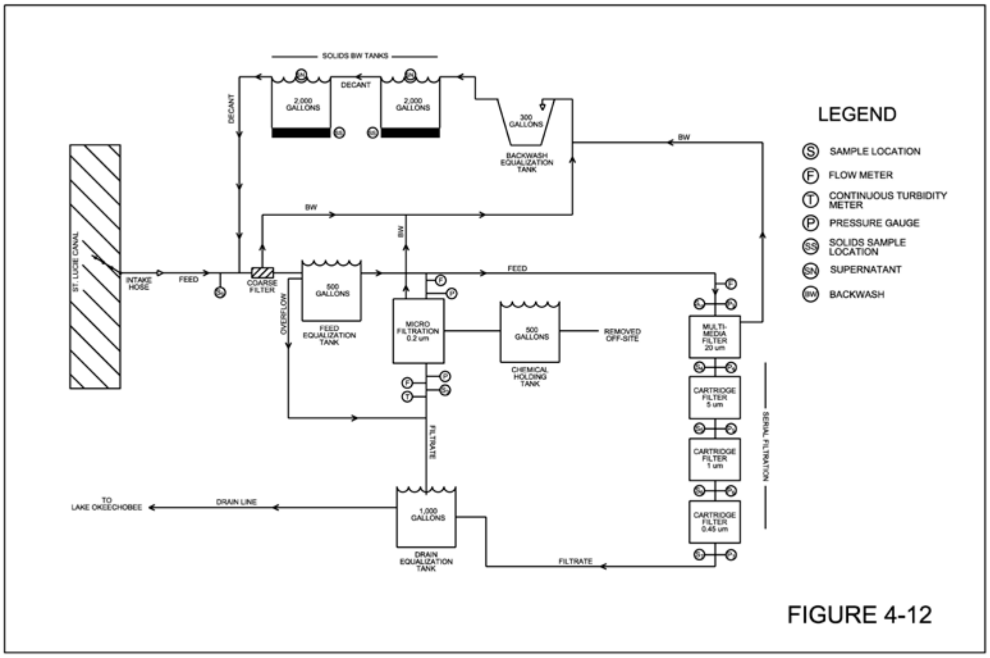


Figure 4-5 -- Microfiltration treatment test schematic.

The filtration facility was operational during August-September 2002 for a total of 35 days. During the test, MF flow, flux rate (flow per unit of MF membrane area), and backwash frequency were altered to determine the settings that would produce the highest membrane yields with the longest uninterrupted run times between chemical cleanings. Flow, and therefore flux, through the serial filtration (SF) unit was also varied to determine filter change out intervals. Both MF and SF systems are detailed in the following **Sections 4.4.1** and **4.4.2** respectively, with tables compiling test results located in **Section 4.4.3**.

4.4.1 Microfiltration

The microfiltration (MF) process is a physical solids separation technique using membranes capable of removing small particulate matter and suspended solids. As a result of the small pore size bacteria, protozoans, parasitic cysts, and some viruses can be removed effectively without disinfection. An MF pilot unit (US Filter, Snellville GA, Model 3M10C) having a nominal filter pore size of 0.2-µm and flow rates of 10- to 20-GPM was employed. During testing, the influent flow was evenly distributed throughout the top and bottom of all modules. The influent feed pump pressurized the modules to nearly 30-psi, forcing the water through the hollow membrane fibers as permeate was collected. Upon backwashing, the modules were injected with approximately 90-psi of compressed air opposite to the normal flow direction, thus effectively cleaning the membranes. The MF unit was a completely automated, continuously operating, and self-cleaning apparatus. A programmable logic controller (PLC) controlled all flow rates, chemical cleans, and backwash intervals. In addition, the PLC contained an automatic data logger that recorded filtrate turbidity, run hours, feed pressure, filtrate pressure, transmembrane pressure, feed flow, filtrate, flow, filtrate totalizer, and information on emergency shutdown conditions (HSA, 2003).

Overall, the MF unit was operational for a total of 755 hours. During the test, the MF process throughput and backwash frequency were altered to determine the settings that would produce the highest membrane yields with the longest uninterrupted run times between flux restoration (chemical cleaning). The MF pilot unit was continuously operational for 95.5 percent of the test, but was down approximately 85 hours as a result of two storm-induced power outages and plumbing repairs on the treatment system. The MF unit itself did not pose any technical operational upsets and ran efficiently throughout the test.

Fecal coliform concentrations within the influent canal source water varied from less than 1 to 140 CFU/100 mL and averaged 55 CFU/100 mL. Throughout the duration of the test, no fecal coliforms were detected in the microfiltration filtrate effluent. Turbidity was also reduced from the influent stream by nearly 100 percent throughout the duration of testing and was consistently below the required level of 0.3 NTU. Typical MF filtrate turbidities were approximately 0.1 NTU regardless of the turbidity of the influent stream. The specific conductance of the effluent stream averaged 522 microsiemens/cm (µS/cm) and was nearly identical to that of the source water influent. This was also true of pH. The mean color value of the source water was 250 PCU and, on average, color was reduced by 73 percent by the MF units. Bacteriological and pathogen analyses of the source influent water and MF filtrate were conducted the final week of operation for *Enterococci*, heterotrophic plate count (HPC), total coliform *Giardia*, and *Cryptosporidium*. Phosphorus, sulfate, and chloride also were measured during the final week of operation. No changes in influent source water versus filtrate concentrations for chloride or sulfate were observed. The MF unit did remove approximately 25 percent of total phosphorus and about 50 percent of the total phosphorus from the source influent stream (HSA, 2003).

Overall, the performance of the MF unit successfully met drinking water standards for primary and secondary drinking water standards. Fecal coliforms were reduced from an average of 55 CFU/100 mL to below detection level. Turbidity also was adequately reduced. Backwash times were not excessive; however, backwash volumes (greater than 88,000 gallons) represented 20 percent of the process run volume. This requires the microfilters to be rated 20 percent above design to achieve full performance (HSA, 2003). Use of MF technology will require several thousand gallons of water and cleaning chemicals to maintain the filters, which will increase disposal costs.

4.4.2 Serial Filtration

The serial filtration (SF) unit was supplied by Ionics Corporation and consisted of a 20-µm multimedia filter followed, in series, by 5-, 1-, and 0.45-µm cartridge filters **(Figure 4-6)**. The purpose of the test was to determine if these were feasible in any application for an ASR facility. The 20-µm filter was used to approximate the performance of a pressure filter so it could compensate the data gap between the Carollo (2003) and HAS (2003). The serial filtration tests were conducted simultaneously with the MF tests.

The SF unit operated for 625 hours, or for 77 percent of the test duration. The unit was down approximately 205 hours during testing. Approximately 85 of those down hours were the result of the power outages and plumbing repairs resulting from storm activity. The remaining 120 hours of downtime were due to technical difficulties regarding the filter cartridges clogging rapidly during normal filtration. Specifically, the 0.45-µm cartridge would become completely blocked within 20 minutes at a flow rate of 10 GPM. When clogging occurred, pressure build-up across the system reduced water flow to 5 GPM or less. After the first week of testing, the 0.45-µm cartridge was bypassed making the 1-µm cartridge the final filter in the serial system. Flow rate through the 1-µm cartridge was difficult to stabilize. Flow rate greater than 10 GPM was rarely maintained, as the gauge pressure would increase sometimes by 15 psi within two hours before backwashing the 20-µm filter. Optimal serial filter throughput occurred at flows less than 6 GPM with a total daily backwash time of about 30 minutes. These conditions yielded about 49,000 gallons of filtrate over 150 hours of operation before cartridge replacement was required (HSA, 2003).

Figure 4-6 -- Photo showing Ionics serial filtration system with 20-, 5-, 1-, and 0.45-µm cartridge filters (left to right).

On average, the 1-µm SF filtrate contained 22 CFU/100 mL of fecal coliform. Roughly 50 percent of fecal coliform colonies were removed from the source influent stream by the SF unit during the test. The SF unit also reduced turbidity from the source influent stream by about 61 percent. The conductivity of the effluent stream was on average 522 µS/cm and was nearly identical to that of the source water influent. This was also true of pH. The mean color value of the influent source water was 250 PCU and, on average, color was reduced by 44 percent by the SF units. Bacteriological and pathogen analyses of the source influent water and SF filtrate were conducted the final week of operation for *Enterococci*, HPC, total coliform, *Giardia*, and *Cryptosporidium*. Little difference was observed between the influent source water versus the filtrate samples for concentrations of phosphorus, sulfate or chloride. It is was noted that the pressure filters of all pore sizes would require disinfection to inactivate total coliforms The 20-µm pressure filter would be able to be backwashed at full-scale operation, however backwashing a 5-µm or 1-µm screen at full operation would not be feasible. Overall, the SF test failed on several points and proved to be unreliable for fecal coliform removal or turbidity reduction in influent source water (HSA, 2003).

4.4.3 Microfiltration and Serial Filtration Result Tables

Summaries of the microfiltration (MF) and serial filtration (SF) performances are shown in **Table 4-9** and **Table 4-10.**

Table 4-9 -- Microbe Reduction During Microfiltration and Serial Filtration Tests

Analysis	Avg. Source Water Value	Units	Percent Removal Microfiltration	Percent Removal Serial Filtration
E. Coli	55	CFU/100 mL	100	25
Enterococci	207	CFU/100 mL	100	21
Giardia and *Cryptosporidium*	None Detected	cysts/100 mL	NA	NA
HPC	5,900	CFU/1 mL	92	12
Total Coliform	None Detected	CFU/100 mL	NA	NA

Table 4-10 -- MF and SF Performance Summary

Element	Units	Microfiltration	Serial Filtration
Run Time[1]	Hours	731	624
Approx. Volume of Filtrate	Gallons	420,000	170,000
Total Downtime for Chem Cleaning / Cartridge Change	Hours	24	1
Non-routine Downtime	Hours	37	180
Time Backwashing	percent of Total Time	10	5
Volume of Backwash	Gallons	88,000	9,000
Solids Production	Lbs/Million Gallons Filtrate	25	N/A
Total Power Used	kWh	1360	582
Consumption Rate	kWh/Million gallons filtrate	3200	3400
Average Filtrate Turbidity	NTU	0.1	6.3
Sufficient Pathogen Removal?	-	Yes	No
Avg Fecal Coliform in Filtrate	CFU/100 mL	None Detected	22
Number of Chemical Cleans?	-	3	N/A
Citric Acid Consumption Rate	Lbs/Million Gallons Filtrate	57	N/A
NaOCl Consumption Rate	Ounces/Million Gallons Filtrate	690	N/A
Operational Effeciency[2]	percent of time operational	95.5	77

1. Runtime does not include times of chemical cleaning or cartridge cleaning.
2. Project goal as per RFP was 85 percent operational efficiency.
3. Data from HSA, 2003.

4.5 Screen Filtration Feasibility Study

Feasibility testing of the TeKleen screen filtration system (Los Angeles, CA; Model MTF-2) was performed at the Port Mayaca site and the HASR during June 2004. Turbidity, TSS and particle size data were analyzed to determine efficiency of the TeKleen filter system. Testing was conducted to evaluate the efficiency of using 10-µm, 50-µm, and 100-µm filter screens.

Results for turbidity and TSS did not indicate any significant removal of particulates at either site by this system. Particle size analyses showed that the majority of the particles at both sites were 1-µm in diameter or less, and therefore smaller than the openings in the smallest screens (10-µm) provided by the TeKleen filter (PBS&J, 2004).

4.6 Conclusions Based on Treatment Technology Feasibility Studies

Feasibility studies that are described in Section 4 were conducted to define appropriate pre-treatment elements for the ASR systems, and to provide data for subsequent USACE design efforts. The final design recommendations for the surface facilities at both KRASR and HASR are defined in the Pilot Project Design Report (PPDR) (USACE, 2004). Based on the studies summarized above plus additional design work by the USACE, the following alternatives were recommended:

- KRASR: In-Bank Surface Water Intake + Pressure Media Filter + UV Disinfection
- HASR: In-Bank Surface Water Intake + Mechanical Filter + UV Disinfection

Media filters were one of sixteen different technologies evaluated and approved for inclusion in pilot ASR systems since the sand media filters performed adequately during feasibility tests to remove particulate matter. Testing demonstrated that filtration using a sand filter could, on average, reduce turbidity by 78 percent to below 4 NTU. Testing also showed that the sand filter significantly reduced particle counts. Particle counts between 7,000 and 9,000/100 mL in the raw water were reduced an average of 91 percent by the sand filters. The 20-µm multimedia filter used during the serial filtration study is similar in function to pressure media filters. The testing during this study included sampling for turbidity before and after the filter but further analysis of the data would be required to determine its effectiveness as such an analysis was not included in the report.

Although some microbial constituents were removed during testing of the sand filter (Carollo, 2003) and the multimedia and cartridge filters (HSA, 2003), filtration alone is not sufficient to attenuate microbial contamination in the source water to drinking water standards. As noted in the PPDR, filtration systems must be paired with a disinfection method. Testing also demonstrated that ozonation proved to be an unacceptable disinfection option since the dose required for microbial inactivation increased the formation of bromate byproducts exceeding the drinking water criterion. UV disinfection was also evaluated, and also resulted in effluent that did not meet the drinking water criterion for microbes. However, UV disinfection was selected for both systems even though pre-treatment removal of organics was not envisioned as a function of the filtration process. The presence of organics in the filtration effluent suggests a high potential for disinfection byproduct formation with the use of chemical disinfectants. Media filters were ultimately selected for installation at KRASR as one of the major technology groupings to be evaluated during the pilot testing.

The preliminary design of the HASR system assumed that under-drains would be used to capture seepage water from beneath a small pond, which would in effect provide needed filtration of water prior to ASR storage. Inclusion of an in-bank filtration system was proposed in order to include all major technology groupings during pilot testing. However, the PPDR notes that onsite borings coupled with literature data led to the conclusion that such a system was not likely to produce sufficient source water for ASR storage at this site. Subsequently, a screen filter coupled with UV disinfection was selected.

PPDR conclusions are that media and mechanical filters perform similar treatment functions, namely removal of particulates (USACE, 2004). The system ultimately installed at the HASR site consists of mechanical separation units (or filters) initially with 10-µm screens. It is anticipated that these mechanical filters will remove particulates in a fashion similar to the wedge-wire filters tested during the Carollo study (25-µm) or the TeKleen filters (10-µm) and the Kruger disc filters (10-µm) tested in subsequent studies. All studies indicated that these technologies (wedge-wire, TeKleen, and Kruger) were ineffective in removing particulates from the source water. Furthermore, particle size analyses during the Carollo (2003) study indicated particle size distributions ranged from 3- to 15-µm at the Port Mayaca site. A particle size analysis performed as part of the TeKleen study indicated the median size of particles was less than 1 µm for both the Hillsboro and Port Mayaca source waters.

5. Hydrogeologic Setting and Hydraulic Properties of the Floridan Aquifer System at the Kissimmee River and Hillsboro ASR Systems

5.1 Introduction

The thick, permeable marine limestones that include the Floridan Aquifer System are particularly well-suited for ASR. The confined portion of the Upper Floridan Aquifer (UFA) most commonly serves as an ASR storage zone in Florida. The following text briefly describes the geologic and hydrogeologic frameworks within which ASR cycle testing occurs at KRASR and HASR. **Table 5-1** summarizes the geologic (lithostratigraphic units) and the hydrogeologic frameworks (hydrostratigraphic units) that are used for this discussion.

5.2 Geology and Lithostratigraphic Units

A sequence of carbonate rocks composed primarily of limestone and dolostone underlies the southern Florida peninsula. These sediments define the Florida Platform, which has a total thickness that ranges between 2,800 and 3,400 ft (Miller, 1986; 1990). Within this sequence are the Tertiary carbonates, consisting of permeable limestones of early Eocene through Miocene age (approximately 5 to 55 million years ago). This sequence was deposited and reworked during sea level fluctuations in a shallow marine depositional environment under tropical and subtropical environmental conditions (Miller, 1986; Cunningham et al., 1998). Many units were subsequently affected by tectonic activity (Cunningham and et al., 2012; Maliva et al., 2002). The most important lithostratigraphic units are defined below, from bottom to top.

The Avon Park Formation (Middle Eocene) consists primarily of dolomitic limestone and dolostone, with interbedded micritic and fossiliferous limestone where dolomitization has not disrupted the original lithology (Reese and Richardson, 2008; Maliva et al., 2011). Late Miocene (or later) fracturing of the dolostone resulted in development of two permeable zones in the Avon Park Formation separated by the MC2 (Maliva et al., 2002; Reese and Richardson, 2008). In some intervals of the Avon Park Formation, diagenetic replacement of parent limestone resulted in a unique “sucrosic dolostone” (texture like a sugar cube), which has high intracrystalline porosity. The Avon Park Formation provides basal confinement for the storage zones at KRASR and HASR.

The Ocala Limestone (Upper Eocene) consists of micritic packstones and wackestones with abundant foraminifera (Miller, 1986; Randazzo, 1997), and often unconformably overlies the Avon Park Formation. The Ocala Limestone was deposited below wave base in a mid- or outer-shelf marine environment of the Florida Platform (Miller, 1986; Ward et al., 2003). The Ocala Formation serves as the storage zone at KRASR.

Table 5-1 -- Nomenclature for Geologic and Hydrogeologic Frameworks for South-Central and Southeastern Florida

<table>
<tr><th>SERIES</th><th>LITHO-STRATIGRAPHIC UNIT</th><th>DOMINANT LITHOLOGY</th><th colspan="2">HYDRO-STRATIGRAPHIC UNIT</th><th>ACRONYM</th></tr>
<tr><td>PLIOCENE-PLEISTOCENE</td><td>unnamed or Anastasia Formation</td><td>Sand, shell, carbonate-cemented sand, and limestone</td><td colspan="2">Surficial Aquifer System</td><td>SAS</td></tr>
<tr><td rowspan="2">MIOCENE</td><td rowspan="2">Arcadia Formation Hawthorn Group</td><td rowspan="2">Carbonate with varying amounts of quartz sand, clay and phosphate</td><td colspan="2">Intermediate Confining Unit</td><td>ICU</td></tr>
<tr><td rowspan="6">FLORIDAN AQUIFER SYSTEM (FAS)</td><td rowspan="3">Upper Floridan Aquifer</td><td rowspan="3">UFA</td></tr>
<tr><td>OLIGOCENE</td><td>Suwannee Limestone</td><td>Grainstone/Packstone Limestone</td></tr>
<tr><td rowspan="4">EOCENE</td><td>Ocala Limestone</td><td>Packstone/Wackestone Limestone</td></tr>
<tr><td rowspan="3">Avon Park Formation</td><td rowspan="3">Micritic limestone, dolomitic limestone, and dolostone</td><td>Middle Confining Unit 1</td><td>MC1</td></tr>
<tr><td>Avon Park Permeable Zone</td><td>APPZ</td></tr>
<tr><td>Middle Confining Unit 2</td><td>MC2</td></tr>
</table>

The Suwannee Limestone (Oligocene) consists of a sequence of packstones and grainstones that grade upward into quartz sand and siliciclastics. This sequence represents the evolution of depositional environments from platform carbonates deposited in an offshore marine environment, to deposition of siliciclastic sediments onto the Florida Platform from the north (Randazzo, 1997). The Suwannee Limestone serves as the storage zone for many ASR systems in the counties surrounding Tampa and in the Florida Keys, as the most common lithologies are permeable nearshore marine carbonates (Cunningham et al., 1998). Across south-central Florida, the Suwannee Limestone unit thins from west to east (Reese, 2000). The Suwannee Limestone is thin (10-ft) at KRASR. Previous interpretations of storage zone lithology at HASR indicated that the Suwannee Limestone was present (Site 26, PBF-12 in Reese and Alvarez-Zarakian, 2007). More recent interpretation suggests that the Suwannee Limestone is absent at HASR, and the Arcadia Formation rests unconformably on the Avon Park Formation (Reese and Cunningham, 2013).

The Hawthorn Group (Miocene) is a thick (400 to 700 ft; Scott, 1988) sequence of interlayered carbonates and siliciclastic sediments. The Hawthorn Group consists of two lithostratigraphic formations in south Florida -- the Arcadia Formation and overlying Peace River Formation. The Peace River Formation is the upper portion of the intermediate confining unit, but is not directly in contact with the UFA and ASR storage zone, and so is omitted from further discussion. Throughout most of south Florida the basal unit of the Hawthorn Group is the Arcadia Formation, which consists primarily of limestone and dolostone containing varying amounts of quartz sand, clay, and phosphate grains. Abundant phosphate grains near the base of the Arcadia Formation show a distinct response on gamma-ray geophysical logs, in contrast to the underlying Suwannee Limestone or Ocala Limestone. This strong gamma-ray response can be observed in borehole geophysical logs throughout south Florida. The Arcadia Formation rests unconformably on the underlying Suwannee Limestone or Ocala Limestone. This unconformity is readily recognized during drilling, and is a feature to avoid when setting well casings. The Arcadia Formation of the Hawthorn Group provides overlying confinement of the storage zone at KRASR and HASR.

Undifferentiated marginal marine sediments (Pliocene and Pleistocene) and alluvium (Holocene) overlie the Hawthorn Group and extend to land surface. These fossil-bearing sediments consist of limestone, carbonate-cemented sandstone, and quartz sand (Reese and Wacker, 2009). Close to the Atlantic Coast north of Broward County, these sediments consist of consolidated and unconsolidated shell coquina known as the Anastasia Formation, which forms unique rock outcrops on many beaches. In Broward and Miami-Dade Counties, these sediments are marine limestones of the Miami Limestone and Fort Thompson Formation, and limestones and quartz sand of the Tamiami Formation. This sequence was deposited and reworked during sea level fluctuations in a shallow marine depositional environment under tropical and subtropical environmental conditions (Cunningham et al., 2006).

5.3 Hydrogeologic Setting and Hydraulic Properties of the UFA

The Floridan Aquifer System (FAS) is one of the largest and most productive aquifers on Earth. The FAS occurs in the sequence of middle and late Tertiary age carbonate rocks that are hydraulically connected to varying degrees, and exhibit permeability several orders of magnitude greater than the confining units that bound its upper and lower surfaces (Miller, 1986). The nomenclature and relationships among the component aquifers of the FAS will follow those published in Reese and Richardson (2008). Those component aquifers and confining units from bottom to top are: Middle Confining Unit 2 (MC2), the Avon Park Permeable Zone (APPZ), the Middle Confining Unit 1 (MC1), the Upper Floridan Aquifer (UFA), the Intermediate Confining Unit (ICU), and the Surficial Aquifer System (SAS). Permeable zones and confining units below MC2 are not discussed here because they are below and not hydraulically connected to the ASR storage zone and lower confining units. Thicknesses and elevation of the top and bottom of the MC1 and MC2 are shown in **Table 5-2**.

The MC1 and MC2 are confining units below the UFA and the APPZ, respectively. Throughout most of south Florida, MC1 and MC2 occur within the Avon Park Formation, and are separated by the APPZ. At KRASR, the uppermost portion of the APPZ is encountered at approximately 1,000-ft bls in the lower zone of the dual-zone storage zone monitor well OKF-100L (1,100-ft SZMW).

Table 5-2 -- Depth of Occurrence and Thickness of the Middle Confining Units 1 and 2 in Boreholes and Wells in the Vicinity of Lake Okeechobee

WELL	MIDDLE CONFINING UNIT 1			MIDDLE CONFINING UNIT 2			SITE	COUNTY	REFERENCE
	THICK-NESS, IN FT	DEPTH OF TOP SURFACE, IN FT BLS	DEPTH OF BOTTOM SURFACE, IN FT BLS	THICK-NESS, IN FT	DEPTH OF TOP SURFACE, IN FT BLS	DEPTH OF BOTTOM SURFACE, IN FT BLS			
OSF-97	100	260	360	530	680	1,210	Osceola	Osceola	Reese and Richardson, 2008
HIF-42	160	790	950	240	1,480	1,720	Paradise Run	Highlands	CH2MHill, 2008.
TCRK-MW	550	760	1,310	130	1,640	1,770	L-63N/Taylor Creek ASR	Okeechobee	Reese & Alvarez-Zarikian,2007
OKF-100	190	810	1,000	240	1,450	1,690	KRASR 1,100 SZMW	Okeechobee	Reese & Alvarez-Zarikian,2007
OKF-105	810	575	1,385	155	1,470	1,625	Okeechobee Utility Authority	Okeechobee	Sunderland et al., 2010
LAB-TW	825	850	1,675	545	1,780	2,325	Labelle Test Well	Hendry	Reese and Richardson, 2008
GLF-6	500	1,110	1,600	130	1,780	1,910	Moore Haven ASR Pilot	Glades	Reese & Alvarez-Zarikian,2007
EXBR-1	> 400 ft	1,000	> 1,400		not encountered		Caloosahatchee ASR Pilot	Hendry	Reese & Alvarez-Zarikian,2007
EXPM-1	not avail	1,040	not encountered		not encountered		Port Mayaca ASR Pilot	Martin	E. Rectenwald, pers. comm.
MF-37	460	1,040	1,500	90	1,700	1,790	Port Mayaca SZMW	Martin	Reese & Alvarez-Zarikian,2007
FPL-FAW1	100	1,250	1,350		not encountered		FP&L West County	Palm Beach	JLA Geosciences, 2008
PBF-12	290	1,230	1,520	475	1,670	2,145	Hillsboro ASR Pilot	Palm Beach	Reese & Alvarez-Zarikian,2007
PBF-15	205	1,075	1,280	274	1,606	1,880	L-8 Reservoir	Palm Beach	Anderson, 2008.
PBF-3	108	1,252	1,360	830	1,510	2,340	Lake Lytal Test Well	Palm Beach	Lukasiewicz et al., 2001
PB-1775	240	1,250	1,490		not encountered		Hillsboro Canal East ASR	Palm Beach	Reese & Alvarez-Zarikian,2007
PB-1764	140	1,260	1,400		not encountered		Palm Beach System 3	Palm Beach	Reese & Alvarez-Zarikian,2007

The MC1 separates the base of the UFA from the APPZ, with a thickness of approximately 100 to 300 ft in the northern and eastern regions adjacent to Lake Okeechobee. The MC1 is interpreted as a semi-confining unit, and it is leaky in character (Reese and Richardson, 2008). Because the MC1 serves as the base of the ASR storage zone, the hydrologic characteristics of this unit are important because the MC1 must limit hydraulic connection between the ASR storage zone and the underlying APPZ. In most areas, water quality of the APPZ is characterized by higher TDS and chloride concentrations. In areas where the MC1 is thin or has high vertical hydraulic conductivity, saline water from deeper in the APPZ could be captured by upconing during recovery, resulting in lower percent recovery (Reese and Alvarez-Zarakian, 2007).

The UFA serves as a storage zone at most potable and reclaimed water ASR systems in south Florida (Reese and Alvarez-Zarikian, 2007). The upper boundary of the UFA progressively deepens from north to south along the peninsula arch and towards the east and west coasts. This illustrated in the well data **(Table 5-3)** where the UFA goes from a high of 110-ft bls at OSF-97 in northern Osceola County, to a low of 985 ft bls at the HASR system at the southern end of Palm Beach County.

5.3.1 Hydraulic Properties of the Upper Floridan Aquifer

The UFA is the most productive part of the part of the FAS, but permeability is not uniform with depth. The UFA shows single-, double-, and triple-porosity characteristics throughout the region (Budd and Vacher, 2004; Kuniansky and Bellino, 2012), complicating efforts to characterize and simulate groundwater flow. Characterization of hydraulic properties in an ASR storage zone is critical for successful ASR operations. Hydraulic properties (transmissivity, storage coefficient, and leakance) are determined most accurately by long duration, high- and constant-rate aquifer pumping tests in a multi-well system. Single-well constant rate tests provide only transmissivity estimates. Hydraulic properties based on aquifer pumping test interpretation in the UFA have been compiled in Reese (2002), Reese and Alvarez-Zarikian (2007), Kuniansky and Bellino (2012) and site-specific consultant reports. A discussion of storage zone hydraulics at KRASR and HASR is found in **Sections 5.4** and **5.5.**

Transmissivity is the capacity of an aquifer to transmit water of a prevailing kinematic viscosity, and is equal to the product of the hydraulic conductivity and saturated thickness of the aquifer (Heath, 1983). Kuniansky and Bellino (2012) report a mean transmissivity estimate of 98,000 ft^2/day for the UFA throughout Florida, with values that range between 8 and 9,300,000 ft^2/day. Considering the UFA in the area around Lake Okeechobee, transmissivity estimates vary less widely. Transmissivity estimates from multi-well aquifer pumping tests generally range between 3,000 and 140,000 ft^2/day **(Table 5-4).** Variation in hydraulic parameter estimates results from many factors, such as 1) length of a well's open interval versus aquifer thickness; 2) variations in test pumping rate; 3) well acidization prior to the test; and 4) analytical solution used for interpretation (Reese and Alvarez-Zarikian, 2007).

Table 5-3 -- Depth of Occurrence and Thickness of the Upper Floridan Aquifer in Boreholes and Wells in the Vicinity of Lake Okeechobee

WELL	UPPER FLORIDAN AQUIFER			SITE	COUNTY	REFERENCE
	THICK-NESS, IN FT	DEPTH OF TOP SURFACE, IN FT BLS	DEPTH OF BOTTOM SURFACE, IN FT BLS			
OSF-97	150	110	260	Osceola	Osceola	Reese and Richardson, 2008
HIF-42	240	550	790	Paradise Run	Highlands	CH2MHill, 2008.
OKF-105	133	372	505	Kissimmee River at S65C	Okeechobee	Sunderland et al., 2010
TCRK-MW	285	990	1,275	L-63N/Taylor Creek ASR	Okeechobee	Reese&Alvarez-Zarikian,2007
OKF-100	238	562	800	KRASR 1,100 SZMW	Okeechobee	Reese&Alvarez-Zarikian,2007
LAB-TW	185	665	850	Labelle Test Well	Hendry	Reese and Richardson, 2008
GLF-6	260	840	1,100	Moore Haven ASR Pilot	Glades	Reese&Alvarez-Zarikian,2007
EXBR-1	360	640	1,000	Caloosahatchee ASR Pilot	Hendry	Reese&Alvarez-Zarikian,2007
EXPM-1	285	755	1,040	Port Mayaca ASR Pilot	Martin	E. Rectenwald, pers. comm.
MF-37	335	765	1,100	Port Mayaca SZMW	Martin	Reese&Alvarez-Zarikian,2007
PBF-15	190	885	1,075	L-8 Reservoir	Palm Beach	Anderson, 2008.
FPLFAW1	340	910	1,250	FP&L West County	Palm Beach	JLA Geosciences, 2008
PBF-12	240	985	1,225	Hillsboro ASR Pilot	Palm Beach	Reese&Alvarez-Zarikian,2007
PBF-3	337	915	1,252	Lake Lytal Test Well	Palm Beach	Lukasiewicz et al., 2001
PB-1775	299	951	1,250	Hillsboro Canal East ASR	Palm Beach	Reese&Alvarez-Zarikian,2007
PB-1764	290	970	1,260	Palm Beach System 3	Palm Beach	Reese&Alvarez-Zarikian,2007

Storage coefficient (or storativity) is the volume of water released or gained by an aquifer per unit surface area and per unit change in head (Heath, 1983). Typical storage coefficient values for a confined aquifer range between 10^{-5} and 10^{-3} (Heath, 1983). UFA storage coefficients range between 0.0001 and 0.0004 at sites surrounding Lake Okeechobee **(Table 5-4).**

Leakance describes the vertical transmission property between layers, and is calculated as the volume of water that flows through a unit area of a semi-confining unit per unit of head difference per unit time. Leakance values determined elsewhere for the UFA are 0.0049 day^{-1} (Tampa; Motz, 1990); and they range of 0.0015 to 0.0175 day^{-1} (Flagler, Putnam, and St. Johns Counties; Stringfeld, 1966). Leakance values are only available for an interval that includes the UFA, MC1, and APPZ **(Table 5-4)**. These values probably reflect upward leakance from the MC1, rather than downward leakance from the ICU.

Table 5-4 -- Hydraulic Parameter Estimates from Multi-Well Aquifer Pumping Tests in the Upper Floridan Aquifer in the Vicinity of Lake Okeechobee

WELL	Tested Interval, in ft	Transmis-sivity, in ft^2/day	Storage Coefficient, unitless	Leakance, in 1/day	Hydrostrati-graphic unit	SITE	COUNTY	REFERENCE
HIF-42	560 - 1,100	12,000	n.d.	n.d.	UFA-MC1	Paradise Run	Highlands	CH2MHill, 2008.
TCRK-MW1	1,268 - 1,710	586,000	0.00125	0.01 - 0.001	APPZ-MC2	L-63N/Taylor Creek ASR	Okeechobee	Reese, 2002
EXKR-1	562 - 875	26,884	0.0002	n.d.	UFA	KRASR, ASR well	Okeechobee	CH2MHill, 2008
EXBRY-1	634 - 658	2,710	n.d.	n.d.	UFA	Caloosahatchee ASR Pilot	Hendry	Water Resource Solutions, Inc. 2005
EXPM-1	800 - 1,040	12,872	n.d.	n.d.	UFA	Port Mayaca ASR Pilot	Martin	E. Rectenwald, pers. Comm.
FPL-FAW1	1,065 - 1,610	353,000	0.0003	n.d.	UFA-APPZ	FP&L West County	Palm Beach	JLA Geosciences, 2008
FPL-FAW3	1,063 - 1,490	102,400	0.0002	0.0240	UFA-APPZ	FP&L West County	Palm Beach	JLA Geosciences, 2008
EXW-1	1,015 - 1,225	8,104	9.70E-05	n.d.	UFA	HCASR ASR Well	Palm Beach	Bennett et al., 2001
FAMW	985 - 1,200	138,000	0.0004	n.d.	UFA	West Palm Beach WTP	Palm Beach	Reese, 2002
FAMW	1,010 - 1,650	9,965	n.d.	n.d.	UFA	Hillsboro Canal East SZMW	Palm Beach	Palm Beach Co. Water Util. Dept., 2003
ASR Well	1,010 - 1,225	18,984	n.d.	n.d.	UFA	Hillsboro Canal East SZMW	Palm Beach	Palm Beach Co. Water Util. Dept., 2003

5.3.2 Permeability Distribution in the UFA

Permeability in the UFA is not uniform with depth, due to post-depositional compaction and cementation of carbonate grainstones (Budd, 2002), and development of conduits that occur at and near contacts between the overlying Hawthorn Group sediments and the Ocala and Suwannee Limestones (Meyer, 1989; Reese and Richardson, 2008). Characterization of permeability in the ASR storage zone is critical for accurate simulations of groundwater flow at an ASR system. In some locations the UFA can be characterized as a “triple porosity” system, in which water flows through the matrix, fractures, and conduits, but it is difficult to quantify which component is most important without synthesis of aquifer pumping tests, permeability measurements on core samples, and borehole geophysical log data. The confined portion of the UFA is thought to have a significant component of matrix permeability, because the Ocala Limestone and Suwannee Limestone, and upper Avon Park Formation lithologies are young (geologically) and are not deeply buried. Budd and Vacher (2004) showed that permeability is directly related to the limestone facies, with grainstones and sucrosic dolostones showing greatest values of matrix permeability ranging between $10^{-12.4}$ and $10^{-11.5}$ m^2 ($10^{-11.1}$ and $10^{-10.5}$ ft^2). These permeability estimates suggest that matrix permeability in the UFA is of equal significance to fracture permeability, particularly in the far-field (sub-regional) scale (Budd and Vacher, 2004). However, considering permeability at the near-field (borehole) scale, there is clear evidence of preferential flow zones that form by dissolution along formation contacts (Meyer, 1989; Reese and Richardson, 2008) and these preferential flow zones appear in a consistent stratigraphic position in many boreholes in the Lake Okeechobee area. The significance of these flow zones is apparent at KRASR and HASR, and will be discussed in the site-specific sections.

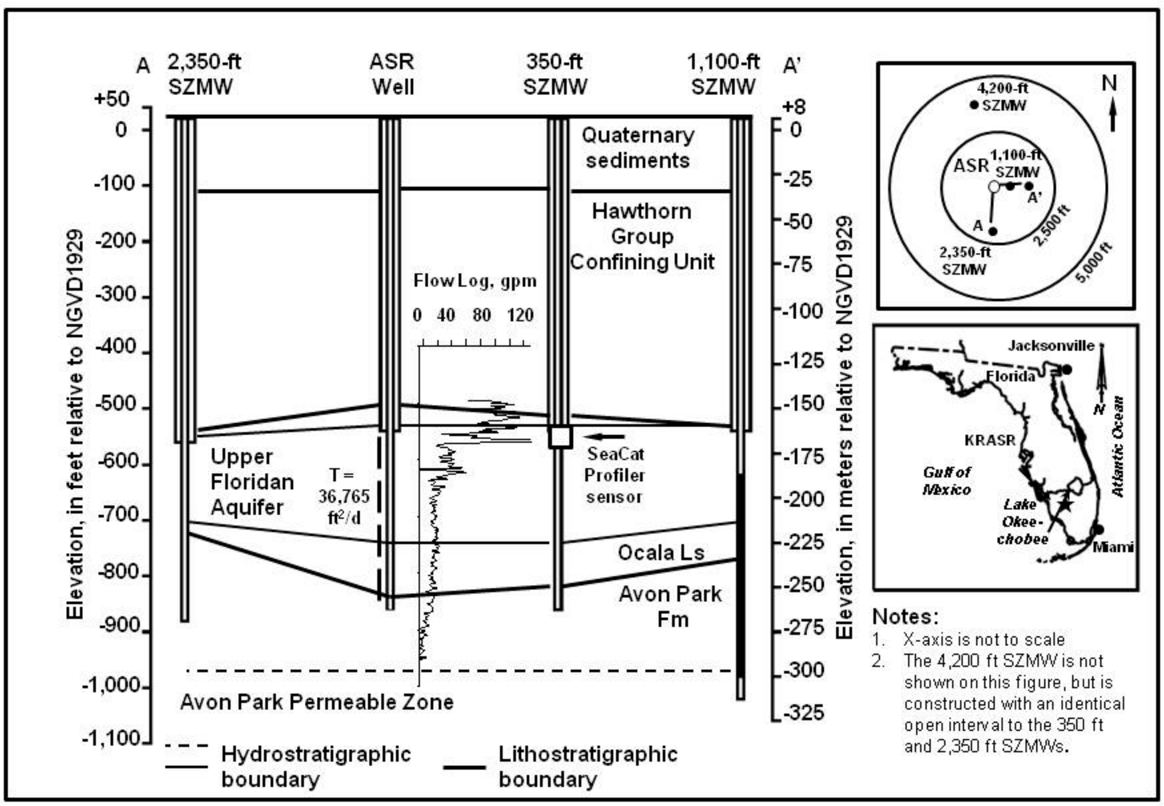
5.4 Hydraulic Properties of the Storage Zone (Upper Floridan Aquifer) at KRASR

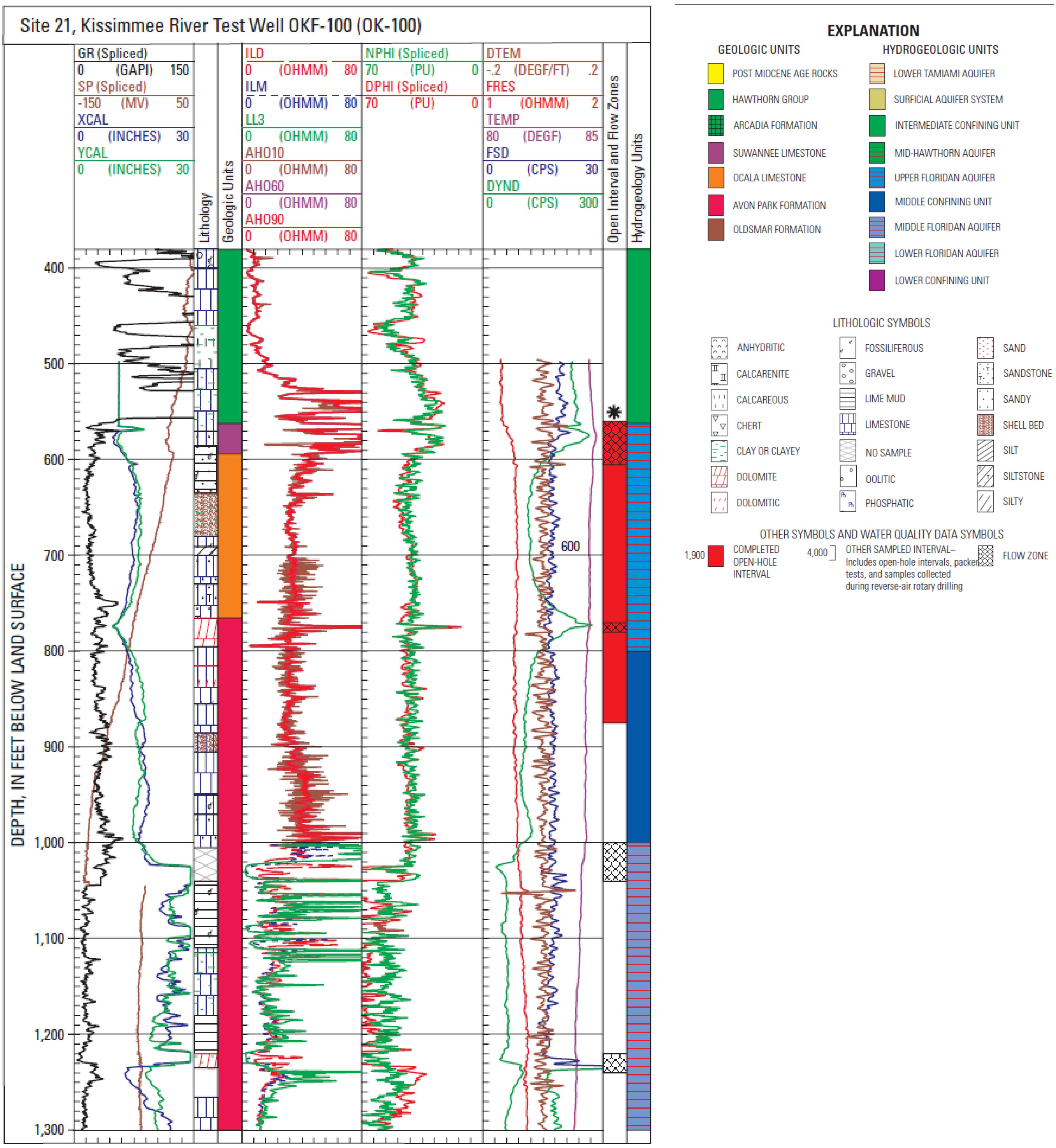
Evaluation of near-field (site-specific) hydraulic properties of the storage zone at KRASR is based on a synthesis of borehole geophysical log data and aquifer pumping test interpretations. Borehole geophysical log data were obtained during construction of the ASR and monitor wells.

The storage zone at KRASR occurs primarily in the Ocala Limestone and is confined by the Arcadia Formation, within the lower Hawthorn Group. The depth of the open interval in the ASR and monitor wells is approximately -550 to -870 ft NGVD 1929 (approximately 562 to 880 ft bls). The storage zone occurs at a uniform depth and thickness throughout the KRASR wellfield. A cross-section across the site shows the hydrogeologic setting and well field orientation at KRASR **(Figure 5-1).** Porosity and permeability are not distributed uniformly with depth in the UFA. At least one preferential flow zone can be defined in the KRASR storage zone. This thin (20- to 30-ft) zone generally consists of poorly consolidated material and is cased off during well construction. The flow zone occurs above the Ocala Limestone (-550 to -570 ft NGVD 1929) and is interpreted variously as “Suwannee Limestone or equivalent” (Entrix, 2010 a,b; Reese and Alvarez-Zarikian, 2007); undifferentiated Arcadia Formation (CH2MHill, 2004; Florida Geological Survey core log for W-18466); and “sucrosic dolosilt” (Florida Geological Survey core log for W-18255).

Borehole geophysical flow, resistivity, and caliper log data obtained from the 1,100-ft SZMW during well construction indicate that there is at least one discrete flow zone within the storage zone at KRASR **(Figure 5-2).** Borehole log data in the interval between -550 and -570 ft NGVD 1929 show the following characteristics that support flow zone interpretations (Reese and Alvarez-Zarikian, 2007). The X-Y caliper logs (XCAL, YCAL) show inflections indicating a large borehole diameter. The formation resistivity logs (induction log deep, ILD; array induction logs AHO10) show a large zone of fluctuating high and low values, consistent with a zone of interlayered clay and limestone lithologies. The static and dynamic flow logs (FSD and DYND, respectively) show increasing counts per second indicating a discrete zone of groundwater flow. The similar log characteristics are exhibited at a depth of approximately -780 to -790 ft NGVD29, which suggests a second (minor) flow zone at or near the contact of the Ocala Limestone and the underlying Avon Park Formation. Discrete flow zones were interpreted at similar depths or stratigraphic positions at Taylor Creek/L63 ASR, Moore Haven, and Port Mayaca, suggesting that the flow zones are a regional feature (Reese and Alvarez-Zarikian, 2007).

Figure 5-1 -- Diagram showing a hydrogeologic cross-section across the KRASR wellfield.





✱ Open interval is for well EXKR-1 (OK-101) at the same site. Well OKF-100 has not been completed, but casing was set at 565 feet.

Figure 5-2 -- Borehole geophysical logs and interpretations from the 1,100-ft SZMW (OKF-100).

Figure from Reese and Alvarez-Zarikian (2007).

Analysis of the dynamic flow log data indicates that 63 percent of the total flow emanates from the depth interval of approximately -550 to -570 ft NGVD29 (Mirecki et al., 2012). Therefore, this flow zone serves as an important flowpath for recharged groundwater during ASR cycle testing. For this reason, the SeaCat profiler water quality sensor was positioned at the flow zone depth in the 350-ft SZMW. The short open interval in the upper zone of the 1,100-ft SZMW intersects the flow zone farther away from the ASR well. Specific conductance and chloride data obtained during recharge phases of the cycle testing program define recharge water breakthrough curves. Breakthrough curves provide estimated flow rates under pumping conditions, and can be used to estimate the maximum extent of recharge water in the aquifer. Breakthrough curves are defined during the recharge phase of cycle tests 1 and 3, because there is sufficient compositional contrast between the native UFA and recharge water quality. Native UFA chloride concentrations range between 150 and 281 mg/L, and specific conductance values range between approximately 1,000 and 1,400 µS/cm. Recharge water chloride mean concentration is 31 +/- 8 mg/L, and specific conductance mean value is 223 +/- 50 µS/cm. This contrast is sufficient to define solute breakthrough curves as recharge water flows away from the ASR well.

Breakthrough curves were defined using wellhead samples for cycle tests 1 through 3. Breakthrough curves plotted for cycle test 2 data showed poor goodness of fit ($r^2 < 0.7$) so are not reported. No breakthrough curves were calculated during cycle test 4 because monthly sampling at the wellhead provided insufficient resolution. Breakthrough curves were defined by plotting normalized concentration (C_x/C_0, where C_x is concentration at time x, and C_0 is the native UFA concentration at each well) versus time (x), in hours. Curves were fit using a single 2-parameter exponential decay function (1),

$$y = ae^{-bx} \qquad (1)$$

where: $y = C_x/C_0$ x = time, in hours a and b are estimated coefficients

Curve-fitting and parameter estimates (a, b) were calculated using SigmaPlot (SPSS, Inc., Chicago, IL). The decay equation is solved for x (time) when ($C_x/C_{0)}$ equals 0.5. Examples of breakthrough curves using chloride and specific conductance measured in wellhead samples over time are shown in **Figure 5-3**.

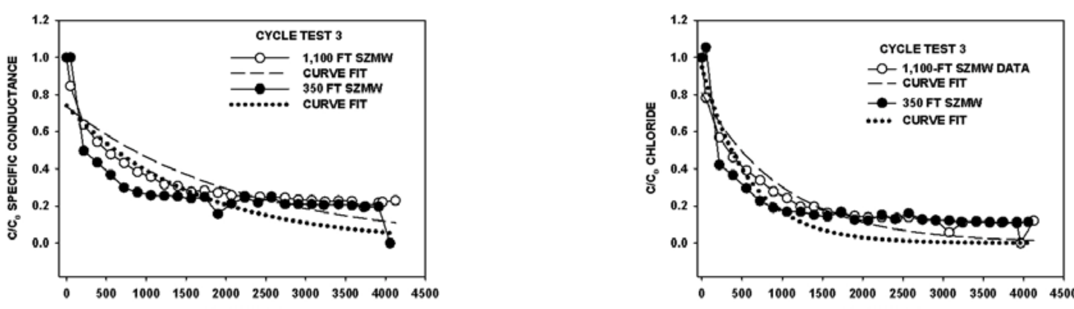


Figure 5-3 -- Plots showing breakthrough curves and curve fits using normalized specific conductance and chloride data at the 1,100-ft SZMW.

Apparent linear flow rates were estimated for solute breakthrough as measured in wellhead samples at the 350-ft SZMW and the 1,100-ft SZMW during cycle tests 1 and 3 **(Table 5-5).** Breakthrough curves based on chloride analyses show better goodness of fit (r^2 ranges from 0.80 to 0.94) than those based on specific conductance (r^2 ranges from 0.69 to 0.94), probably because specific conductance is a measure of conservative and non-conservative solutes. The median value of linear flow rate is 51 ft/day (n = 8**, Table 5-5**). The range of flow rates calculated with the best-fit curves (r^2 > 0.89) is 55 to 58 ft/day, at both the 350-ft and 1,100-ft SZMWs. The similarity of flow rates at the 350-ft and 1,100-ft SZMW seems unlikely given proximal and distal locations from the ASR well pumping stress, and may be related to well construction differences between these two wells.

Table 5-5 -- Estimates of Linear Flow Rate Determined from Breakthrough Curves. Breakthrough curves were defined using chloride and specific conductance analyses in wellhead samples at the 350-ft and 1,100-ft SZMWs during the recharge phase of cycle tests 1 and 3.

		Cycle Test 1			
		350-ft SZMW		**1,100-ft-SZMW**	
Constituent	**Unit**	**Chloride**	**Specific Conductance**	**Chloride**	**Specific Conductance**
Linear flow rate	ft/hr	2.3	1.9	4.3	2.4
Linear flow rate	ft/day	55	46	103	58
Goodness of fit	r^2	0.89	0.69	0.80	0.94
		Cycle Test 3			
		350-ft SZMW		**1,100-ft-SZMW**	
Constituent	**Unit**	**Chloride**	**Specific Conductance**	**Chloride**	**Specific Conductance**
Linear flow rate	ft/hr	0.93	0.53	2.3	1.5
Linear flow rate	ft/day	22	13	55	36
Goodness of fit	r^2	0.89	0.67	0.94	0.79

Borehole geophysical flow log interpretations indicated that 63 percent of the flow of the UFA at KRASR occurs between depths of -550 to -570 ft NGVD29 (Mirecki et al., 2012). The SeaCat sensor is suspended at this interval in the 350-ft SZMW, making hourly measurements of temperature, pH, specific conductance, dissolved oxygen, pressure, and oxidation reduction potential (ORP) at a depth of approximately -550 ft NGVD29. A breakthrough curve and estimation of near-field linear flow rates in the flow zone were developed from specific conductance values obtained during cycle test 2 recharge phase **(**Figure 5-4**).**

The breakthrough curve based on SeaCat sensor data in the 350-ft SZMW defines discrete flow zone characteristics in the upper UFA at a location proximal to the ASR well. Data were only available for cycle test 2 due to instrument performance and SCADA issues. This curve cannot be fit by simple exponential decay or sigmoid functions, so the flow rate was estimated at C_x/C_0 = 0.5 **(**Figure 5-4**),** resulting in a linear flow rate estimate of approximately 120 ft/day. This linear flow rate is significantly higher than those estimated from wellhead samples. Higher linear flow rate in the discrete interval can occur because the sensor directly measures specific conductance in the flow zone. Wellhead samples, in comparison, integrate concentrations from the entire open interval. Faster apparent flow rates also can result from displacement of residual fresh recharge water remaining from cycle test 1 during recharge of cycle test 2.

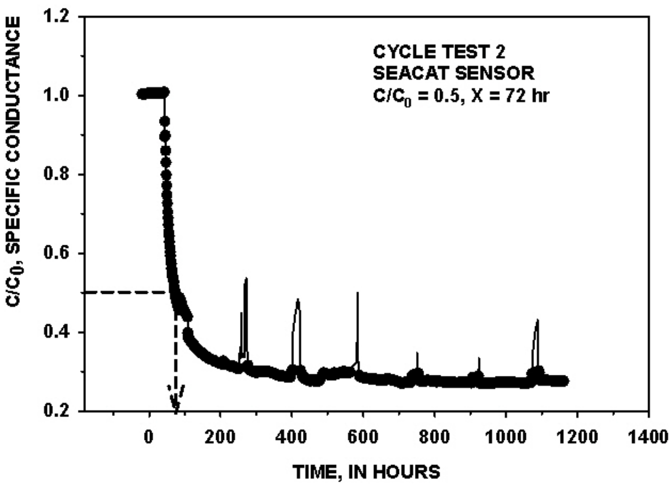


Figure 5-4 -- Breakthrough curve developed using specific conductance values measured by the SeaCat probe suspended at -550 ft NGVD29 in the 350-ft SZMW.

Inflections are measurements taken during wellhead sampling events. These values were removed from the dataset for rate calculation.

The 1,100-ft SZMW was constructed with a very short (20-ft; -537 to -557-ft NGVD29) open interval that intersects the flow zone at a distal location from the ASR well. Thus the best overall estimates of linear flow rate are obtained for the flow zone, using Sea Cat data at the proximal 350-ft SZMW, and wellhead data at the distal 1,100-ft SZMW. During cycle test 2 recharge, the apparent linear flow rate at the 350-ft SZMW is approximately 120 ft/day. During cycle tests 1 and 3 recharge, the apparent linear flow rates at the 1,100-ft SZMW are approximately 55 to 58 ft/day. Groundwater flow rate slows farther from the pumping stress.

5.4.1 Confinement of the Storage Zone at KRASR

One of the major concerns about ASR operations is the potential for pumping to affect the integrity of the overlying confining unit, particularly during recharge. The intermediate confining unit (ICU) in Hawthorn Group sediments is approximately 500-ft thick at KRASR. While there probably is a low risk that hydraulic fracturing will propagate through this unit to cause leakage between the SAS and UFA**,** this hypothesis was tested two ways: 1) by comparing simultaneous pressure measurements in the ICU and UFA; and 2) using geotechnical analysis to predict rock failure thresholds.

Hydraulic connection between the ICU and the UFA were evaluated by graphical comparison of simultaneous wellhead pressure data in the ASR well and the OKH-100 well screened in the ICU (approximately -330 to -350-ft NGVD29). This well is instrumented with a pressure transducer that provides continuous, hourly water level measurements. The record from well OKH-100 allows evaluation of hydraulic effects, if any, on the ICU during cycle testing.

This comparison shows daily average ASR wellhead pressures during each phase of cycle tests 1 through 4, and is superimposed on the pressures measured simultaneously in OKH-100 **(Figure 5-5).**

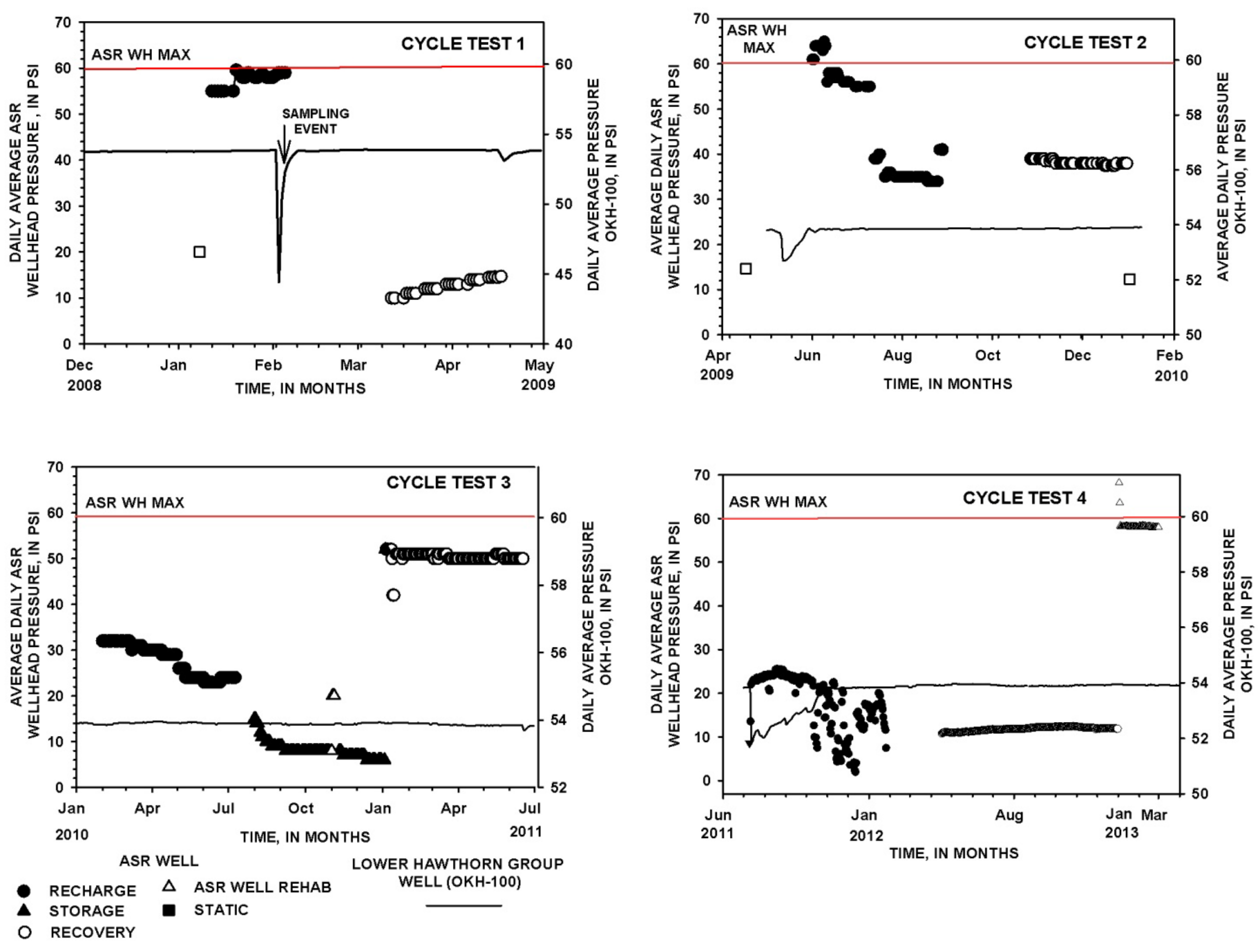


Figure 5-5 -- Plots showing average daily wellhead pressures measured at the ASR well versus time during cycle tests 1 through 4.

Pressures are measured at the ASR well head (gage; left axis) and at the confining unit well OKH-100 (pressure transducer; right axis). ASR WH max is the permitted maximum pressure at the ASR wellhead.

Variations in daily average pressure in the ICU are minimal, and cannot be correlated directly to pumping into or out of the ASR storage zone during cycle testing **(Figure 5-5).** The inflection in the OKH-100 record during cycle test 1 occurred during an unsuccessful attempt to acquire a water quality sample from the well by pumping. Declining pressure also occurred during the early recharge phases of cycle tests 2 and 4. During cycle test 2 recharge, pressure declined and rebounded approximately 1 psi over an 8 day period (10 to 18 May 2009). During cycle test 4 recharge, pressure declined and rebounded approximately 2 psi over a 4.5 month period (7 July to 22 October 2011). If a close hydraulic connection existed between the UFA and ICU, the potentiometric surface (as measured in OKH-100) would rise during the recharge phase and decline during the recovery phase. Systematic changes in the potentiometric surface elevation of the ICU during cycle testing were not observed at the KRASR wellfield. Minor amounts of leakage might exist but not be noted in the data due to delays in passing through the 500-ft ICU.

Evaluation of rock fracturing potential in the upper part of the storage zone was completed by geotechnical analysis of representative rock samples from the KRASR storage zone and overlying confining unit (Geibel and Brown, 2012). Core samples from the ASR well (EXKR-1) exploratory borehole were included in this analysis.This study found that the most probable failure mode is microfracturing. Deformation by shear and tensile methods require pressures that far exceed those of typical ASR operation. The minimum ASR wellhead pressure that could induce microfracturing at KRASR is 85 psi. This threshold pressure includes a 10 percent factor of safety. ASR wellhead pressures never exceeded 66 psi during all cycle tests **(Figure 5-5)**. ASR wellhead pressure declined through successive cycle tests due to wellhead rehabilitation, and development of the storage zone.

It is more difficult to evaluate hydraulic and geotechnical integrity of the lower confining unit, MC1. At KRASR, the MC1 separates a minor permeable zone in the lowermost UFA from the APPZ, and is approximately 190 ft thick **(Table 5-2).** The MC1 generally is interpreted as a leaky confining unit (Reese and Richardson, 2008), so potential upconing of more saline APPZ water is possible during the recovery phase of a cycle test. The native APPZ chloride concentration at KRASR is 356 +/- 115 mg/L, which is greater than native UFA (231+/- 53 mg/L) or recharge water chloride concentrations. The maximum chloride concentration measured in the ASR well during the recovery phases of cycle tests 1 through 4 is 200 mg/L. Because chloride concentrations in the storage zone do not exceed native values, upconing of saline water from the APPZ through a leaky MC1 is not interpreted to occur during recovery phases.

Hydraulic and geotechnical evaluation at KRASR indicates that the storage zone has good upper and lower confinement, and that there is a low probability of pressure-induced microfracturing in the upper part of the storage zone or overlying confining unit at typical operating pressures. This conclusion is based on three lines of evidence: 1) there is no hydraulic response in the ICU well (OKH-100) during recharge and recovery phases of cycle tests 1 through 4; 2) ASR wellhead pressures never approach the minimum microfracturing pressure threshold (85 psi at KRASR); and 3) integrity of the lower confining unit (MC1) is sufficient to prevent upconing of saline APPZ water during the recovery phase of cycle tests 1 through 3.

5.4.2 Aquifer Pumping Test Analysis at KRASR

Head data obtained during ASR cycle testing at KRASR can be used to estimate aquifer properties. AQTESOLV 4.50 Professional (HydroSOLVE, Inc., Reston VA) was used to fit the data to a number of common pump test solutions, including the Cooper-Jacob method (Cooper and Jacob, 1946) and the Hantush-Jacob method (Hantush and Jacob, 1955).

The data having the highest time resolution were obtained in the 350-ft SZMW and the 1,100-ft SZMW immediately following the end of the recovery (extraction) phase of cycle test 1. Head data were collected at each well on 15-second time intervals for approximately 72 hours. The displacement versus time plot for the 350-ft SZMW is shown **(Figure 5-6)** with the Cooper-Jacob confined aquifer solution. Estimates are made based on a pumping rate of 4.8 MGD, which was the final pumping rate during the recovery phase of cycle test 1.

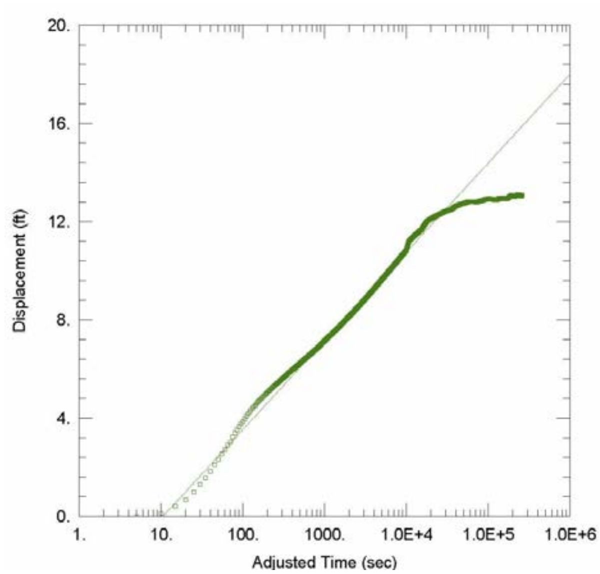


Figure 5-6 -- Displacement versus Time for the 350-ft SZMW immediately after the end of the recovery (extraction) phase of cycle test 1 at KRASR.

Straight line is the best fit Cooper-Jacob solution for a confined aquifer.

Transmissivity = 32,500 ft^2/d

Storage coefficient = 7.49×10^{-5}

Similar data are shown for the 1,100-ft SZMW **Figure 5-7** below. Note that in both cases, late time displacements fall below the Cooper-Jacob straight line estimate, which often indicates a leaky confining unit. Leakage visible in the displacement vs. time plots **(Figure 5-6 and Figure 5-7)** could be due to leakance through either the ICU or MC1. Note also that the transmissivity estimate for the 1,100-ft SZMW is slightly greater than that for the 350-ft SZMW. This is evidence of heterogeneity in the storage zone, which may also account for differences between the measured data and the fitted curves. Both sets of data were fit to the Hantush-Jacob solution for a leaky confined unit. These results are shown in **Figure 5-8** and **Figure 5-9.**

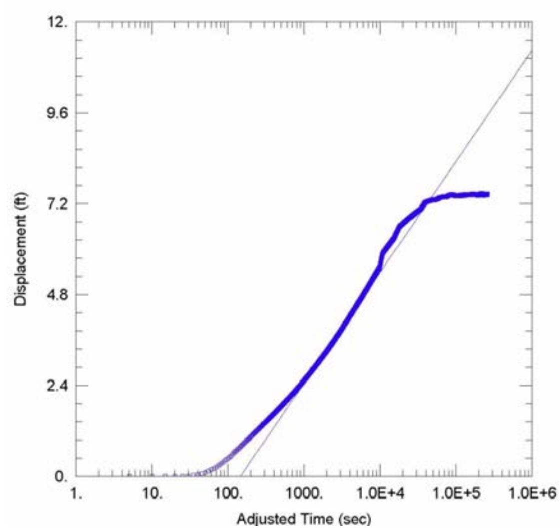


Figure 5-7 -- Displacement versus Time for the 1,100-ft SZMW immediately after the end of the recovery (extraction) phase of cycle test 1 at KRASR.

Straight line is the best fit Cooper-Jacob solution for a confined aquifer.

Transmissivity = 40,100 ft^2/d

Storage coefficient 3.26 x 10^{-5}

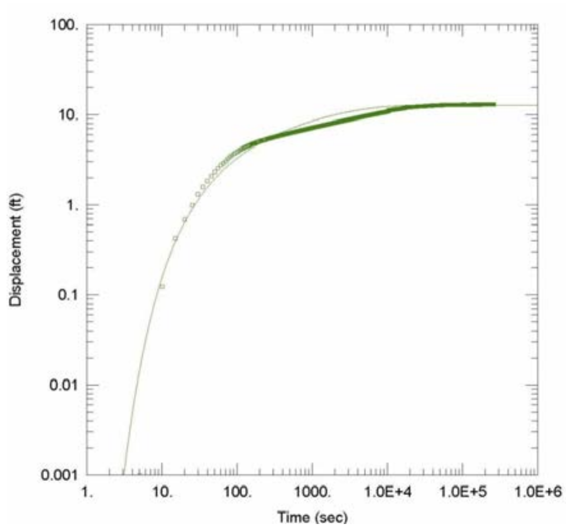


Figure 5-8 -- Displacement versus Time for the 350-ft SZMW immediately after the end of the recovery (extraction) phase of cycle test 1 at KRASR.

Fitted curve is the Hantush-Jacob solution for a leaky confined aquifer.

Transmissivity = 20,100 ft^2/d

Storage coefficient = 1.44 x 10^{-4}

Leakage factor (1/B) = 2.64 x 10^{-4} ft^{-1}

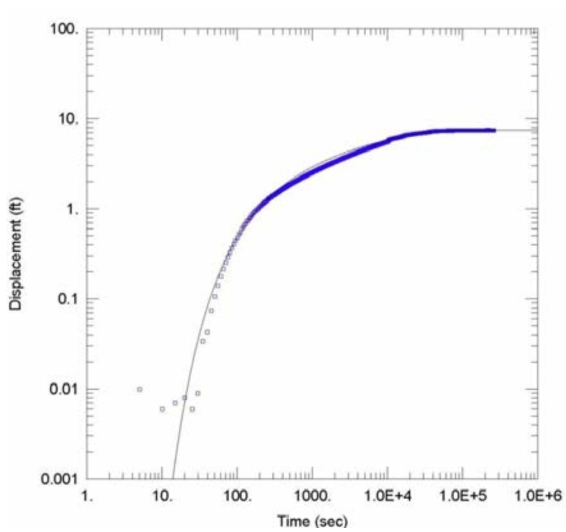


Figure 5-9 -- Displacement versus Time for 1,100-ft SZMW immediately after the end of the recovery (extraction) phase of cycle test 1 at KRASR.

Fitted curve is the Hantush-Jacob solution for a leaky confined aquifer.

Transmissivity = 36,500 ft^2/d

Storage = 6.92 x 10^{-5}

Leakage factor (1/B) = 5.77 x 10^{-4} ft^{-1}

Note that for both solutions, the transmissivity estimated for the 1,100-ft SZMW is greater than that estimated using the 350-ft SZMW. The existence of a small (20 – 30 feet thick) flow zone near the top of the Upper Floridan Aquifer (UFA) at KRASR was presented earlier **(Section 5.4.1)**. The well construction diagrams indicate that this flow zone was cased off in the 350-ft SZMW, but is intersected by the upper open interval in the 1,100-ft SZMW. Thus, it is likely that the transmissivities estimated for the 1,100-ft SZMW are more indicative of conditions in this flow zone, while those estimated for the 350-ft SZMW are more indicative of conditions in the rest of the aquifer.

In **Figure 5-10**, both wells are combined onto a single plot and the time scale is adjusted by dividing each time stamp by the square of the distance to the monitoring well. In a homogeneous aquifer, the straight-line portions of both data sets should match. Note that, in this case, the two plots do not match, indicating that there are differences in the aquifer parameters along the paths to the two monitoring wells and supporting the idea that the two monitoring wells are tapping different units of the aquifer. The straight line solution shown on **Figure 5-10** has been selected to be between the datasets but it does not match either dataset very well.

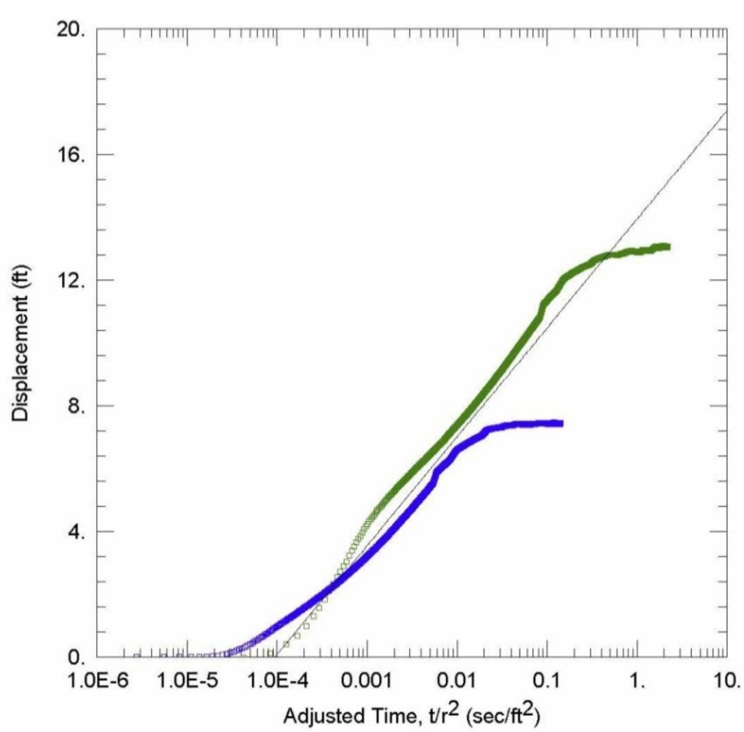


Figure 5-10 -- Displacement versus Adjusted Time for both SZMWs immediately after the end of the recovery (extraction) phase of cycle test 1 at KRASR.

Green points are for the 350-ft SZMW; blue points are for the 1,100-ft SZMW. Straight line is the Cooper-Jacob solution for a confined aquifer.

Transmissivity = 33,900 ft^2/d

Storage coefficient = 8.34×10^{-5}

Figure 5-11 shows the attempt to match the Hantush-Jacob solution to the composite plot with adjusted time on the x-axis. Again, the fact that each monitor well taps a different section of the aquifer made it impossible to select a solution that would match the data at both wells. An estimate was selected between the two datasets and neither dataset is well-matched.

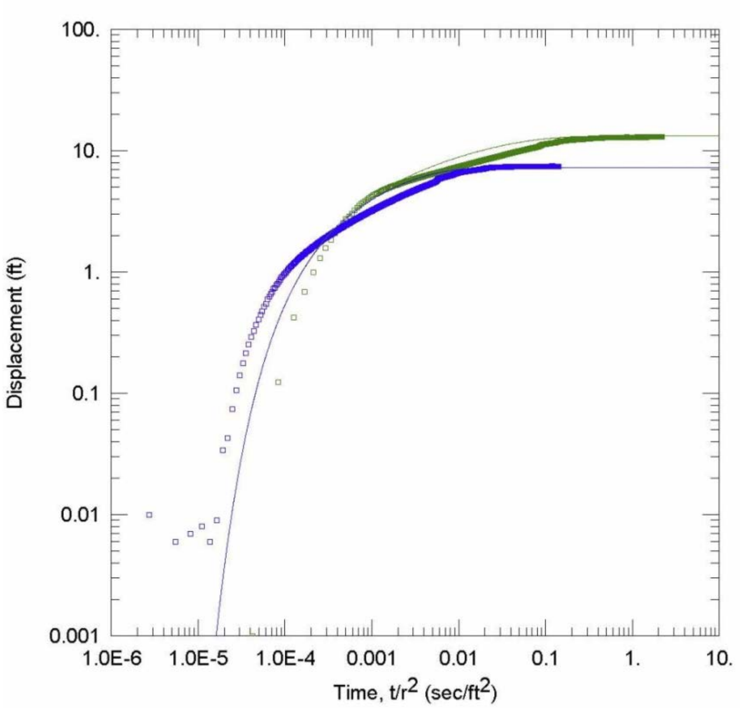


Figure 5-11 – Displacement versus Adjusted Time for both SZMWs immediately after the end of the recovery (extraction) phase of cycle test 1 at KRASR.

Green points are for the 350-ft SZMW; blue points are for the 1,100-ft SZMW. Fitted curve is the Hantush-Jacob solution for a leaky confined aquifer.

Transmissivity = 23,200 ft^2/d

Storage coefficient = 1.00 x 10^{-4}

Leakage factor (1/B) =1.63 x 10^4 ft^{-1}

An additional analysis can be done using head data taken at the 350-ft SZMW during the first 51 hours of the recovery phase of cycle 3 at KRASR. The calculations are made using the daily average reported flow rate for the ASR well. The flow rates vary only slightly (less than 1 percent) from an average rate of 5 MGD. The Cooper-Jacob estimate is shown in **Figure 5-12**. The time on the x-axis has been adjusted for flow rate changes. **Figure 5-13** shows the Hantush-Jacob estimates.

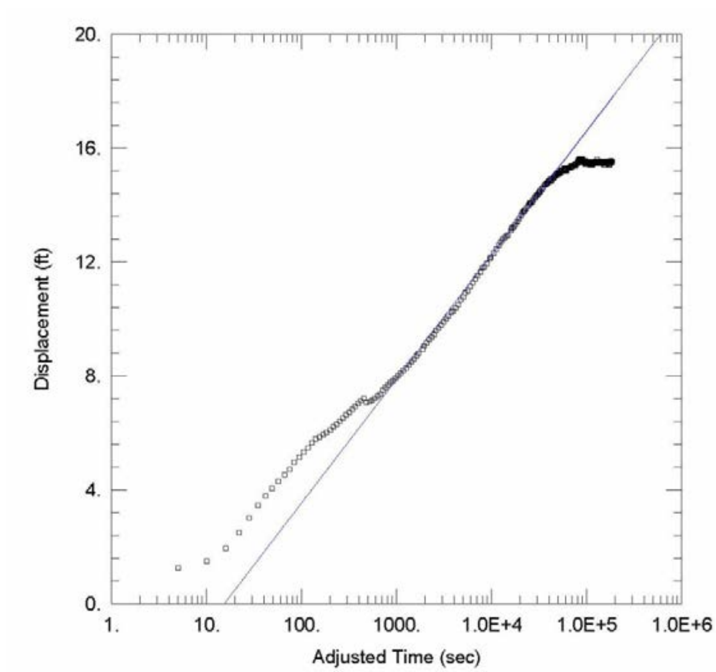


Figure 5-12 – Displacement versus Time for the 350-ft SZMW during the recovery (extraction) phase of cycle test 3 at KRASR.

Straight line is Cooper-Jacob solution for a confined aquifer.

Transmissivity = 28,200 ft^2/d

Storage coefficient = 9.39 x 10^{-5}

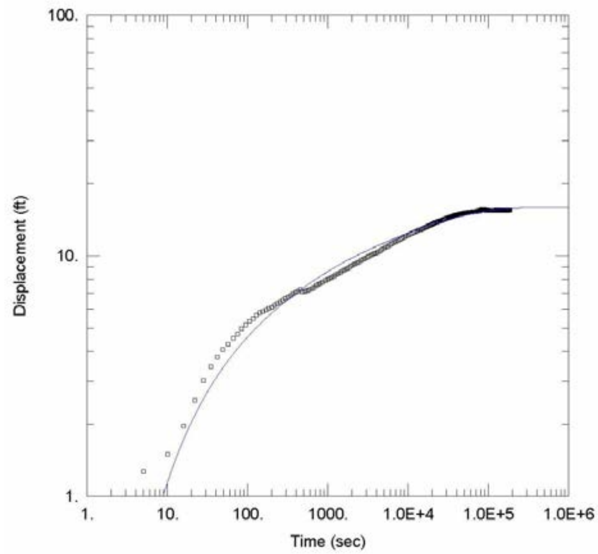


Figure 5-13 -- Displacement versus Time for the 350-ft SZMW during the recovery (extraction) phase of cycle test 3 at KRASR.

Fitted curve is the Hantush-Jacob solution for a confined aquifer.

Transmissivity = 30,200 ft^2/d

Storage = 5.12×10^{-5}

Leakage factor (1/B) = 0.012 ft^{-1}

There are several odd anomalies in the first 15 minutes of the dataset that are not well-matched by either of the estimation methods. This monitor well is quite close to the ASR well and may be influenced by early well-conditioning during the first few minutes of the test. Both methods show better matches of the later data.

All hydraulic parameter estimates are summarized in **Table 5-6.** Composite estimates are equivocal since they do not adequately match the data from either monitor well. The Hantush-Jacob results probably are more reliable than the Cooper-Jacob results, which do not account for the leakage.

Table 5-6 -- Summary of Estimated Transmissivity and Storage Coefficient Values. Values are estimated using KRASR aquifer performance test data

Parameter	Data	Solution	350-ft SZMW	1,100-ft SZMW	Composite
Transmissivity (ft^2/d)	Post Recovery (Extraction), Cycle 1	Cooper-Jacob	32,500	40,100	33,900
		Hantush-Jacob	20,100	36,500	23,200
	Recovery (Extraction), Cycle 3	Cooper-Jacob	28,200		
		Hantush-Jacob	30,200		
	Average		**27,750**	**38,300**	**28,550**
Storage	Post Recovery (Extraction), Cycle 1	Cooper-Jacob	7.49×10^{-5}	8.26×10^{-5}	8.34×10^{-5}
		Hantush-Jacob	1.44×10^{-4}	6.92×10^{-5}	1.00×10^{-4}
	Recovery (Extraction), Cycle 3	Cooper-Jacob	9.39×10^{-5}		
		Hantush-Jacob	5.11×10^{-5}		
	Log Average		**8.48×10^{-5}**	**7.56×10^{-5}**	**9.13×10^{-5}**

5.4.3 Local-Scale Groundwater Model for KRASR

A groundwater model was constructed at the KRASR system using the SEAWAT (version 4) modeling code (Langevin et al., 2008, Langevin et al., 2003, Guo and Langevin, 2002, Guo and Bennett, 1998) in order to evaluate local effects of ASR well fields. The model was calibrated to cycle test data, and simulations refined the conceptual hydrogeologic model by identifying a flow zone and investigating the possibility of anisotropy. Finally, a "proof of concept" exercise demonstrated the capabilities of a local-scale model for examining a proposed ASR system. In general, local scale models of this type can evaluate criteria such as drawdown, recovery efficiency, areal extent of the recharge water, well spacing, and well-to-well interactions.

The regional-scale ASR groundwater flow and solute transport model, previously constructed as part of the CERP ASR regional study (USACE, 2011), provided a starting point for local scale model construction and calibration. The local scale model domain is a square, extending approximately 9 miles on each side and centered on the KRASR site (**Figure 5-14**). Head and TDS data collected at five monitoring wells (35-ft SZMW, upper and lower zones of the 1,100-ft SZMW, and distal 2,350-ft and 4200-ft SZMWs) during cycle tests 1, 2, 3, and the recharge phase of cycle test 4 provided a calibration dataset.

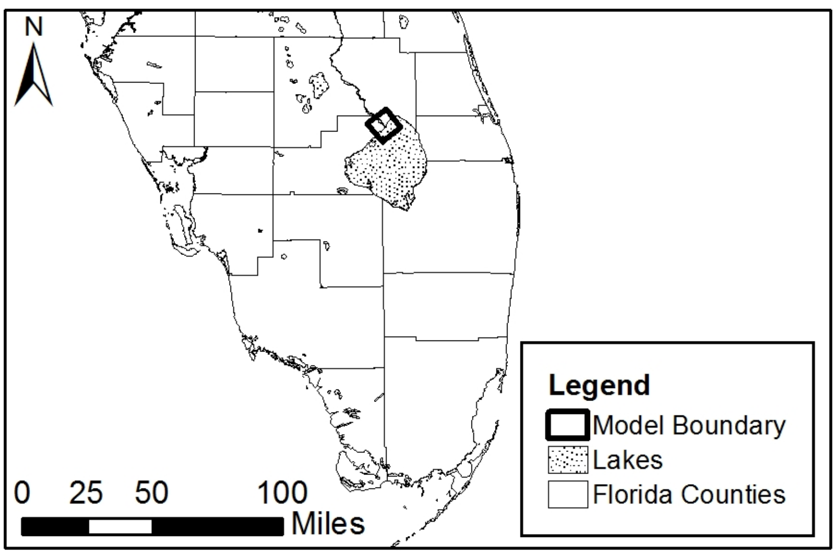


Figure 5-14 -- Boundary of the local-scale groundwater flow model at KRASR.

Early efforts at calibration indicated that a small flow zone at the top of the UFA was important to local ASR effects. This preferential flow zone **(Section 5.4.1)** was incorporated into the hydrogeologic layering of the local scale model and given a constant thickness of 25-ft over the model domain. To simulate the conduit-like flow that occurs in the flow zone, these model layers were assigned a high hydraulic conductivity (300 ft/day) and a low effective porosity (0.01). Porosity in the preferential flow zone proved to be the parameter most influential to the travel distance of the recharged water. The hydraulic conductivity of the UFA was reduced from 140 ft/day to approximately 75 ft/day near the ASR well in order to keep the thickness-averaged hydraulic conductivity of the combined UFA and flow zone close to the calibrated conductivity value from the regional model. These values fall within the range of APT results presented in **Section 5.4.3**. A porosity value of 0.25 was assigned to the UFA to simulate matrix flow.

The calibrated local scale model adequately matches the observed head data from the UFA and flow zone and the TDS data from the flow zone. The model simulations showed that pressure changes from ASR recharge or recovery propagate evenly through the UFA and flow zone. However, the recharge water can travel much farther in the flow zone than in the UFA.

The calibrated local-scale model was used to run a series of simulations to examine the effects of ASR well spacing for hypothetical well field expansion. Currently, no additional ASR wells are planned for the KRASR system, so the wellfield configurations used in these production simulations were presented only to demonstrate the capability for ASR system assessment. Six wellfield arrangements were tested using the UFA and the APPZ aquifers as storage zones and differing well spacing. The impacts on head and TDS were assessed for each production scenario by examining maximum pump pressure requirements, maximum drawdown during ASR recovery, maximum "draw-up" during recharge, and the TDS concentration of recovered water.

The development of a local scale model at the KRASR site and the analysis of well field configurations can serve as an example of the steps necessary to assess the local effects of future ASR sites. A more comprehensive discussion of the local scale model development and results can be found in Appendix A.

5.5 Hydraulic Properties of the Storage Zone (Upper Floridan Aquifer) at HASR

Evaluation of near-field (site-specific) hydraulic properties of the storage zone at HASR is based on a synthesis of borehole geophysical data, a cross-well tomography study (Parra et al., 2003), and aquifer performance test interpretations. Borehole geophysical log data were obtained during construction of the ASR well (PBF-13; Bennett et al., 2001), and the storage zone intervals from a deep borehole (PBF-12; Reese and Alvarez-Zarakian, 2007), and the 1,010-ft SZMW (PBF-14; CH2MHill, 2007).

5.5.1 Hydrogeologic Setting at HASR

The storage zone at HASR was originally interpreted to occur in the Suwannee Limestone, and is confined by limestone and calcarenites of the Lower Hawthorn Group (**Figure 5-15;** Reese and Alvarez-Zarikian, 2007**)**. Subsequent re-evaluation of core cuttings and geophysical logs in PBF-12 and other nearby cores resulted in new interpretation of the storage zone lithologies at HASR. The HASR storage zone now occurs in the Lower Arcadia Formation and the Avon Park Formation, at depths of approximately -997 ft to -1,212 ft NGVD 29 (1,010-ft to 1,225 ft bls; Reese and Cunningham, in review). Thus, the Suwannee Limestone and Ocala Limestone are absent at HASR. The storage zone occurs at a uniform depth and thickness across the one-quarter mile length of the wellfield.

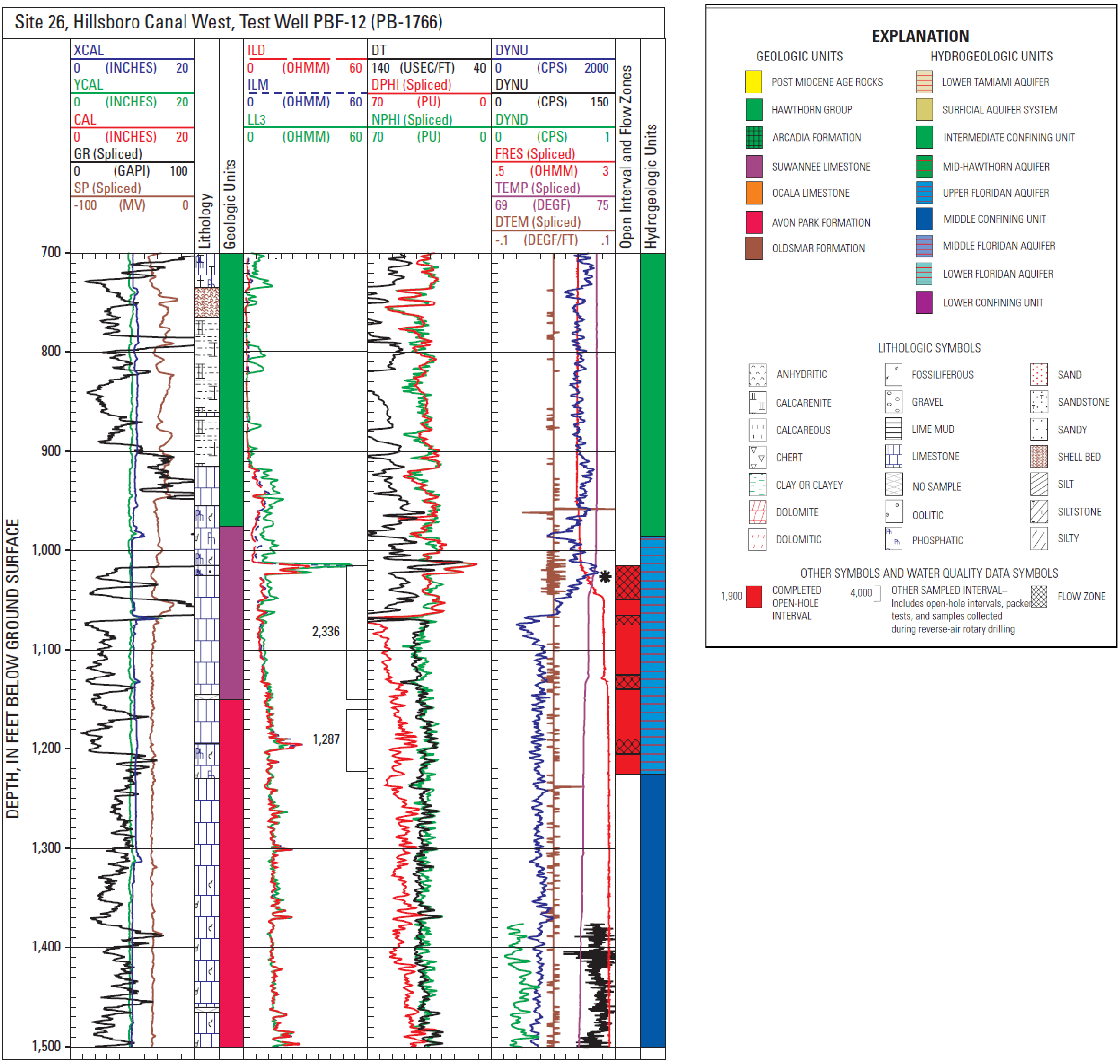


Figure 5-15-- Borehole geophysical logs and interpretations from the upper interval of the APPZ well (PBF-12).

Figure from Reese and Alvarez-Zarikian (2007).

Several preferential flow zones are interpreted in the UFA at HASR (Bennett et al., 2001; CH2MHill, 2007; Reese and Alvarez-Zarikian, 2007). A flow zone occurs at the top of the UFA (approximately -1,008 ft to -1,038 ft NGVD29), immediately below the elevated gamma-ray signature that characterizes phosphate-rich units of the Arcadia Formation. A second flow zone is interpreted in the middle part of the UFA (approximately -1,038 to -1,058 ft NGVD29). These flow zones are in a similar stratigraphic position to those documented at KRASR and elsewhere in south Florida. Native UFA water quality at the HASR system is brackish, with mean chloride concentration of 2,420 +/- 180 mg/L (n=20), and mean specific conductance value of 8,750 +/- 410 µS/cm (N=18)

Detailed permeability and porosity characterization was interpreted during a unique geophysical study that incorporated borehole nuclear magnetic resonance (NMR) and sonic data, along with cross-well seismic reflectivity data between wells PBF-10 and PBF-13 (Parra et al., 2003). They interpreted the HASR storage zone to consist of two high permeability units (approximately -1,000 to -1,040 ft, and -1,060 to -1,130 ft NGVD 29; **Figure 5-16**). The upper unit is a sandy calcarenite with macroporous porosity, while the lower unit is a permeable carbonate with interparticle and vuggy porosity. These two permeable units are separated by a 20-ft thick well-cemented fine-grained dolomitic carbonate that has low permeability but high porosity (Parra et al., 2003).

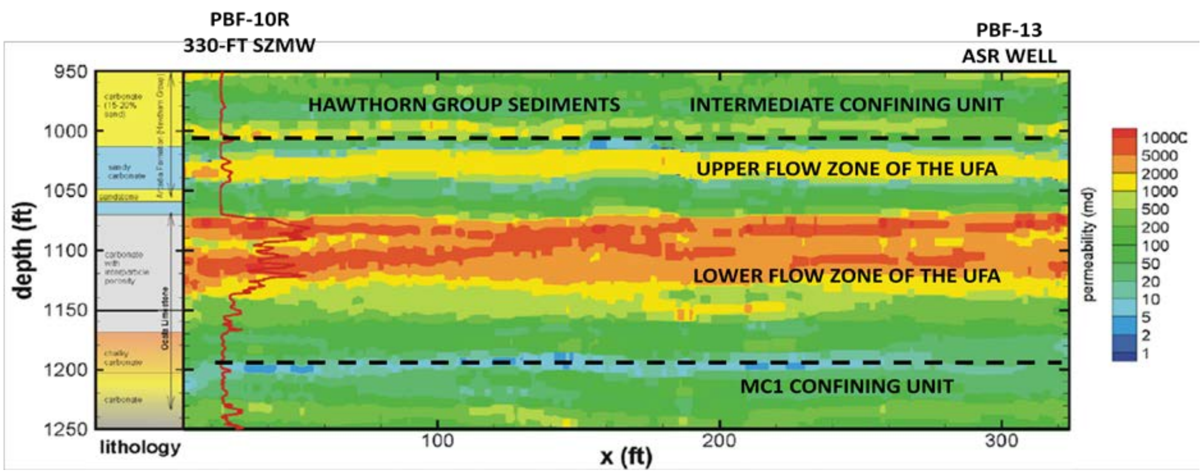


Figure 5-16 -- Hydrogeologic cross-section based on cross-well seismic reflection data and interpreted permeability at the HASR storage zone.

Permeability is greatest at zones characterized by warmer colors. Figure revised from Parra et al. (2003).

5.5.2 Confinement of the Storage Zone at HASR

One of the major concerns about ASR operations is the potential for pumping to affect the integrity of the overlying confining unit, particularly during recharge. Evaluation of upper and lower confinement and pressure-induced changes during cycle testing at HASR is accomplished using the following hydraulic and geotechnical approaches: 1) confirmation of upper and lower confining unit thickness; 2) graphical comparison of simultaneous wellhead pressure measurements in the ASR well (PBF-13) and APPZ well (PBF-11) located 130 ft from the ASR well; and 3) interpretation of geotechnical test data to define pressure thresholds that would induce microfracturing in representative rock samples from the overlying confining unit and storage zone (Geibel and Brown, 2012). HASR core samples from the PBF-11 exploratory borehole were included in this analysis. Unlike at KRASR, there is no monitor well open to the Hawthorn Group at HASR.

The ICU thickness is approximately 780 ft, at depths of -190 ft to -970 ft NGVD29 (Bennett et al., 2001), so there is little risk that fracturing in the storage zone will propagate upward through the interbedded crystalline and micritic marine limestones and silty clays to cause upward leakage. The MC1 thickness is approximately 290 ft, at depths of -1,210 ft to -1,500 ft NGVD29. The MC1 separates the storage zone from the underlying APPZ. The MC1 generally is interpreted as a leaky confining unit (Reese and Richardson, 2008), so potential upconing of fresher APPZ water is possible during the recovery phase of a cycle test. The native APPZ chloride concentration at HASR is 1,162+/- 100 mg/L **(Table 9-19)**, which is fresher than native UFA (2,293 +/- 27 mg/L). Because percent recoveries are relatively low (20 to 41 percent by volume less than 250 mg/L chloride) at HASR due to native brackish groundwater in the UFA, it is not possible to evaluate upconing of fresher water APPZ during recovery.

A graphical comparison of wellhead pressure changes in the APPZ well and ASR well provides a qualitative indication of hydraulic connection between the storage zone and underlying APPZ **(Figure 5-17)**. Monitor well PBF-11 is located 130 ft southeast of the ASR well, and is open to the Avon Park Formation at depths of -1,485 ft to -1,650 ft NGVD29. A hydraulic response in this well would suggest that MC1 is a leaky confining unit. There is no sustained hydraulic response observed in PBF-11 during recharge or recovery phases of cycle tests 1 through 3 **(Figure 5-17)**. Minor inflections in that record were the result of sampling events at PBF-11. There is a limited pressure record in PBF-11 during cycle test 3 because the pressure transducers were removed during the first two weeks of cycle testing. The ASR wellhead pressure record (from gauge readings) is often near ambient (no pumping) pressure during cycle test 3 due to facility operations issues.

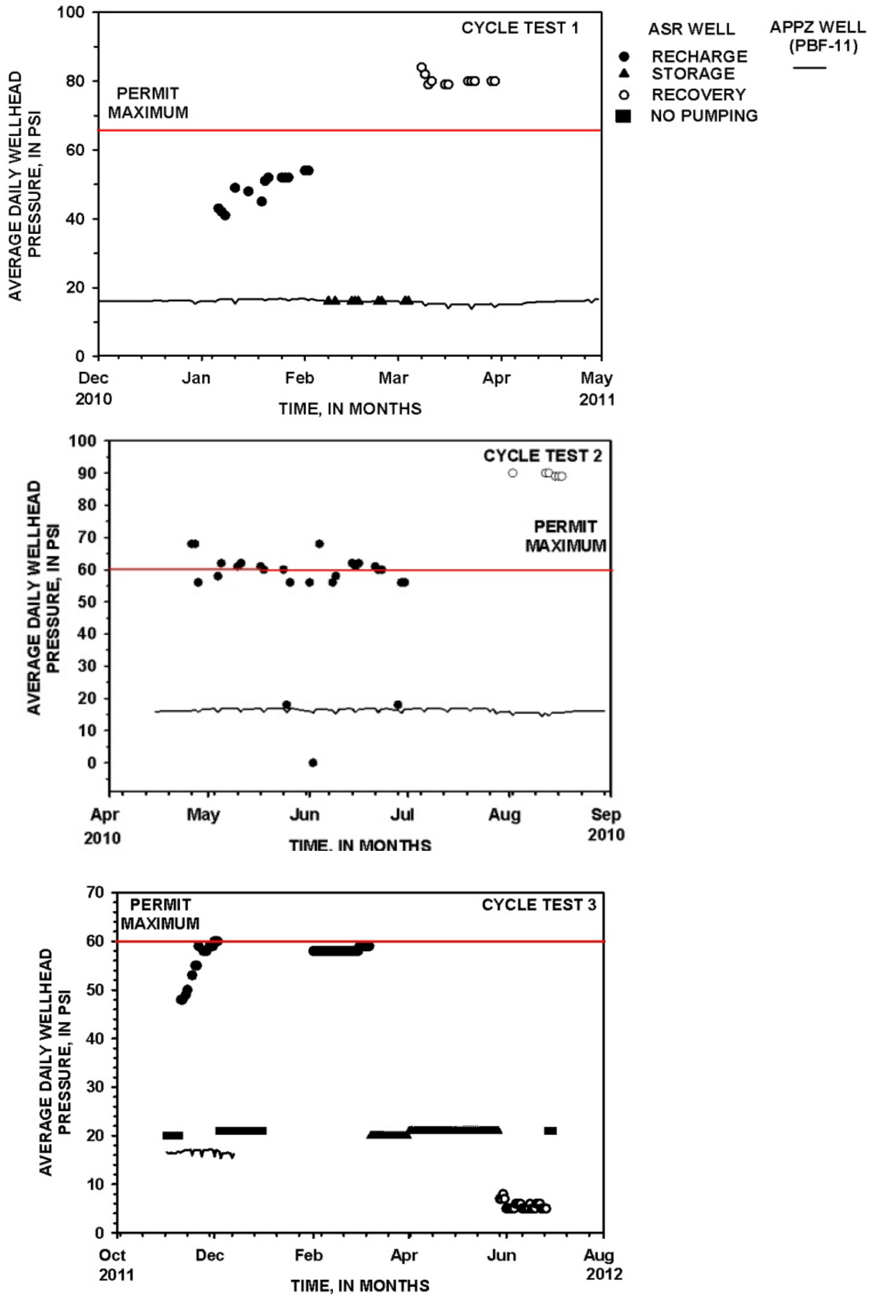


Figure 5-17 -- Plots comparing average daily wellhead pressures measured at the ASR well (PBF-13) and PBF-11 (APPZ) versus time during cycle tests 1 through 3.

Pressures are measured at the ASR PBF-13 wellhead (gauge), and the APPZ PBF-11 well (pressure transducer).

Evaluation of rock fracturing potential in the upper part of the storage zone was completed by geotechnical analysis of representative rock samples from the HASR storage zone and overlying confining unit (Geibel and Brown, 2012; **Appendix K**). This study found that the most probable failure mode is microfracturing. Deformation by shear and tensile methods require pressures that far exceed those of typical ASR operation. The minimum ASR wellhead pressure that could induce microfracturing at HASR is 149 psi. This estimated minimum pressure includes a 10 percent factor of safety. ASR wellhead pressures never exceeded 90 psi during all cycle tests **(Figure 5-17)**. ASR wellhead pressure declined through successive cycle tests due to wellhead rehabilitation prior to cycle test 3, and development of the storage zone.

Hydraulic and geotechnical evaluations at HASR indicate that the storage zone has good upper and lower confinement, and that there is a low probability of pressure-induced microfracturing in the upper part of the storage zone or overlying confining unit at typical operating pressures. This conclusion is based on three lines of evidence: 1) 780-ft thickness of the upper confining unit (ICU); 2) that ASR wellhead pressures never approach the minimum microfracturing pressure threshold (149 psi at HASR); and 3) the lower confining unit (MC1) is sufficient to prevent hydraulic connection between the APPZ and UFA during the recovery phase of cycle tests 1 through 3.

5.5.3 Aquifer Pumping Test Analysis at HASR

Head data at monitor wells near the Hillsboro ASR well were used to estimate aquifer parameters using a number of common methodologies, including the Cooper-Jacob method (Cooper and Jacob, 1946) and the Hantush-Jacob method (Hantush and Jacob, 1955). Aqtesolv 4.0 Professional (HydroSOLVE, Inc., Reston VA) was used to analyze the data and make the estimations.

Wellhead pressure data and conductivity-temperate-depth (CTD) probe data were available for a 330-ft SZMW and a 1,010-ft SZMW during the recharge and recovery portions of cycle test 1. Wellhead pressures were recorded at 15-minute intervals; CTD probe data were recorded at 60 minute intervals. These large time intervals may preclude some early data analysis, which is normally available for APT tests, but should provide enough information for the estimations desired. Differences between wellhead pressure measurements and CTD probe data were minor, though the wellhead data seemed to be more affected by water quality sampling events. Well flows were based on daily average flow rates at the ASR well. Daily flow rates varied by about 5 percent from an average of 4.9 MGD.

Figure 5-19 and **Figure 5-19** show the data at the 330-ft SZMW from the CTD probe measurements with the Cooper-Jacob and Hantush-Jacob estimated curves. Note that there is some variability in the pumping data at the ASR well. The same analyses are then presented in **Figure 5-21** and **Figure 5-21** for the wellhead data. In both Cooper-Jacob plots, the x-axis has been adjusted to account for the variable pump rates. Both Cooper-Jacob plots show that late time displacement values are below the straight line estimate, which is often indicative of the presence of a leaky confined aquifer. **Section 5.5.2** presents data showing that there is no significant leakage of pressure through the confining units above and below the storage zone. The late time displacement below the Cooper-Jacob straight line, then, is an indication of significant heterogeneity in the storage zone.

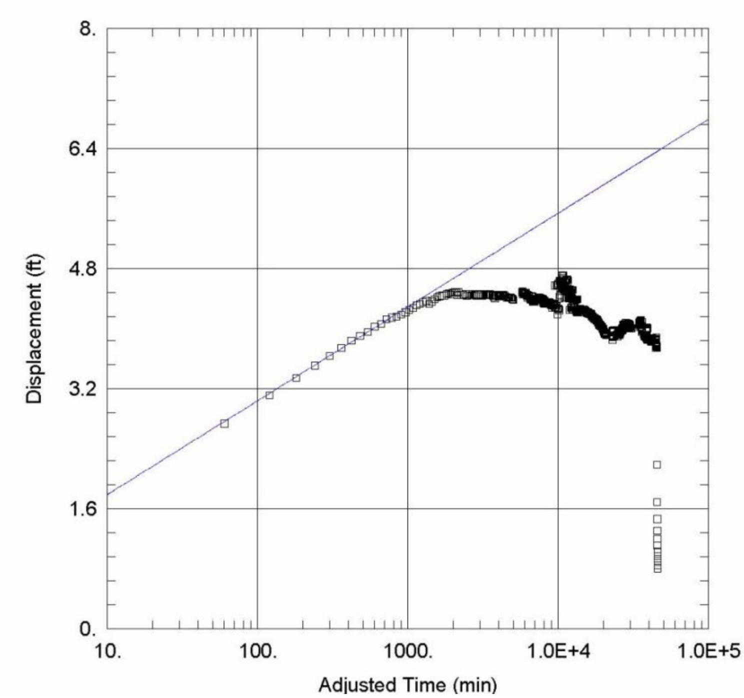


Figure 5-18 -- Displacement versus Time for 330-ft SZMW (CTD data) during the recharge (injection) phase of cycle 1 at HASR.

Straight line is Cooper-Jacob solution for a confined aquifer.

Transmissivity = 21,800 ft^2/d

Storage = 1.08 x 10^{-4}

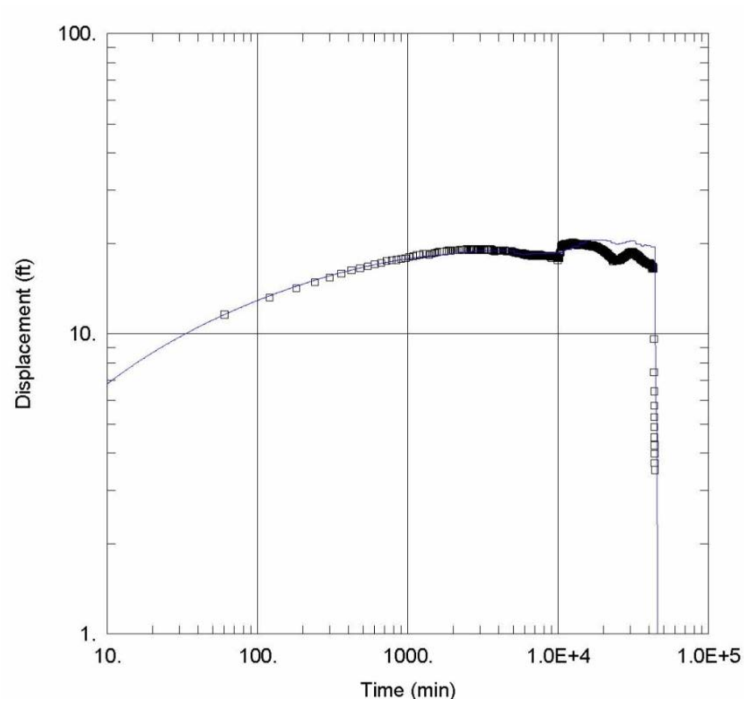


Figure 5-19 -- Displacement versus Time for the 330-ft SZMW (CTD data) during the recharge (injection) phase of cycle test 1 at HASR.

Curved line is Hantush-Jacob solution for a leaky confined aquifer.

Transmissivity = 18,000 ft^2/d

Storage = 2.20 x 10^{-4}

Leakage factor (1/B) = 1.13 x 10^{-4} ft^{-1}

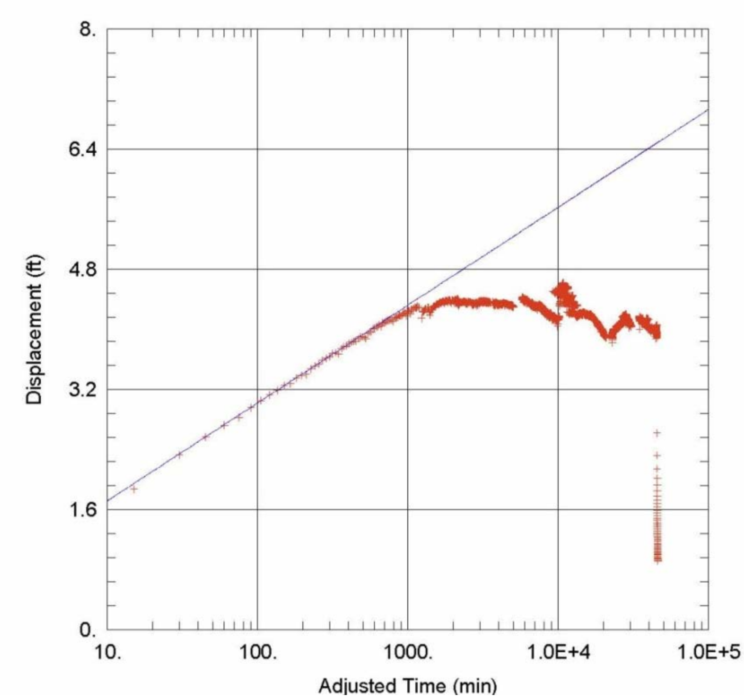


Figure 5-20 -- Displacement versus Time for the 330-ft SZMW (wellhead data) during the recharge (injection) phase of cycle test 1 at HASR.

Straight line is Cooper-Jacob solution for a confined aquifer.

Transmissivity = 20,900 ft^2/d

Storage = 1.36×10^{-4}

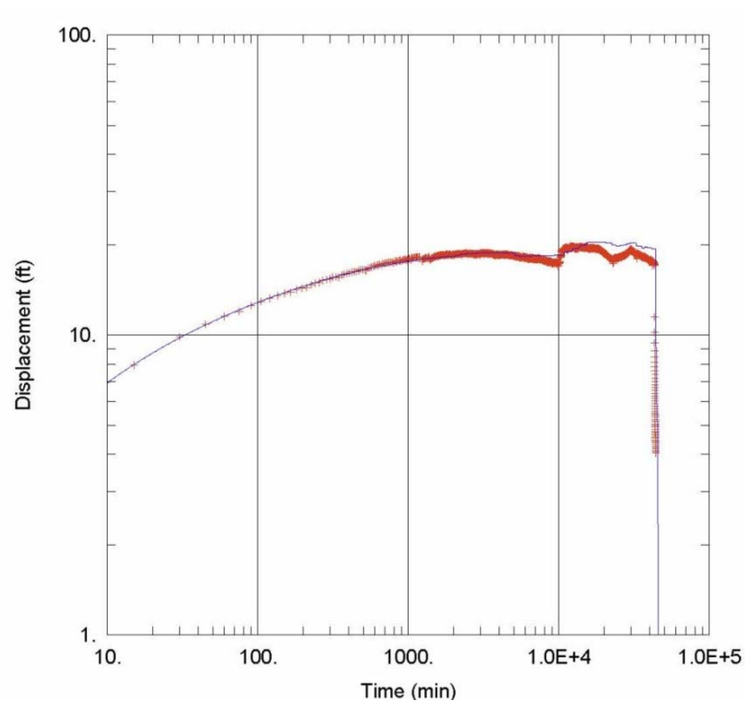


Figure 5-21 -- Displacement versus Time for 330-ft SZMW (wellhead data) during the recharge (injection) phase of cycle test 1 at HASR.

Curved line is Hantush-Jacob solution for a leaky confined aquifer.

Transmissivity = 18,700 ft^2/d

Storage = 1.99×10^{-4}

Leakage factor (1/B) = 1.02×10^{-4} ft^{-1}

Figure 5-22 through **Figure 5-25** show the same data for the 1,010-ft SZMW. The time axes on the Cooper-Jacobs plots have again been adjusted to account for variable flow rates at the ASR well. The Cooper-Jacob plots again show the presence of heterogeneity.

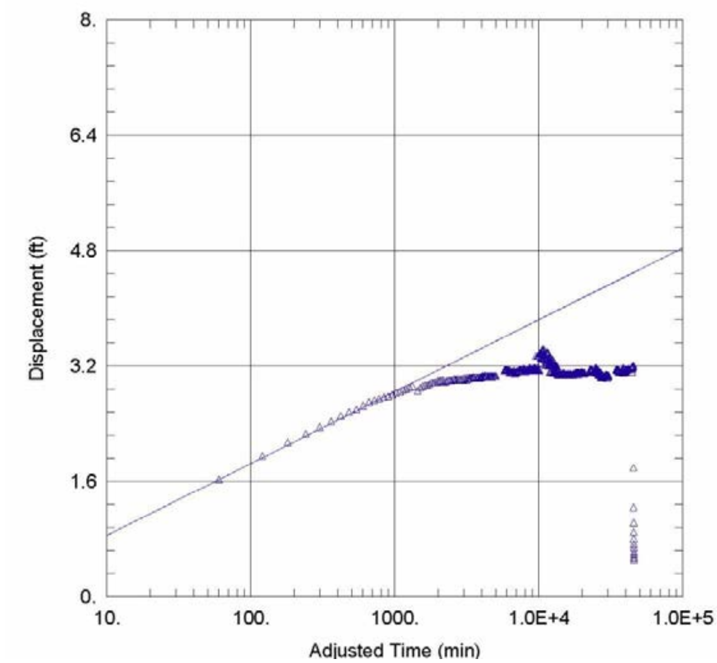


Figure 5-22 -- Displacement versus Time for the 1,010-ft SZMW (CTD data) during the recharge (injection) phase of cycle test 1 at HASR.

Straight line is Cooper-Jacob solution for a confined aquifer.

Transmissivity = 27,400 ft^2/d

Storage = 6.04×10^{-5}

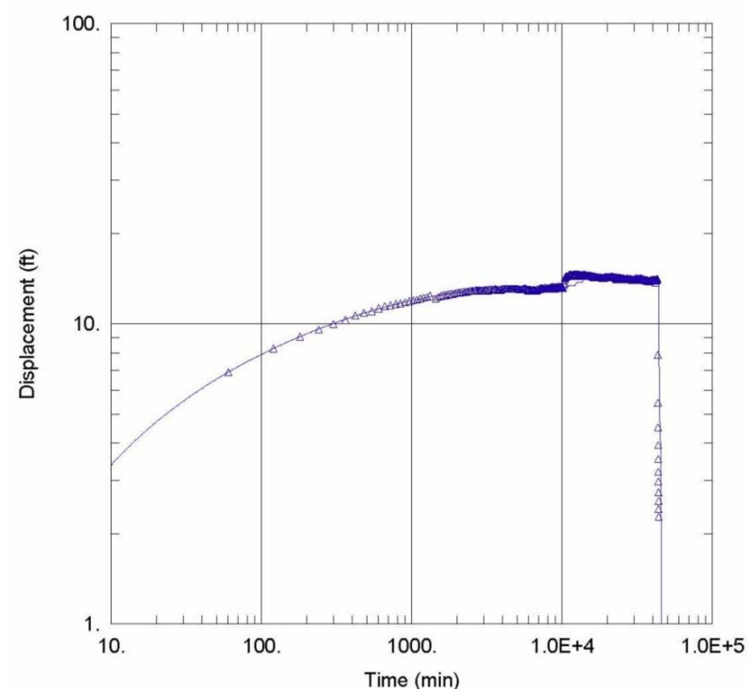


Figure 5-23 -- Displacement versus Time for the 1,010-ft SZMW (CTD data) during the recharge (injection) phase of cycle test 1 at HASR.

Curved line is Hantush-Jacob solution for a leaky confined aquifer.

Transmissivity = 23,900 ft^2/d

Storage = 8.48×10^{-5}

Leakage factor (1/B) = $4.86 \times 10^{-5} ft^{-1}$

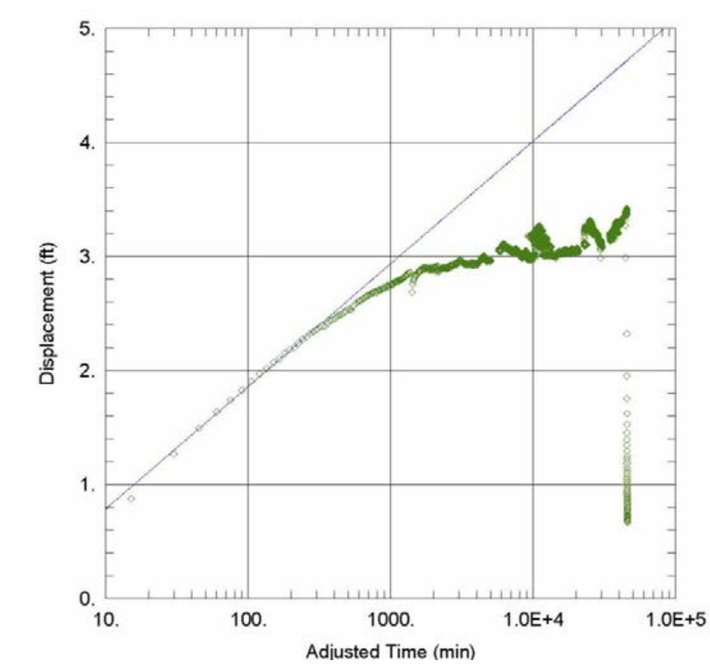


Figure 5-24 -- Displacement versus Time for the 1,010-ft SZMW (wellhead data) during the recharge (injection) phase of cycle test 1 at HASR.

Straight line is Cooper-Jacob solution for a confined aquifer.

Transmissivity = 25,400 ft^2/d

Storage = 7.46 x 10^{-5}

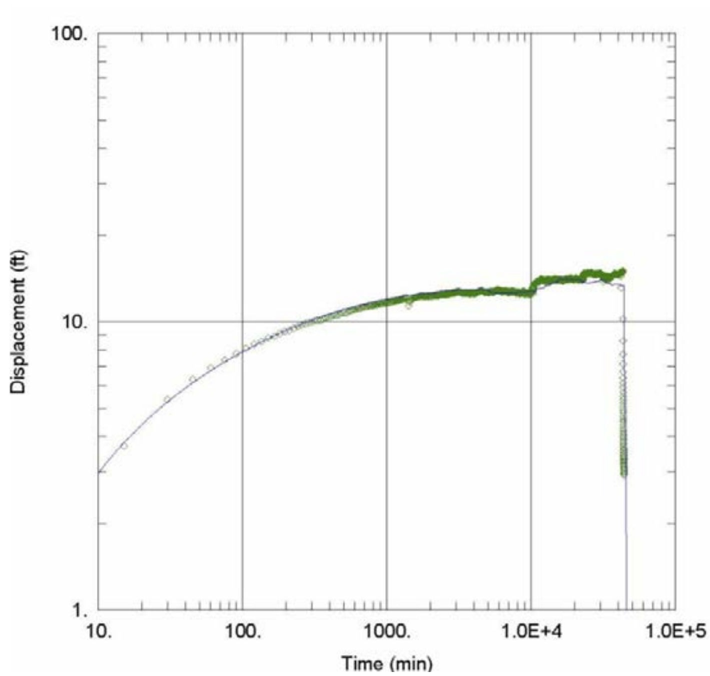


Figure 5-25 -- Displacement versus Time for the 1,010-ft SZMW (wellhead data) during the recharge (injection) phase of cycle test 1 at HASR.

Curved line is Hantush-Jacob solution for a leaky confined aquifer.

Transmissivity = 21,400 ft^2/d

Storage = 1.13 x 10^{-4}

Leakage factor (1/B) = 7.35 x 10^{-5} ft^{-1}

Figure 5-26 and **Figure 5-27** show the data from the CTD probes and the wellhead measurements for both monitor wells. The data have been overlain by adjusting the x-axis for variable pumping rates and then dividing the times by the square of the distance to the monitor wells. For the calculation of composite aquifer parameters, the early data of all plots should lie on top of each other. In both plots, this seems to be the case, though the earliest data is missed by the sparse data collection. In each case, estimates of the transmissivity and storage are listed.

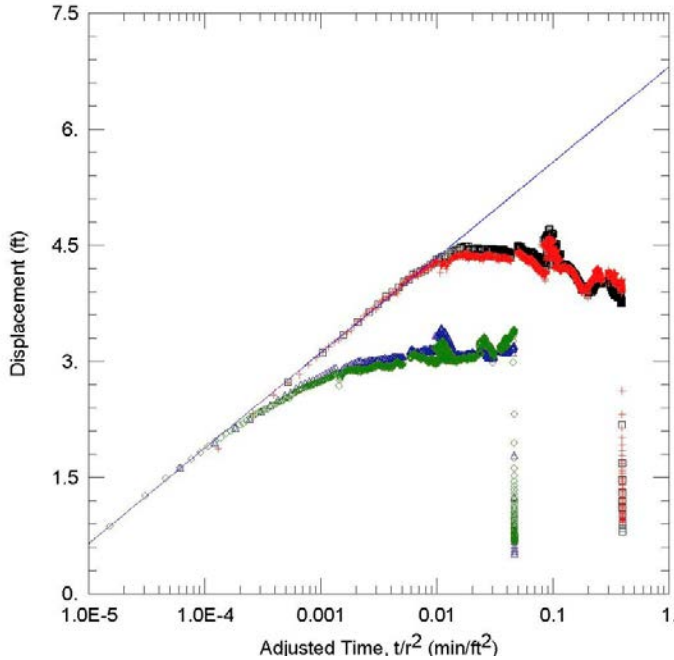


Figure 5-26 -- Displacement versus Adjusted Time for both SZMW (CTD and wellhead data) during the recharge (injection) phase of cycle test 1 at HASR.

Straight line is Cooper-Jacob solution for a confined aquifer.

Transmissivity = 22,100 ft^2/d

Storage = 2.02 x 10^{-4}

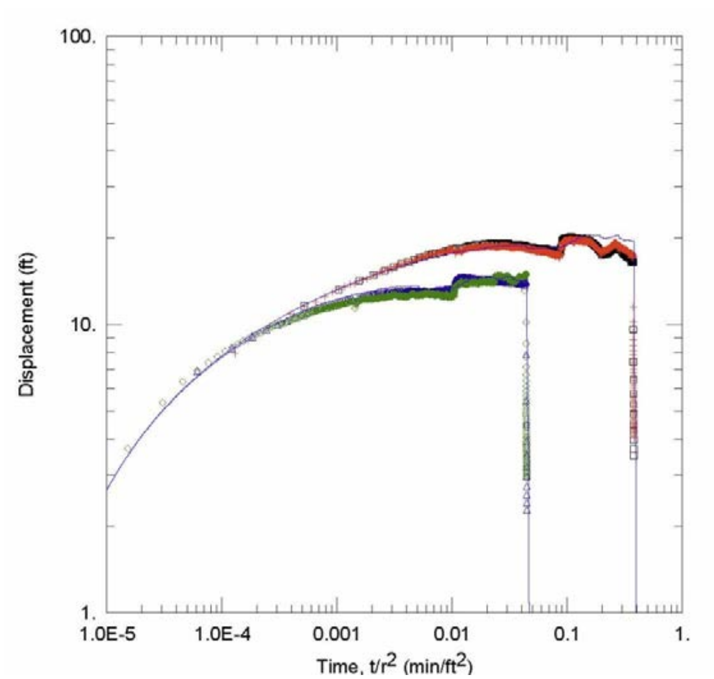


Figure 5-27 -- Displacement versus Adjusted Time for both SZMW (CTD and well head data) during the recharge (injection) phase of cycle 1 at HASR.

Curved lines are Hantush-Jacob solutions for a leaky confined aquifer.

Transmissivity = 20,600 ft^2/d

Storage = 1.33 x 10^{-4}

Leakage factor (1/B) = 7.03 x 10^{-5} ft^{-1}

The same type of data is available at the two monitor wells for a period 2 months later when the ASR well was shifted to its recovery phase. All of the same analyses are provided for this data in the following figures **(Figure 5-28** through **Figure 5-35)**.

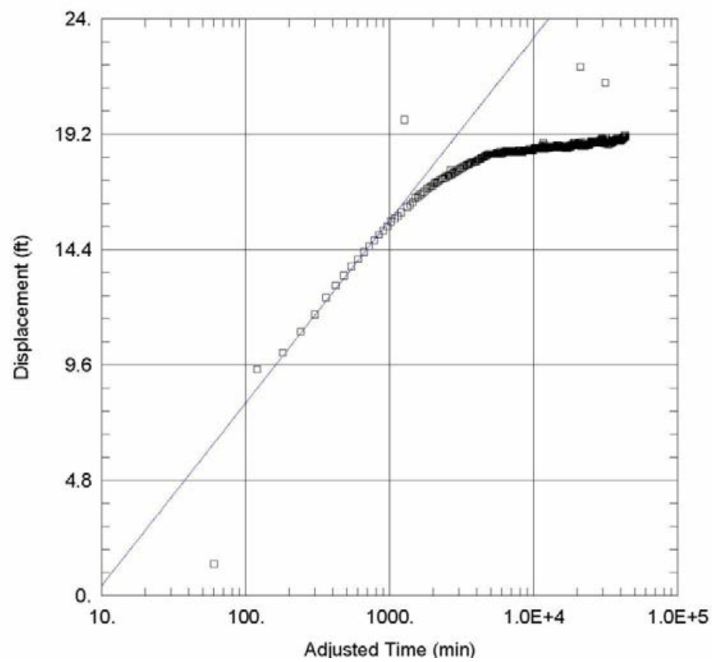


Figure 5-28 -- Drawdown vs. Time for the 330-ft SZMW (CTD data) during the recovery (extraction) phase of cycle test 1 at HASR.

Straight line is Cooper-Jacob solution for a confined aquifer.

Transmissivity = 16,200 ft^2/d

Storage = 1.92 x 10^{-3}

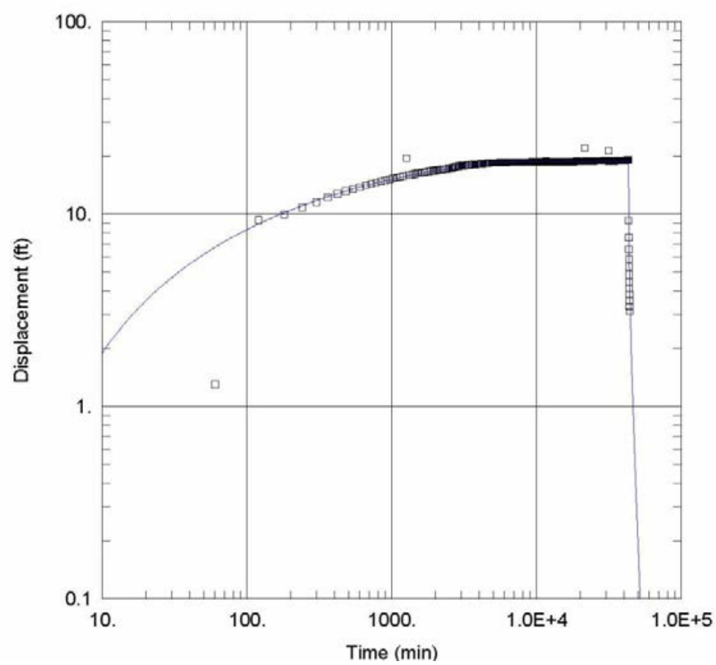


Figure 5-29 -- Drawdown versus Time for the 330-ft SZMW (CTD data) during the recovery (extraction) phase of cycle test 1 at HASR.

Curve is Hantush-Jacob solution for a leaky confined aquifer.

Transmissivity = 15,500 ft^2/d

Storage = 1.86 x 10^{-3}

Leakage factor (1/B) = 2.18 x 10^{-4} ft^{-1}

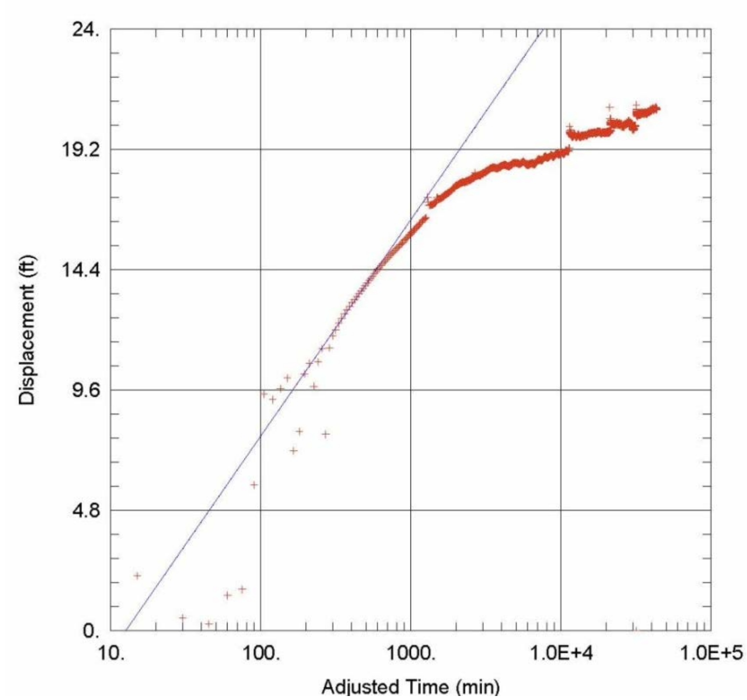


Figure 5-30 -- Drawdown versus Time for the 330-ft SZMW (wellhead data) during the recovery (extraction) phase of cycle test 1 at HASR.

Straight line is Cooper-Jacob solution for a confined aquifer.

Transmissivity = 14,200 ft^2/d

Storage = 2.42 x 10^{-3}

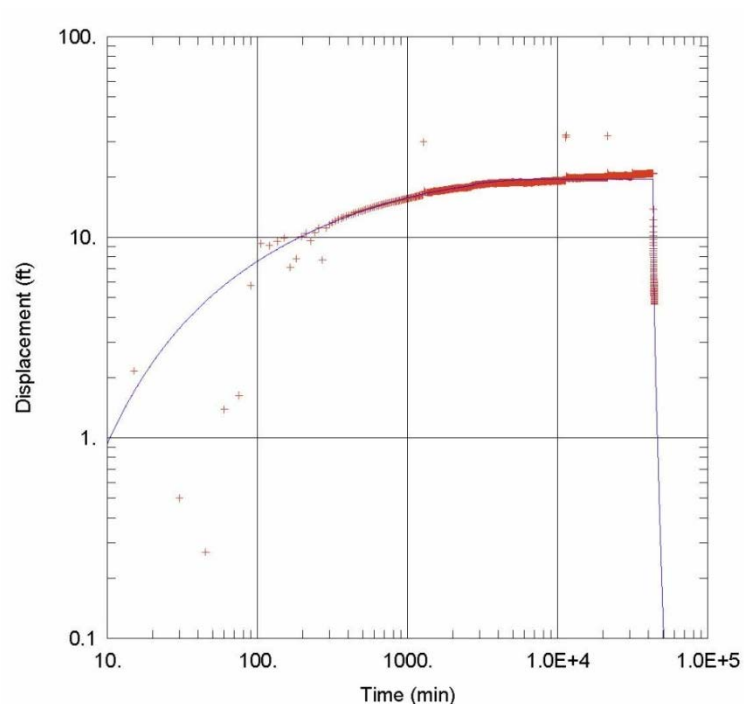


Figure 5-31 -- Drawdown versus Time for the 330-ft SZMW (wellhead data) during the recovery (extraction) phase of cycle test 1 at HASR.

Curve is Hantush-Jacob solution for a leaky confined aquifer.

Transmissivity = 12,500 ft^2/d

Storage = 2.97 x 10^{-3}

Leakage factor (1/B) = 3.40 x 10^{-4} ft^{-1}

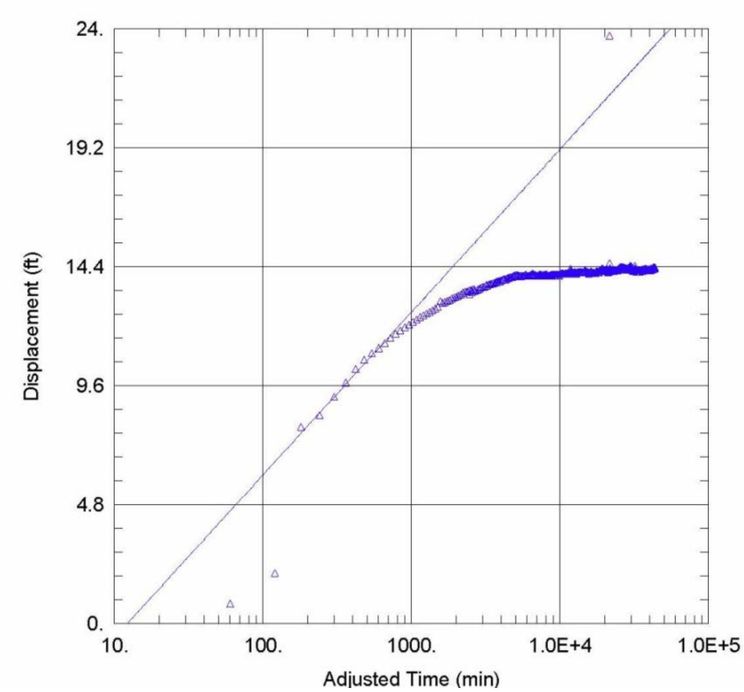


Figure 5-32 -- Drawdown versus Time for the 1,010-ft SZMW (CTD data) during the recovery (extraction) phase of cycle test 1 at HASR.

Straight line is Cooper-Jacob solution for a confined aquifer.

Transmissivity = 18,700 ft^2/d

Storage = 3.61 x 10^{-4}

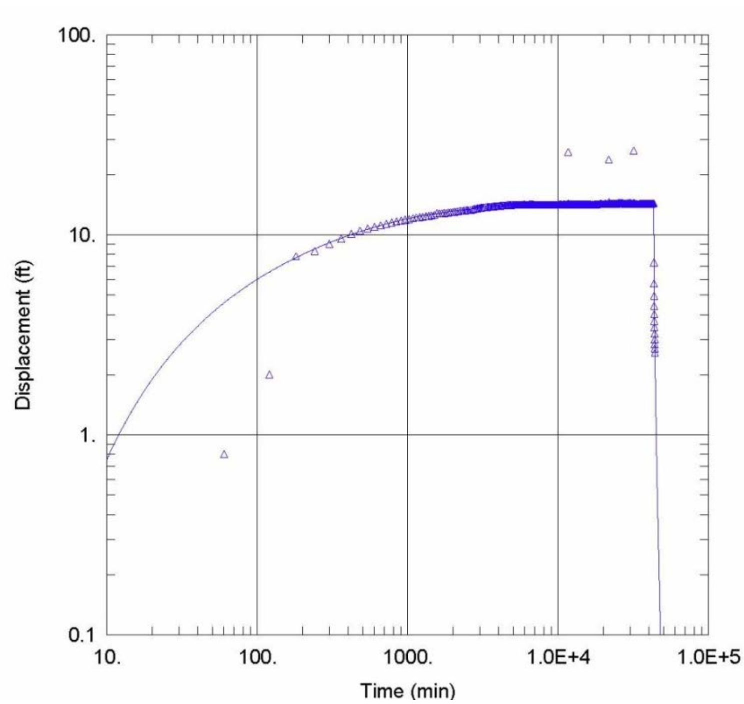


Figure 5-33 -- Drawdown versus Time for the 1,010-ft SZMW (CTD data) during the recovery (extraction) phase of cycle test 1 at HASR.

Curve is Hantush-Jacob solution for a leaky confined aquifer.

Transmissivity = 15,900 ft^2/d

Storage = 4.36 x 10^{-4}

Leakage factor (1/B) = 1.421 x 10^{-4} ft^{-1}

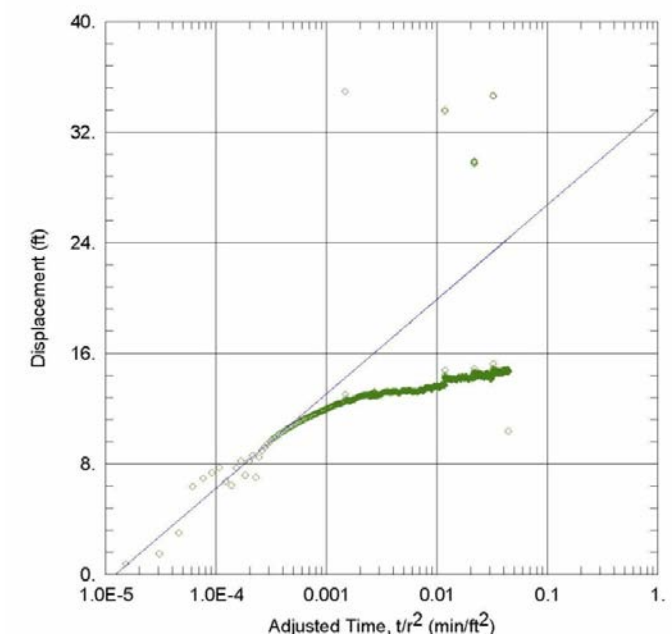


Figure 5-34 -- Drawdown versus Time for the 1,010-ft SZMW (wellhead data) during the recovery (extraction) phase of cycle test 1 at HASR.

Straight line is Cooper-Jacob solution for a confined aquifer.

Transmissivity = 18,000 ft^2/d

Storage = 3.63 x 10^{-4}

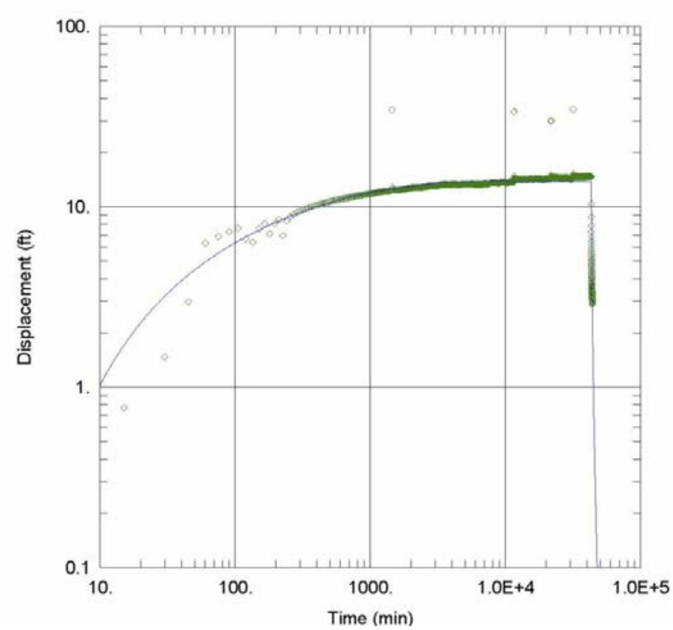


Figure 5-35 -- Drawdown versus Time for the 1,010-ft SZMW (wellhead data) during the recovery (extraction) phase of cycle test 1 at HASR.

Curve is Hantush-Jacob solution for a leaky confined aquifer.

Transmissivity = 16,900 ft^2/d

Storage = 3.63 x 10^{-4}

Leakage factor (1/B) = 1.28 x 10^{-4} ft^{-1}

Unlike the recharge data shown in **Figure 5-26** and **Figure 5-27**, the composite analyses of this data set **(Figure 5-36** and **Figure 5-37)** do not yield a good composite set of aquifer parameters for the data at both observation wells. The reasons for this difference are not clear, but the composite parameter estimates for the recovery data are not reliable since they cannot match all of the data.

Table 5-7 summarizes the results of the analyses. The close correlation between the CTD and wellhead data is apparent in the similar results in nearly every case, but the CTD data is considered to be more accurate since it is not as easily affected by water quality sampling events. The Hantush-Jacob results are considered to be more reliable since they better account for the heterogeneity. The composite analysis of the recharge cycle data showed that the data from both wells yielded similar aquifer parameters, but the composite data at each well for the recovery cycle did not correlate well. The most reliable estimates are likely to be from the Hantush-Jacob composite analysis of the recharge phase.

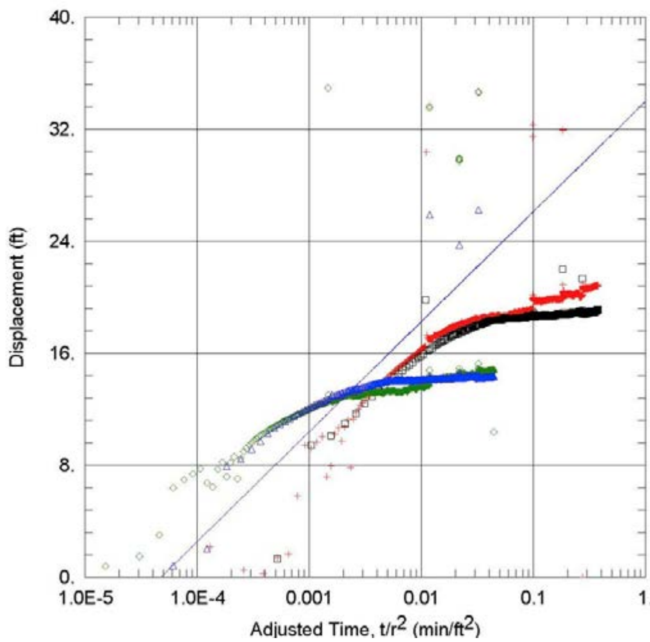


Figure 5-36 -- Drawdown versus Adjusted Time for both SZMWs (CTD and wellhead data) during the recovery (extraction) phase of cycle test 1 at HASR.

Straight line is Cooper-Jacob solution for a confined aquifer. Not considered a good estimate for all data.

Transmissivity = 15,600 ft^2/d

Storage = 1.15×10^{-3}

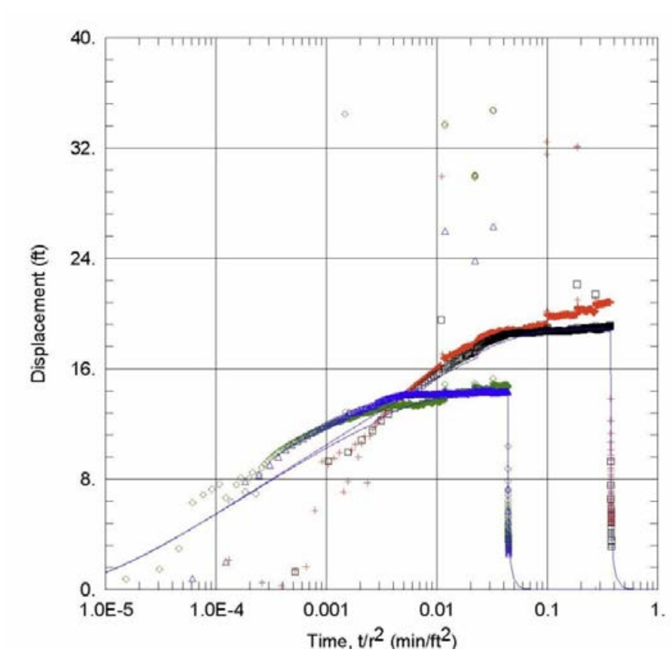


Figure 5-37 -- Drawdown versus Adjusted Time for both SZMWs (CTD and wellhead data) during the recovery (extraction) phase of cycle test 1 at HASR.

Curves are Hantush-Jacob solutions for a leaky confined aquifer. Not considered a good estimate for all data.

Transmissivity = 23,600 ft^2/d

Storage = 3.28×10^{-4}

Leakage factor = 5.06×10^{-5} ft^{-1}

Table 5-7 -- Summary of Estimated Transmissivity and Storage Coefficient Values. Estimates are for the storage zone using aquifer performance test data at HASR.

Parameter	Solution	ASR Cycle	Data	330-ft SZMW	1,010-ft SZMW	Composite
Transmissivity	Cooper-Jacob	Recharge (Injection), cycle test 1	CTD	21,800	27,400	22,100
			Wellhead	20,900	25,400	
		Recovery (Extraction), cycle test 1	CTD	16,200	18,700	15,600*
			Wellhead	14,200	18,000	
	Hantush-Jacob	Recharge (Injection), cycle test 1	CTD	18,000	23,900	**20,600**
			Wellhead	18,700	21,400	
		Recovery (Extraction), cycle test 1	CTD	15,500	15,900	23,600*
			Wellhead	12,500	16,900	
	Average (all data)			17,200	20,900	
	Average (just CTD data and Hantush-Jacob estimates			16,800	19,900	
Storage	Cooper-Jacob	Recharge (Injection), cycle test 1	CTD	1.08×10^{-4}	6.04E-5	1.02×10^{-4}
			Wellhead	1.36×10^{-4}	7.46E-5	
		Recovery (Extraction), cycle test 1	CTD	1.92×10^{-3}	3.61×10^{-4}	1.15×10^{-3}*
			Wellhead	2.42×10^{-3}	3.42×10^{-4}	
	Hantush-Jacob	Recharge (Injection), cycle test 1	CTD	2.20×10^{-4}	8.48E-5	**1.33×10^{-4}**
			Wellhead	1.99×10^{-4}	1.13×10^{-4}	
		Recovery (Extraction), cycle test 1	CTD	1.86×10^{-3}	4.36×10^{-4}	3.28×10^{-4}*
			Wellhead	2.97×10^{-3}	3.63×10^{-4}	
	Log Average (all data)			5.98×10^{-4}	1.74×10^{-4}	
	Log Average (just CTD data and Hantush-Jacob estimates)			6.39×10^{-4}	1.92×10^{-4}	

*The data from the two wells did not correlate well during the composite analysis. These starred values are not reliable.

5.5.4 Local-Scale Groundwater Model for HASR

A local scale model was constructed at the HASR system using the SEAWAT (version 4) modeling code (Langevin et al., 2008; Langevin et al., 2003; Guo and Langevin, 2002; Guo and Bennett; 1998) in order to evaluate local effects of ASR well fields. The model was calibrated on a limited basis to available data from cycle testing, but data collection problems and shorter ASR cycles limited the usefulness of this model in evaluating local effects of an ASR system. The primary utility of this model was to simulate the effects of multiple ASR well configurations at HASR. The model boundary is shown in **Figure 5-38.**

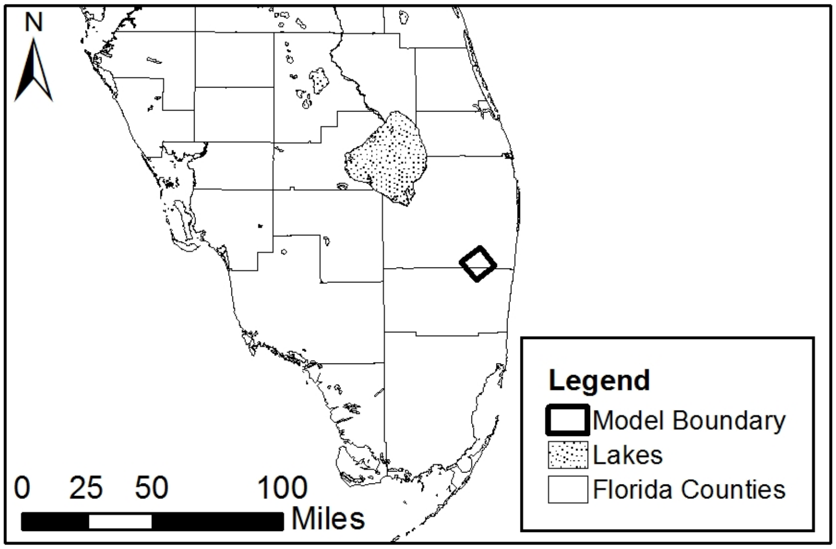


Figure 5-38 – Boundary of the local scale groundwater flow model at HASR.

The regional scale ASR model, previously constructed as part of the CERP ASR regional study (USACE, 2011), provided a starting point for the local scale model construction and calibration. The local scale model is nine miles by nine miles in size and centered at HASR. Head data collected at four monitoring wells (PBF-10R, PBF-11, PBF-12, and PBF-14) during cycle tests 1 and 2 provided the calibration dataset. The data collection problems precluded any calibration to water quality at the monitoring wells and prevented the use of this model for analysis of recovery efficiency, freshwater "bubble" extent or well-to-well water quality interactions.

During model calibration, the hydraulic conductivity of the UFA and MC1 were adjusted slightly from the values used in the regional model in order to match the observed head data. The model was able to reasonably reproduce the head impacts of the cycle testing.

A series of production scenarios were created to estimate the number of wells that can be placed at the Site 1 Impoundment, located adjacent to the HASR system. Because calibration of transport parameters was not possible, only criteria related to head and pressure impacts could be assessed with this model. Production simulations showed that a total of 12 UFA ASR wells and 1 APPZ ASR well can be placed at the Site 1 Impoundment while still meeting performance criteria based on maximum pump pressure (100 psi). These results can serve only as preliminary guidance. Further study is necessary to ensure that water quality criteria are met with any ASR system design at this site. A more comprehensive discussion of the local scale modeling efforts can be found in **Appendix A.**

5.5.5 Long-Term Hydraulic Responses in HASR Storage Zone Monitor Wells

Water level data were recorded in the 330-ft SZMW (PBF-10R) for approximately 10 years by the SFWMD, from mid-2002 through June 2013, with the exception of the period from early to late 2012 (cycle test 3 recovery phase; **Figure 5-39**). Water level data also were recorded continuously in the 1,010-ft SZMW (PBF-14) for approximately 6 years, from 2007 through 2013 **(Figure 5-39)**. Data from the both wells indicate that water levels were on a gradual regional upward trend during the years preceding cycle testing. During recharge, approximately 20-ft of head was induced at well PBF-10R. Spurious data obtained during cycle test 2 probably reflect the open-hole collapse that occurred in this well during cycle test 2.

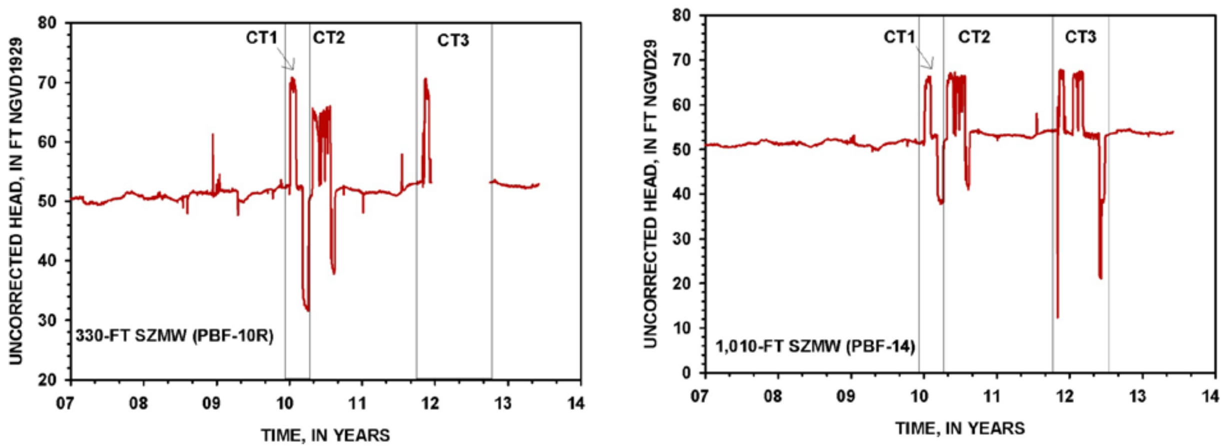


Figure 5-39 -- Water level data (as uncorrected hydraulic head) measured at the 330-ft SZMW (left), and the measured at the 1,010-ft SZMW (right).

After the completion of the third and final cycle test, it appears that water levels at this location remained about 2-ft higher than pre-testing levels. This was primarily the result of the long-term continuation of increasing regional water levels plus the lower density of water in the monitor well casing as a result of the freshening of water produced from this well. Prior to the initiation of cycle testing, the total dissolved solids (TDS) concentration in water collected from this well was approximately 5,170 mg/L. Upon completion of cycle testing, the final TDS concentration of water from this well was 3,610 mg/L, representing a 30 percent decline in overall salinity. This reduction in salinity resulted in lower density of water in the well casing, which translated to nearly a 1-ft rise in the water level attributable solely to lower density water. Additionally, some smaller amount of the increase may be a result of additional buoyant head in the aquifer from fresh water remaining in the area after the completion of cycle test 3.

Water level data recorded at 1,010 SZMW (PBF-14; **Figure 5-39)** also indicated subtle increase in regional water levels during the years preceding cycle testing at the HASR system. During recharge, approximately 7-ft of head was induced at this location (a distance of 1,010 feet from the ASR well). These data are useful in anticipating the interference effects that ASR well clusters might exert locally during recharge and recovery operations. If ASR well clusters are constructed at this site, they should be separated a minimum distance of approximately 1,000-ft, so as to avoid excessive interference effects upon each other. Safer well distances may be on the order of 2,000-ft, if the site can accommodate that spacing.

An additional observation from the 1,010 SZMW is that water levels remained about 2-ft higher at this location after the completion of cycle testing relative to pre-testing conditions. As with the 330-ft SZMW (PBF-10R), the increase in head is primarily attributed to the longer-term trend of rising in water levels in this area and the freshening of water collected from this well, resulting in a decrease in water density within the casing. To a lesser extent, there may also be a component of buoyant forces within the aquifer, resulting from fresh water that was not recovered by the end of cycle testing.

5.6 ASR Well Performance Improvement From Rehabilitation

Well clogging is a common occurrence at ASR systems that recharge other than drinking water (Pavelic et al., 2007). Maintaining optimum well performance requires periodic ASR well rehabilitation, which usually consists of acidization of the well bore to remove biofilms, mineral precipitates, and particles entrained in the aquifer. Evaluating the effectiveness of ASR well rehabilitation by acidization is determined by comparison of specific capacity tests conducted before and after each acidization event. At KRASR, acidization events were conducted during well construction (2004) to improve productivity. Acidization events were performed again during cycle test 2 storage (2009) and after cycle test 2 recovery (2010) to reduce borehole clogging and rising wellhead pressures. At HASR, acidization events were performed during well construction (2000), and after cycle test 2 was completed (2009), for the same reasons as the KRASR tests. Acidization during the period of cycle testing improves well capacity. At KRASR, well capacities doubled with each successive test (Table 5-8). At HASR, well capacity improved approximately 25 percent during the 2011 event, and specific capacity values returned to their original, post-construction (2000) values. Well rehabilitation should be incorporated as a normal maintenance activity when increasing wellhead pressures are observed. Costs of ASR well rehabilitation are presented in Section 11.1.1.

Table 5-8 – Results of Specific Capacity Tests in ASR Wells. Tests conducted before and after well rehabilitation by acidization.

ASR SYSTEM	WELL	DATE	WELL CONDITION	PUMPING RATE, IN GPM	SPECIFIC CAPACITY	SPECIFIC INJECTIVITY	UNIT	REFERENCE
HASR	ASR	June 2000	Pre-acidization	1,000 - 3,000	26.5		gpm/ft	Bennett et al., 2001
		June 2000	Post-acidization	2,000 - 5,200	50		gpm/ft	
		July 2011	Pre-acidization	3,500		39 to 41	gpm/ft	Cardno-Entrix, 2011b
		July 2011	Post-acidization	3,500		50.5	gpm/ft	
KRASR	ASR	March 2004	Pre-acidization	800 - 1,350	15.8 - 12.3		gpm/ft	CH2M Hill, 2004
		March 2004	Post-acidization test 1	2,000 - 3,500	37.3 - 29.2		gpm/ft	
		April 2004	Post Acidization test 2	1,070 - 2,700	107 - 50.1		gpm/ft	
		October 2009	Pre-acidization - Event 1	3,500	38.3		gpm/ft	Cardno-Entrix, 2011a
		October 2009	Post-acidization test 1	3,500	61.6		gpm/ft	
		January 2010	Pre-acidization - Event 2	3,465	60.8		gpm/ft	
		January 2010	Post-acidization test2	3,460	138.2		gpm/ft	
	4,200-ft SZMW	July 2010	well construction	210	3.45		gpm/ft	Entrix, 2010a
	2,350-ft SZMW	July 2010	well construction	210	4.3		gpm/ft	Entrix, 2010b

5.7 Summary and Conclusions

Detailed hydrogeologic, hydraulic, and geotechnical evaluations were completed at KRASR and HASR to characterize and simulate groundwater flow and pressure changes during cycle testing. The major conclusions of these studies at KRASR are:

- The storage zone occurs within the Ocala Limestone and uppermost Avon Park Formation at a depth range of -550 to -870-ft NGVD29. The storage zone is in the UFA, with overlying confinement by the ICU (Hawthorn Group, lower Arcadia Formation), and underlying confinement by the MC1 (upper Avon Park Formation). Native water quality of the storage zone is fresh, characterized by chloride concentrations that range between 50 and 281 mg/L, and specific conductance values that range between approximately 1,000 and 1,400 µS/cm.

- Permeability is not uniformly distributed with depth in the KRASR storage zone. A prominent flow zone exists at the top of the UFA (approximately -550 to -570-ft NGVD29), coincident with the unconformable contact between the Arcadia Formation and the Ocala Limestone. A minor flow zone exists near the base of the storage zone (-780 to -790-ft NGVD29), possibly coincident with the unconformable contact between the Ocala Limestone and the Avon Park Formation. Borehole flowmeter analysis shows that 63 percent of the borehole flow emanates from the upper flow zone. During cycle test 2 recharge, the apparent linear flow rate at the 350-ft SZMW is 117 ft/day. During cycle tests 1 and 3 recharge, the apparent linear flow rates at the 1,100-ft SZMW are approximately 55 to 58 ft/day. Flow rate slows farther from the pumping stress.

- Transmissivities were estimated from limited aquifer performance test data obtained during rebound at the end of recovery (cycle test 1) and drawdown at the start of recovery (cycle test 3). Best estimates of transmissivity were obtained using the Hantush-Jacob solution, with values of 20,100 and 30,200 ft^2/day (350-ft SZMW), and 36,500 ft^2/day (1,100-ft SZMW). The lower values are consistent with values estimated during construction of the ASR well (26,884 ft^2/day). The higher value probably represents the upper flow zone that is intersected by the short open interval of the 1,100 SZMW.

- Storage coefficients also were estimated from the same aquifer performance test data. Best estimates of storage coefficients were obtained using the Hantush-Jacob solution, with values of 0.00014, 0.00005 and 0.00007. These values are less than values estimated during construction of the ASR well (0.0002).

- A local scale groundwater flow and solute transport model of the KRASR system was developed and calibrated using the SEAWAT modeling code. Early calibration efforts demonstrated the importance of discretely modeling the preferential flow zone that exists at the top of the UFA. The model simulations showed that pressure changes from ASR recharge or recovery propagate evenly through the UFA and flow zone. However, recharge water can travel much farther in the flow zone than in the UFA. This model can be used to assess multiple aspects of an ASR system, including drawdown, recovery efficiency, areal extent of recharge water, well spacing, and well-to-well interactions.

- Geotechnical evaluation of rock fracturing potential at KRASR indicates that the only possible failure mode is microfracturing, and that microfracturing is unlikely to be propagated into the overlying intermediate confining unit (ICU) at typical operating pressures. The minimum wellhead pressure that would generate microfracturing at KRASR is 89 psi, which includes a 10 percent factor of safety. ASR wellhead pressures never exceeded 66 psi during cycle testing.

- There is good upper and lower confinement of the storage zone at KRASR. No hydraulic response was observed at the ICU well during the entire cycle testing program. Chloride concentrations in the storage zone did not increase beyond native conditions during four recovery phases. Upconing of more saline APPZ groundwater through a leaky lower confining unit was not detected at KRASR.

- ASR well rehabilitation by acidization significantly improved well performance. Specific capacity values doubled after each acidization event. ASR well rehabilitation should be included in an ASR system maintenance plan to reduce ASR wellhead pressures due to borehole clogging.

The major conclusions of these studies at HASR are:

- The storage zone occurs within the lower Arcadia Formation and the Avon Park Formation, at depths of approximately -997 ft to -1,212-ft NGVD29. The storage zone includes the UFA, with overlying confinement by the ICU (Hawthorn Group, lower Arcadia Formation), and underlying confinement by the MC1 (upper Avon Park Formation). Native UFA water quality at the HASR system is brackish, with mean chloride concentration of 2,420 +/- 180 mg/L (n=20), and mean specific conductance value of 8,750 +/- 410 µS/cm (N=18)

- Permeability is not uniformly distributed with depth in the HASR storage zone. A flow zone was interpreted from geophysical flow log data at the top of the UFA (approximately -1,008- ft to -1,038 ft NGVD29), immediately below the elevated gamma-ray signature that characterizes phosphate-rich units of the Arcadia Formation. A lower flow zone exists in the middle part of the UFA (approximately -1,038 to -1,058 ft NGVD). Detailed permeability and porosity characterization was interpreted from a unique geophysical study that incorporated NMR, sonic, and seismic reflectivity data through the storage zone wells. The storage zone consists of two high permeability units (approximately -1,000 to -1,040 ft, and -1,060 to -1,130 ft NGVD 29) separated by a low permeability/high porosity unit.

- Transmissivities were estimated from aquifer performance test data obtained during recharge and recovery phases of cycle test 1. The best estimate of transmissivity was 20,600 ft^2/day, with the Hantush-Jacob solution using recharge phase data. This value differs from that estimated during construction of the ASR well (8,104 ft^2/day), but is consistent with other estimates of UFA transmissivity in the region.

- Storage coefficients were estimated from the same aquifer performance test data. The best estimate of storage coefficients was 0.0001, with the Hantush-Jacob solution using recharge phase data. This value is identical to the value estimated during construction of the ASR well.

- A local scale groundwater flow and solute transport model of the HASR system was developed and calibrated using the SEAWAT modeling code. The calibrated model reasonably reproduces head impacts observed during cycle testing. However, the TDS data collected during cycle testing were not sufficient to calibrate the transport parameters. As a result of data limitations, use of this model is restricted to assessing only head and pressure impacts of an ASR system.

- Geotechnical evaluation of rock fracturing potential at HASR indicates that the only possible failure mode is microfracturing, and that microfracturing is unlikely to be propagated into the overlying intermediate confining unit (ICU) at typical operating pressures. The minimum wellhead pressure that would generate microfracturing at HASR is 149 psi, which includes a 10 percent factor of safety. ASR wellhead pressures never exceeded 99 psi throughout the cycle testing program.

- There is good upper confinement of the storage zone at HASR. The ICU thickness is approximately 780-ft, at depths of -190 ft to -970 ft NGVD29 so there is little risk that fracturing in the storage zone will propagate upward through the confining unit. The integrity of the lower confining unit MC1 is more difficult to evaluate because recovery phases of each cycle test are relatively short. The MC1 thickness is approximately 290 ft, at depths of -1,210 ft to -1,500 ft NGVD29. The lack of hydraulic response during cycle testing in an APPZ well located 130-ft from the ASR well suggests that the lower confining unit (MC1) is sufficient to prevent hydraulic connection between the APPZ and UFA.

- Water levels measured the storage zone are approximately 2-ft higher than pre-cycle testing levels, as measured at both the 330-ft and 1,010-ft SZMWs. This was primarily the result of the long-term continuation of increasing regional water levels plus the lower density of water in the monitor well casing as a result of the freshening of aquifer.

- ASR well rehabilitation by acidization improved well performance. Specific capacity values increased 24 percent after a single acidization event. ASR well rehabilitation should be included in an ASR system maintenance plan to reduce ASR wellhead pressures due to borehole clogging.

6. Surface Facility Engineering and Design

The surface facility designs at KRASR and HASR differ, to evaluate different approaches to ASR system operations. The KRASR system is envisioned to recharge, store, and recover large volumes of water over several years, whereas the HASR system operates on an annual wet season/dry season recharge and recovery cycle. Regarding pre-treatment components, the filters differ between systems due to treatment requirements of each source water. Both systems employed the same UV disinfection technology, differing only in number of in-line units. Both systems have similar pumping capacities (5 MGD), although each system could be modified to increase pumping capacity. Both ASR systems were designed for remote operation; however, an operator was present at KRASR on weekday to ensure constant, consistent operation particularly during recharge. The HASR system was unmanned. This section defines the design of each ASR system, and also summarizes results of testing to improve KRASR system performance during cycle testing.

6.1 Kissimmee River ASR System

6.1.1 Surface Facility Design

The KRASR facility is designed to withdraw and treat water from the Kissimmee River, recharge and store it within an artesian aquifer, and recover and discharge the stored water as needed. The system components include: the source water intake, a recharge pump station, a pressure filtration system, a disinfection system, an aquifer storage and recovery well (with recovery pump), a backwash equalization pond, a decant pump station, a backwash solids pump and a cascade aerator (R2T, Inc., 2011; Appendix B). A schematic diagram of the processes is shown in **Figure 6-1**.

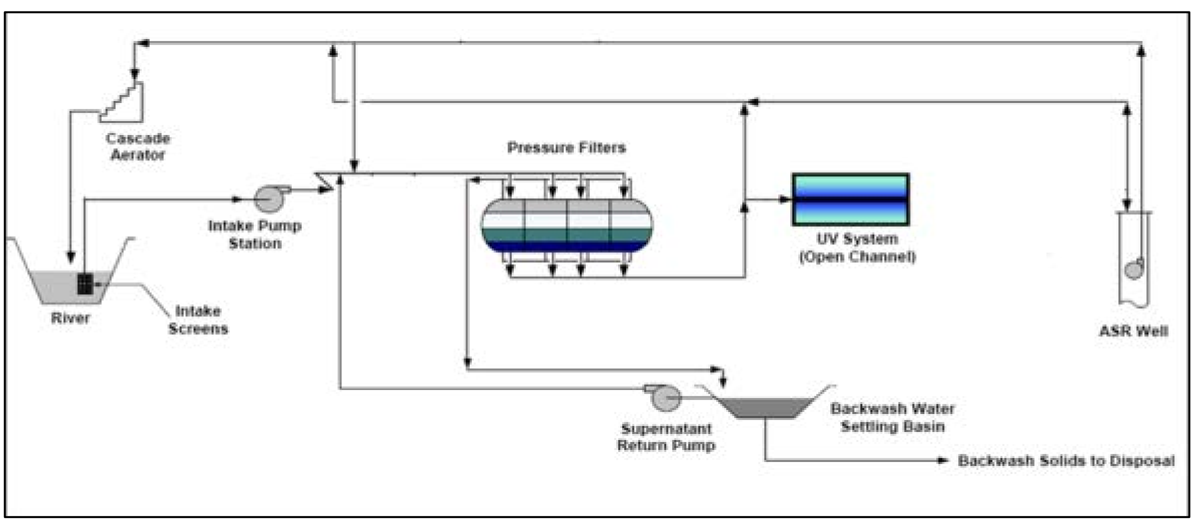


Figure 6-1 -- Diagram showing the KRASR surface facility process

6.1.2 ASR System Components

6.1.2.1 Intake Design and Operation

The intake system consists of a submerged intake structure and pump station that delivers surface water to the treatment components. The pump station is constructed of cast-in-place concrete comprising of a wet well, intake portal, and top slab. The pump station equipment includes an intake screen, intake screen air scour system and recharge pump. The intake structure is designed to prevent fish larvae and debris from entering the system. It consists of a 48-in diameter T-shaped cylindrical passive intake screen (Hendrick Screen, Owensboro, KY) that is located about 60-ft from the pump station concrete wall. The screen grid mesh size is 1-mm, and was designed for a flow velocity of 0.25 ft/sec in compliance with the USFWS requirements to prevent larval entrainment. The screen blockage factor is 30 percent. The intake design depth is at least 2.5-ft below the Kissimmee River water level to prevent pump cavitation. Water is conveyed through a 24-in ductile iron pipe to the pump station.

An air scour system cleans the intake screen by bursting air from a 280-gallon compressed air tank through a 6-in pipe that ends with an internally mounted manifold **(Figure 6-2)**. Air burst pressure is 175 psig that lasts about 2 to 3 seconds. A pneumatic-actuated check butterfly valve on the air holding tank rapidly discharges air through the pipe. The air scour system has three modes of operation: pre-set head loss set point, pre-set timer, and manual. Specific information on the source water intake components is presented in **Table 6-1**. The process and instrumentation diagrams for the intake are also shown on sheets 1-G-10, 1-G-11, 1-G-12 and 1-I-2 in **Appendix C**.

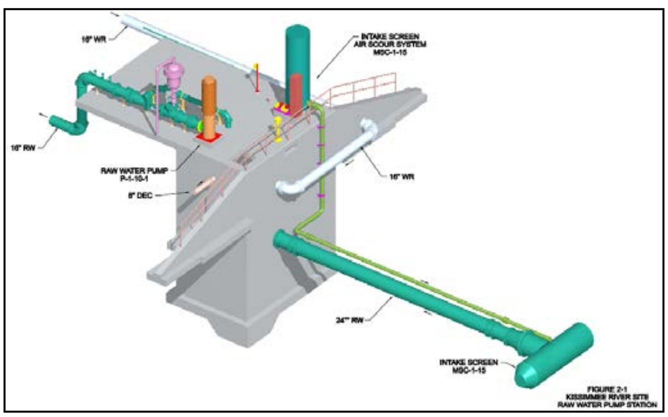


Figure 6-2 -- Intake design layout (left), and intake structure under construction (right).

Table 6-1 -- Intake Specifications

Intake Screen		**Compressor**		**Recharge Pump**	
Capacity	5 MGD	Air burst rate	17.3 ACFM	Capacity	4000gpm@235 ft
Slot opening	1 mm	Air burst pressure	175 psig	No. of stages	5
Average flow	5 MGD	Scour Duration	2-3 sec	HP	300
Flow through velocity	0.25 ft/sec	Compressor power	5 HP	Drive	Constant speed
Screen blockage factor	30 percent	Receiving tank vol	280 gal	Speed	1190 rpm
Minimum submergence	2.5 ft below low water (10.7 ft)			Nominal Efficiency	95.4

6.1.2.2 Recharge Pump

The recharge pump (Weir Floway, Inc., Fresno CA) is a 350-HP vertical turbine pump with 4,000 GPM capacity at 235-ft total dynamic head (TDH). The pump pressurizes water to pass through the filters, UV disinfection system, and into the aquifer. This recharge pump was selected to account for minimum water level, maximum back-pressure at the ASR well, and head loss in piping and treatment facilities. Additional pump capacity is provided to allow for higher flow or for future higher pressure rating of the ASR well. Discharge pressure is monitored locally by a pressure gauge. The low and high water levels are monitored by a float in the wet well to automatically shut down pumping at water levels beyond design criteria. A pressure relief valve and the associated piping are designed for surge and pressure relief control. Pressure relief piping directs the flow from the pump back into the wet well. The pump station and air compressor are shown in Figure **6-3**. The pressure relief valve also provides additional protection in the event of power loss or if the pressure exceeds the valve set point (150 psi) (R2T, Inc., 2011).

Figure 6-3 -- Recharge pump at intake (left) and air compressor (right).

6.1.2.3 Filtration

Treatment of source water prior to aquifer recharge is required for compliance with Federal and State UIC requirements. For the KRASR, the UIC permit required addressing two constituents: suspended solids and total coliforms. The USACE selected and designed a treatment process consisting of a pressure filter for suspended solids removal and UV disinfection system for coliform inactivation. Filtration vessels and associated piping are shown in **Figure 6-4**.

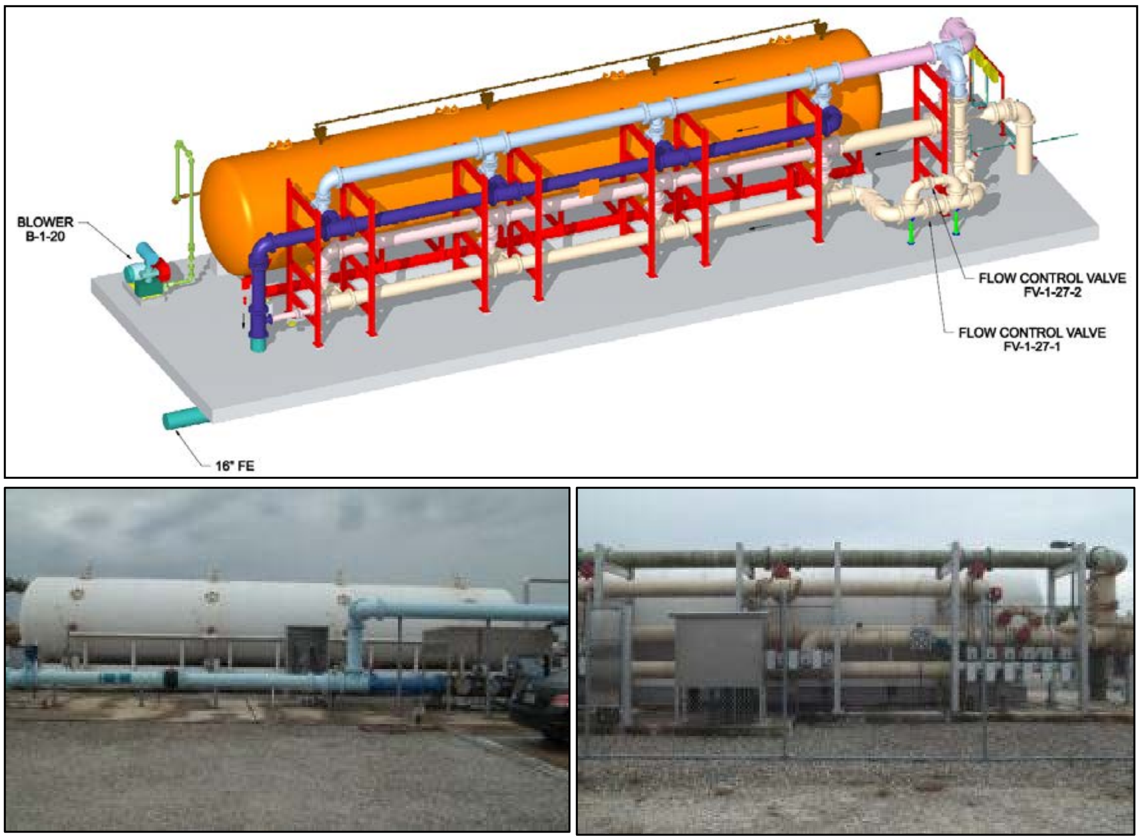


Figure 6-4 -- The Tonka pressure filter and backwash piping diagram, and photographs showing the chamber (left) and backwash piping (right).

The pressure filter (Tonka Equipment Co., Plymouth, MN) consists of four cells in a 62-ft long by 10-ft diameter steel tank. Each cell has influent, effluent, and backwash piping to allow backwashing of every cell individually while the remaining cells are in operation. Filters are equipped with dual-media filters and operated at a surface loading rate of 6 gpm/ft^2 at 5 MGD, with one cell out of service. Detailed information on the technical specifications of the filtration systems is provided in the R2T, Inc. (2011). Specific information on the filter components are given in **Table 6-2.** The process and instrumentation diagram for the intake is provided on sheet 1-I-3 in **Appendix C**.

Table 6-2 -- Filter and Backwash Blower Specifications			
Pressure filter		**Backwash blower**	
No. of cells per vessel	4	Capacity	441 cfm
Surface area per cell	150 ft^2	Discharge pressure	5 psi
Loading rate	6 gpm/ ft^2	Blower power	15 HP
Media	gravel/sand/anthracite		

Backwashing of the filters is accomplished utilizing the Simul-Wash™ Backwash System (Tonka Equipment Company, 2012). This is a sustained, low-rate, simultaneous air/water filter backwash system where air and water at sub-fluidized rates set up a condition called collapse pulsing. This action causes agitation that frees captured filter debris, prevents mudballs, extends the life of the filter media and minimizes backwash waste. The air/water backwash includes four steps: drain, air/water Simul-Wash effluent from the pressure filter, high-rate backwash, and air purge/refill. These steps are summarized in **Table 6-3**. Backwashing is done based on a pre-set time or on high differential pressure. A full backwashing cycle produces about 140,000 gallons of water (R2T, Inc., 2011).

Table 6-3 -- Backwash Sequence Specifications			
Process	**Flow rate**	**Time**	**Description**
Drain	-	Approx. 2 min	Drains the backwash effluent from the filter.
Simul-Backwash ™	4-6 gpm/ft^2 (water) 1 - 3 cfm/ft^2 (air)	Approx. 10 min	Blows air and water into the filter media to break adhered solids.
High rate backwash	10-15 gpm/ft^2	Approx. 12 min	Removes the remaining solids on the filter bed surface and re-stratifies multiple media beds.
Air purge/refill	15 gpm/ft^2	Approx. 2 min	Removes entrapped air from the filter media with water flow. The flow direction is from bottom to top with the top valve closed and bottom valve open.
Note: The flow rate and the time may be chosen within the range based on the source water quality. For more turbid source waters, the process may be left longer with a higher flow rate to remove the silt built-up.			

The pressure filter is effective for reduction of total suspended solids (TSS), as measured by the reduction of turbidity when filter influent (source water) and filter effluent are compared. Typically, TSS concentrations and turbidity values are low in Kissimmee River source water, generally less than 10 NTU except during high flow events, or the onset of wet season flows. Particle sizes are in the range of large colloids, with diameters less than 1-µm. Therefore the pressure filter is most effective at removing larger suspended solids during high flow events, than removing colloidal particles when source water quality is better. During cycle test 4 recharge phase (October 2011), an episode of poor source water quality occurred, characterized by daily average turbidity values of 20 to 60 NTU **(Figure 6-5)**. Source water filtration reduced turbidity values by half during this episode, with no subsequent well clogging.

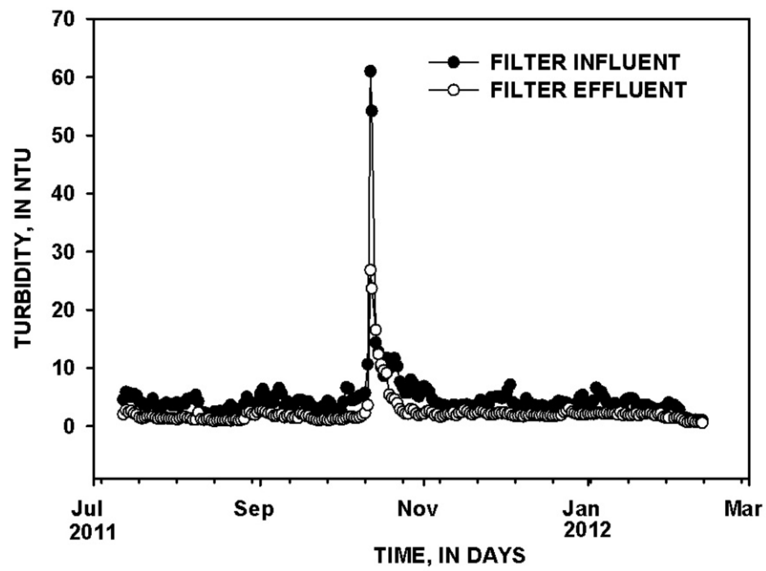


Figure 6-5 -- Daily average turbidity values of influent and effluent water at the pressure filter measured during cycle test 4.

6.1.2.4 Ultraviolet Disinfection System

UIC permit compliance requires microbial disinfection prior to recharge. The KRASR system relies on ultraviolet (UV) inactivation for microbial disinfection. The UV disinfection system (Aquionics, Inc., Erlanger, KY) consists of three UV units in series to disinfect filtered water prior to recharging through the ASR well. Each stainless steel unit has 12 medium-pressure UV lamps in quartz sleeves that are oriented perpendicular to the flow direction (**Figure 6-6**). Each UV unit is designed for a minimum UV Transmittance (UVT) of 25 percent at 3600 gpm. The maximum working pressure and temperature in each unit are 145 psi and 45°C, respectively. Each UV unit is fitted with a motor-driven, automatic, mechanical cleaning mechanism for wiping the sleeves to prevent fouling, an access hatch for visual inspection, a UV intensity monitor to measure relative lamp intensity, and a temperature sensor to prevent overheating. To protect the UV units from rain water, an enclosure was constructed above the units.

An UV intensity monitor system measures the intensity of each lamp, providing continuous performance verification over the specified water transmission range. Monitoring of UV intensity is continuous within the germicidal wavelength range. The intensity of the UV lamp decreases with lamp age, varying water quality, and/or fouling of the quartz sleeve. If the control module detects that a signal from the UV monitor has reached a preset minimum level, an alarm is generated. The design criteria and technical specifications of the UV units are presented in **Table 6-4**

Figure 6-6 -- The UV disinfection units. Units are arranged in series (left), and a cross-section view of a single unit showing 12 UV lamps oriented perpendicular to flow direction (right).

An automatic cleaning mechanism periodically wipes the quartz sleeves clean. The cleaning mechanism effectively removes deposits on the quartz sleeve and UV monitor without interrupting the disinfection process. The frequency of the cleaning cycle can be programmed to clean from every 10 minutes to every 12 hours. The cleaning frequency can be changed while the system is on-line.

Table 6-4 -- UV Disinfection System Specifications

Treatment Chamber		Power and Control Modules	
Number of lamp units	2	Number per system	1 per lamp
Installation type	In-line	Lamp power level 1	2650 W
Stages	Series	Lamp power level 2	3100 W
Dose	40 mJ/cm^2	Lamp power level 3	3750 W
Transmittance	25 percent	Power level control	Manual
Capacity	3600 gpm		
Number of lamps per unit	12		

Based on an earlier study at Lake Okeechobee (Carollo, 2003), the UVT of unfiltered source water was approximately 20 percent, while filtered water UVT was approximately 25 percent. Standard in-line UV reactors for water treatment generally are not designed for UVTs less than 80 percent. However, by using in-line UV reactors in series, the desired UV dosage and microbial inactivation can, in theory, be achieved. The UV disinfection system treatment goal was a 4-log_{10} (99.99 percent) inactivation of total coliform levels in the treated water. The original UV system design consisted of two UV units in series. However, because the disinfection requirements were not achieved during system performance testing, a third unit was required. Each unit is supported by its own power panel with a shared control panel. The power panels and control panel are housed in the electrical building (R2T, Inc., 2011). The process and instrumentation diagram for the treatment process is shown on sheet 1-I-4 of **Appendix C**.

6.1.2.5 Recovery Pump

The ASR well recharge/recovery system is designed to receive treated flow and recover water from the well. During recharge, treated water flows through the wellhead piping and is injected into the ASR well. During recovery, ASR discharge flows out through the wellhead piping. The recovery pump (Weir Floway, Inc., Fresno CA) is a 150-HP vertical turbine pump with 3,500-GPM capacity at 137-ft total dynamic head (TDH).

The KRASR system well utilizes a vertical turbine constant speed pump to withdraw water from the well as shown in **Figure 6-7**. The ASR system is configured to function in recharge and recovery processes to ensure compliance with pressure rating of the well (66 psi). It is equipped with backpressure monitoring gauge, a pressure transducer, and has a sampling tap. Valves to allow for operation flexibility, and provides a connection to a drain or holding pond to be used during development/cleaning of the well. The flow can be routed to the backwash equalization pond, raw water wet well, or the cascade aerator.

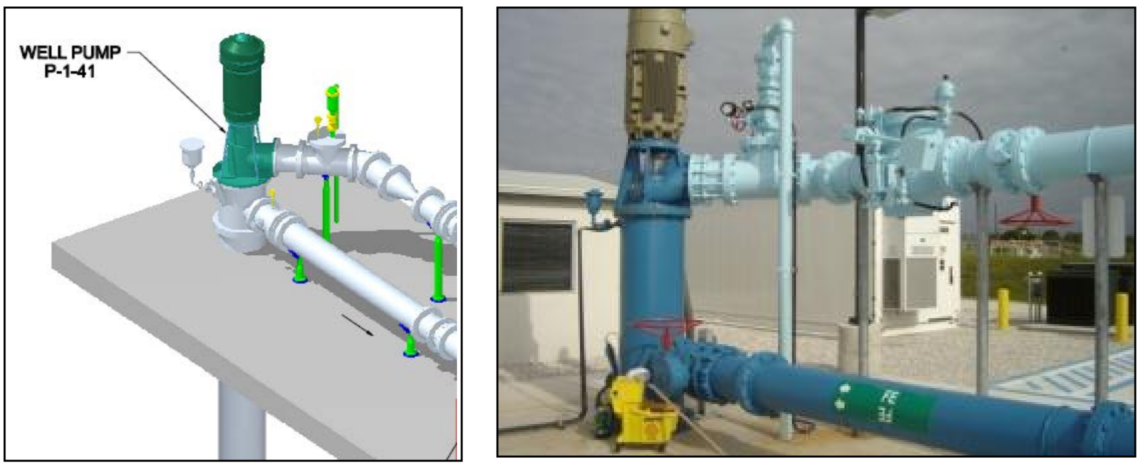


Figure 6-7 -- ASR well recovery pump.

The vertical turbine recovery pump has a 14-in. threaded pump column. Filtered water is injected into the well between the pump column and the well casing. The ASR well system at the Kissimmee River is a 24-in. diameter borehole that was designed and constructed to handle 5-MGD flow. Flow rate, pressure, specific conductance, turbidity, temperature, and water level are measured at the wellhead. An electrically actuated control valve controls flow rates to and from the well. In the case of power loss, the control valve prevents the artesian well from flowing back into the system. During recovery mode, the initial well recovery water is discharged to the backwash equalization pond. When turbidity goals for river discharge are met, water is decanted and discharged to the cascade aerator (R2T, Inc., 2011). The well and recovery pump specifications are listed in **Table 6-5**.

Table 6-5 - The ASR Well and Recovery Pump Specifications			
ASR Well		**ASR Recovery Pump**	
Well Type	Artesian	Pump Type	Vertical Turbine
Well Pad Elevation	20.5 ft NGVD29	Pump Top Bowls Elevation	-112 ft NGVD29
Static Head	22.5 ft	Range of Pumping Level	-62.7 to -77.8 ft NGVD29
Static Water Elevation	45.8 ft NGVD29	Maximum Capacity	3500 GPM
Well Specific Capacity	38 and 61 GPM/ft before and after acidization	Total Dynamic Head	137
Drawdown at 3500 GPM	91 and 57 ft before and after acidization	Pump Power	150 HP
Well Casing Diameter	24-in OD/23-in ID	Stages	3
Well Depth	875 ft bls	Drive	Constant Speed

6.1.2.6 Back Wash/ Solids Storage Ponds

The backwash equalization and solids storage ponds were constructed to manage filter backwash and turbid “first flush” water from the ASR well at the onset of the recovery phase. The backwash equalization pond receives backwash water from the filters and first flush water from the ASR well. The solids storage pond receives water from the backwash equalization pond at a constant flow rate that allows settling as shown in Figure **6-8.**

The backwash equalization pond was sized to retain two filter backwashes per day (with every backwash volume equaling approximately 105,000 gallons), with an additional 20 percent safety factor, plus one hour of ASR backflush. The total retention volume of the backwash equalization pond is 462,000 gallons. The solids storage pond can retain approximately 270,000 gallons and is sized to handle 30 days of solids at a liquid/solids concentration of 0.25 percent (w/v), also with a 20 percent safety factor (R2T, Inc., 2011). The pond solids removal efficiency is 90 percent. In retrospect, the storage capacity was probably excessive. Surface water management at KRASR probably could be accomplished with a single pond.

Two self-priming centrifugal decant pumps shown in were designed to transfer water between the backwash equalization and solids storage ponds, to the cascade aerator, or to the recharge station **(Figure 6-9** ; R2T, Inc., 2011). The different modes of operation include:

- Transferring water from the backwash equalization pond to the solids storage pond during recharge to allow particles to settle from turbid water.
- Transferring water from the solids storage pond to the recharge pump station for re-treatment.
- Transferring water from the solids storage pond to the cascade aerator to blend with the ASR recovered water.

Figure 6-8 -- The backwash equalization pond (left), and solids storage pond (right).

The technical specifications of the backwash equalization pond, solids storage pond and the decant pumps are listed in **Table 6-6.** The process and instrumentation diagram is also shown on sheet 1-I-5 in **Appendix C.**

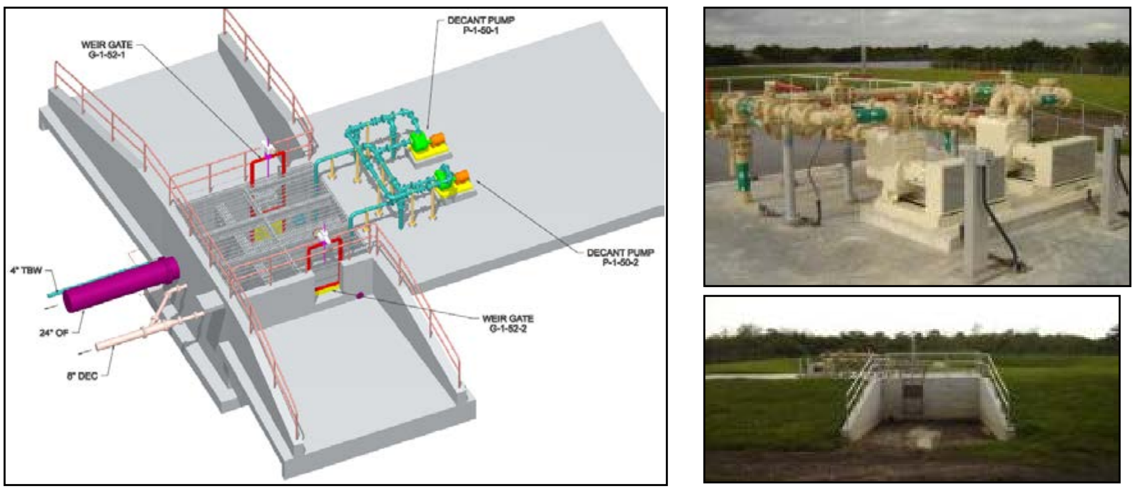


Figure 6-9 -- The decant pumps and backwash equalization pond.

Table 6-6 -- Backwash Equalization Pond, Solids Storage Pond, and Decant Pump Specifications

Backwash Equalization Pond		Solids Storage Pond		Decant Pump	
Volume per backwash	105,000 gal	Dry solids production from filter	173 lbs/day	Quantity	2
Backwash per day	2	Pond removal efficiency	90 percent	Type	Centrifugal
Total backwash volume	210,000 gal	Pond dry solids capture	156.1 lbs./day	Filter backwash handling pumping rate	145 gpm
Safety factor	20 percent	Liquid/solids concentration	0.25 percent	Well backwash handling pumping rate	21 gpm
Volume from back-flushing	210,000 gal	Liquid/solids volume	7,488 gal/day	Total pumping rate	166 gpm
Total pond volume	462,000 gal	Days of wet solids storage	30 days	Impeller Diameter	8.65 in.
		Safety factor	20 percent	RPM	900
		Total pond volume	270,000 gal		

6.1.2.7 Aeration

The native and recovered groundwater in the FAS is anoxic, so dissolved oxygen (DO) concentrations must be increased in recovered water prior to release into the Kissimmee River. Recovered water is oxygenated by passage over a cascade aerator (Figure **6-10)** to meet the 7 mg/L target DO concentration.

Figure 6-10 -- The spill structure and cascade aerator.

A cascade aerator is a simple and effective way to increase DO concentration. The splashing of water down a series of designed steps entrains oxygen from the atmosphere. The number of steps and height of a cascade aerator is dependent upon the required oxygen residual (R2T, Inc., 2011). The specifications of the KRASR cascade aerator are presented in **Table 6-7**.

Table 6-7 -- Cascade Aerator Specifications	
Discharge Flow Rate	5.2 MGD
Influent DO Content	0 mg/L
Temperature	27 degrees C
Desired DO Concentration	7 mg/L
Required Aerator Height	11.2 ft
Aerator Width	21 ft. (based on 250,000 gpd/ft)
Design Water Level	Elevation at 14.28 NGVD29

The cascade aerator only functions during the recovery phase. Depending on water quality, recovered water is pumped from the ASR well to the cascade aerator directly, or to the recharge pump station, through the filter, and then to the aerator. Effluent water quality parameters such as temperature, pH, and specific conductance also are measured at the cascade aerator in real time using on-line instrumentation. Each of these signals is transmitted to the facility programmable logic controller (PLC) in the operations building and subsequently enters the computer database. The DO concentration measured at the base of KRASR cascade aerator effluent ranges between 6 and 8 mg/L depending on air temperature. The process and instrumentation diagram is also shown on sheet 1-I-4 in **Appendix C**.

6.1.2.8 Flow Control

The flow control and valve diagram **(**Figure **6**-**11)** shows the location and the position (open or closed) of the major valves for the different phases of operation. The four actuator valves required for flow and pressure control are described in **Table 6-8**. The control settings for the manual valves required during recharge, storage, recovery, and bypass (required at the start of the recharge phase) are listed in the table in the upper right hand corner of Figure **6**-**11**. The 12-inch "butterfly" flow control valve located between the pressure filter and the UV disinfection system was inadequate for throttling flow. A description of the function of each manual valve is shown in **Table 6-9**.

Table 6-8 -- Major Actuator Valves Specifications

Type	Size	Brand and Model	Actuator Type	Operator	Pressure Range (psi)	Operational Pressure (psi)	Function
12-in Flow Control Valve	12	Limitorque	Electric motor	SCADA/Local	0 – 80	Varies	Regulating the flow
14-in Pressure Reducing Valve	14	Cla-Val/90-01	Hydraulic; diaphragm actuated	Automatic	30 – 300	30	Reducing water backwash pressure
16-in Back Pressure Sus-taining Valve	16	Cla-Val/92-01	Hydraulic; diaphragm actuated	Automatic	20 – 200	88	Maintain back pressure on filter
10-in Pressure Relief Valve	10	Singer/106-PG	Hydraulic; diaphragm actuated	Automatic	Max = 250	90	Release excess recharge pump pressure

Table 6-9 -- Open Manual Valve Functions in Different Modes	
Recharge Mode: In recharge mode, water is pumped from the river, through filtration and disinfection components, then to the ASR well. Listed below are the valves that are utilized:	
Valve ID	**Function**
N	Valve is the inlet valve that allows the flow from the river to the wet well.
M	Valve allows the flow from the wet well to the filter.
D	Valve is on the 16" pipeline, it allows the water to flow from the wet well to the pressure filter.
J	Valve is on the 16" pipeline, it allows flow from the pressure filter to the ASR well.
K	Valve is located on the 16" pipeline at the ASR well; it allows flow directly into the well.
Q	Valve is connected to the 14" discharge backwash line that goes to backwash pond.
Storage Mode: In storage mode, M, N and Q valves are all open. All the other valves are closed.	
Recovery Mode: In recovery mode, water is pulled from the ASR well and directed to the cascade aerator, and then to the river. Listed below are the valves that are utilized:	
Valve ID	**Function**
L	Valve is used to direct the flow that is coming out of the ASR well and going to the cascade aerator.
B	Valve allows the flow that is coming out of the ASR well to continue its route.
C	Valve allows flow that is coming thru to continue its path.
G	Valve directs the flow to the cascade aerator and then to the river.
Bypass/Recharge Mode: In bypass mode at the beginning of recharge, filters are chlorinated, then the water flows through the bypass pipe to the backwash pond. Listed below are the valves that are utilized:	
Valve ID	**Function**
N	Valve is the inlet valve that allows the flow from the river to the wet well.
M	Valve is the 10" valve that allows the flow from the river to the wet well.
D	Valve is on the 16" pipeline, it allows the water to flow from the wet well to the pressure filter.
J	Valve is on the 16" pipeline, it allows flow from the pressure filter to the bypass pipe.
P	Valve on bypass pipe allows water to flow from wet well to cascade aerator.
R	Valve on bypass pipe allows water to flow from wet well to cascade aerator.
Q	Valve is connected to the 14" discharge backwash line that goes to backwash pond.

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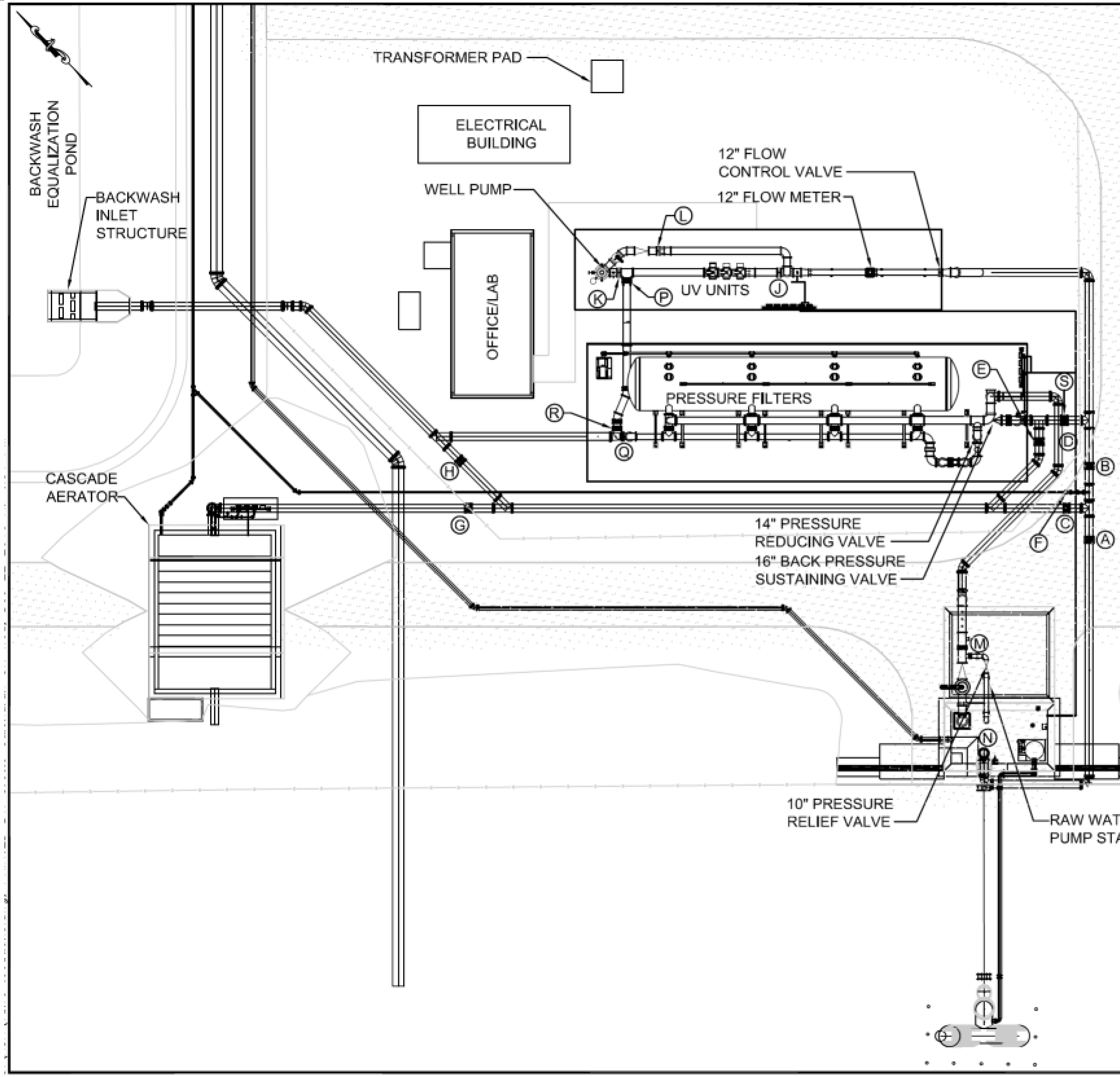

ASR Valves Operational Positions				
Valve Code	Recharge Position	Storage Position	Recovery Position	Bypass/Recharge Position
A	Closed [1]	Closed	Closed	Closed
B	Closed	Closed	Open	Closed
C	Closed	Closed	Open	Closed
D	Open [2]	Closed	Closed	Open
E	Closed	Closed	Closed	Closed
F	Closed	Closed	Closed	Closed
G	Closed	Closed	Open	Closed
H	Closed	Closed	Closed	Closed
J*	Open	Closed	Closed **	Open
K	Open	Closed	Closed **	Closed
L	Closed	Closed	Open	Closed
M	Open	Open	Open	Open
N*	Open	Open	Open	Open
P	Closed	Closed	Closed	Open
Q	Open	Open	Open	Open
R	Closed	Closed	Closed	Open

[1] Closed = Clockwise

[2] Open = Counterclockwise

* Letters I & O have not been used in labeling the valves.

** Valves J & K must be fully colsed during recovery to prevent venturi vacuum condition in UV chambers.

Note: Valve S is not labeled and it is always open to allow the filter effluent to the UV units and ASR well.

RIVER TO TAP

CLIENT: US ARMY CORPS OF ENGINEERS
JACKSONVILLE, FLORIDA

PROJECT: SURFACE FACILITIES FOR LAKE OKEECHOBEE ASR PILOT PROJECTS KISSIMMEE RIVER SITE

© 2010 R2T INC.

REV | DATE | DESCRIPTION

STAMP:

SHEET TITLE: MAJOR VALVE LOCATIONS

ISSUED:
PROJECT NO.
SCALE: 1" = 20'
CHKD BY:
DESIGNED BY:
DRAWN BY:

1 OF 3

Figure 6-11 -- The Kissimmee ASR System Surface Facility Piping and Valve Diagram

6.1.2.9 In-line Monitoring Sensors

The in-line monitoring components are shown on the instrumentation and control diagrams for each system process. The specific details of the in-line monitoring components are discussed in the following subsections.

Magnetic Flowmeter. The magnetic flowmeter measures the flow rate of fluids using a self-generated magnetic field. The flowmeter is located upstream of the UV units **(**Figure **6-11)** and specifications are listed in **Table 6-10**. The flowmeter measures a maximum flow velocity of 15 ft/sec with a high accuracy (0.15 percent) and a turn down ratio of 1500:1. The flowmeter tube and electrode are assembled using Type 304 stainless steel. The metering liner is constructed of material compatible with the fluid being measured. The maximum pressure drop across the meter and appurtenances is 1-psi at the maximum flow rate. It sends signals suitable for remote monitoring by the plant control system and connects to a remote 120-volt AC power supply.

Table 6-10 -- Magnetic Flowmeter Specifications

Type	Size	Brand and Model	Material	Flow range (MGD)		Max pressure limit (psi)	Operating pressure (psi)
				Minimum	Maximum		
Magnetic Flowmeter	12-in	ABB/ MagMaster Plus MFF-HA3	Stainless steel flow tube and probe	0.012	7	150	Varies[1]

[1]During recharge, around 65 psi but varies with flow rate and valve positions.

Pressure Transducers. Pressure transducers or indicators are placed at the following locations:

- At the air tank for the intake screen air scour system
- After the recharge pump to monitor the pumped water pressure to the filter
- At the filter inlet/effluent to show pressure and the loss of head
- Before and after the UV units to control the pressure variation through these units
- On the recharge water pipe to the well to monitor the pressure before injection to the ASR well
- On the recovered water pipe from the well to monitor the pressure after recovery from the ASR well
- Installed at a depth of 130-ft in the ASR well to control the water level.
- On the 1-in valve of a non-potable water line from the ASR well to the control building. The Druck submersible pressure sensor and the Ashcroft pressure switch technical specifications and operation and maintenance instructions are described in R2T, Inc. (2011).

Level Transducers. These transducers signal the water level within the respective wells to ensure water availability and correct facility timing for pump system operation. The level transducers are located at the following locations:

- In the wet well at the intake structure to monitor influent water levels.
- At the decant pump station to monitor the low and high water level for the decant pumps.

Turbidity Monitoring of Pressure Filter Influent and Effluent. Two turbidity meters are located at influent and effluent lines of the pressure filter. Turbidity meters read the intensity of light transmitted from through a cell. Turbidity increases with the suspended solids concentration, and thus decreases the measured light intensity. The turbidity meters used at KRASR were Accu4™ low-range turbidimeter system (Model T53 Analyzer and 8320 Sensor; GLI International, Inc., Loveland, CO). Detailed specification and instruction is described in R2T, Inc. (2011).

Water Quality Sensors. The water quality sensors measure specific conductance, pH, and temperature at different positions in the ASR system. The purpose, design range, problems experienced, and main issues, such as sensor calibration requirements, are described in R2T**,** Inc. (2011).

Specific Conductance, pH and Temperature Sensors. The specific conductance sensor (ABB, Zurich, Switzerland) has a precision of 0.001 microsiemens per centimeter, full-scale range of one siemen per centimeter, pressure ratings to 2,068 kilopascals (300 psig), and temperature ratings of 200°C. Sensor specification, ratings and mounting arrangements are found in R2T Inc. (2011). Locations of the specific conductance probes are located at:

- Between the magnetic flowmeter and the UV units
- At the top of the cascade aerator

The pH sensors are co-located with the specific conductance sensors. The pH is measured with a pH/Redox (ORP) sensor (ABB, TBX 5 Series). The pH meter sends a signal to the ABB single/dual input analyzer, and the pH value appears on the device display screen. The specifications, description, range, operating temperature, and impedance are described in R2T, Inc. (2011).

Water temperature is measured by the thermocouples and resistance thermometers in the sensor. The specifications, description, range, operating temperature, and impedance are described in R2T, Inc. (2011). Locations of temperature sensors are:

- At the electrical enclosure next to the recharge pump station
- Immediately upstream of the UV units
- At the cascade aerator

6.1.2.10 Power Supply

Florida Power & Light supplies the electrical power to the KRASR system. The power provided at this location is at 480 Volts, 3-phase, 60 Hz from Motor Control Center (1MCC-1) located in the electrical enclosure. 1MCC-1 serves the service entrance, and is equipped with a Transient Voltage Surge Suppression Unit, power meter, circuit breakers, and “Solid State Soft Start” starters for motor control of motors 50 HP and greater. A 45 kVA, 480/208-120 volt transformer and a lighting panel is installed within the 1MCC-1 provides power for miscellaneous 120/208 volt loads.

The Kissimmee River ASR system electrical service room is shown in Figure **6-12**. The electrical system includes electrical power supply, lighting, and power distribution providing energy to the all system components.

Figure 6-12 -- The electrical and motor control center enclosure (left); and UV disinfection system control unit box (right).

The outdoor rated, walk-in electrical enclosure contains the Motor Control Center (1MCC-1), UV system power and control panels (including space for future UV system power and control panels), uninterruptable power supply (UPS) and field panel for Instrumentation and Control. The electrical enclosure temperature is maintained by an air-conditioning unit.

Operation building lighting, receptacles, air-conditioning, wiring, and interior power distribution systems are provided as a package system. Metal halide lighting fixtures, with energy-saver ballasts, and lamps are used for outside lighting. Fluorescent lighting fixtures, with energy-saver ballasts, and lamps are used for indoor lighting. Power factor capacitors have been provided to maintain power factor between 0.92 and 0.95, for motors 100-HP and above.

A completely integrated grounding system is provided at the plant in compliance with National Fire Protection Agency (NFPA) 70 ANSI C2. Ground resistance is tested at each facility using fall of potential tests to ensure that the value is less than 3 ohms. Grounding test wells and triangles are provided as needed with an adequate number of supplemental grounding electrodes.

A lightning protection system minimizes the high voltage transients and surges caused in the power system during lightning storms. The system is designed in conformance with the requirements of NFPA 780. All incoming power feeders, panel boards and 120 V power supply circuits to instrumentation are also provided with surge suppressors to minimize impact of high voltage transients caused by lightning. All analog signal lines are provided with surge suppressors on the field transmitter end as well as the control panel end (R2T, 2011). The one-line diagram, electrical enclosure, 1MCC-1 elevation and riser diagram and their related legends are shown on sheets 1-E-3, 1-E-4, 1-G-8 and 1-G-9 of **Appendix C**.

Alternatives for onsite power generation were examined on a conceptual level and are addressed in **Section 13.1.5**. Although numerous options exist for supplementing or replacing the electrical power feed to the facility, each would need to be examined in much greater detail as the power demands exerted by the facility vary significantly from phase to phase and alternatives such as solar, wind, hydro, or natural gas turbines would need to be tailored to site-specific conditions in order to determine cost effectiveness.

6.1.2.11 SCADA System

All components of KRASR system operation are monitored and controlled by a supervisory computer and data acquisition (SCADA) system that consists of the following subsystems: A Human-Machine Interface (HMI) apparatus that presents process data to an operator for monitoring and control; a computer system, that acquires data on the process and sends control commands to the process; Programmable Logic Controllers (PLCs) that serve as field devices; and communication infrastructure that connects the supervisory system to the control units.

The control system monitors and controls the various component processes such as the recharge pump, the ASR well equipment, and the decant pumps. The control system monitors the intake screen air scour system and the pressure filters. The control system monitors and provides limited control of the UV disinfection system. Primary control of the UV system and pressure filters is accomplished by each vendor's package control systems. The instrumentation and control system is shown on sheet 1-I-1 of **Appendix C**.

6.2 Hillsboro ASR System

6.2.1 Surface Facility Design

The HASR facility was constructed as the first phase of an ASR system that would expand to include 30 ASR wells around the periphery of the proposed Site 1 Impoundment at the Fran Reich Preserve. The intent is to integrate the ASR system operations with that of the 13,280 acre-foot impoundment to provide significant seasonal storage of excess surface water from the Hillsboro Canal. The primary function of HASR is to recharge the aquifer during high, wet season flows from the Hillsboro Canal, for storage and recovery during the dry season. Prior to recharge into the aquifer, source water from the canal is filtered and disinfected to reduce suspended solids concentrations and to inactivate coliforms. The treatment process can be summarized as follows: coarse screening, fine filtration (80-µm), UV disinfection, and recharge into the ASR well. After storage in the aquifer, the recovered water is re-oxygenated and returned to the Hillsboro Canal. The ASR system is designed to allow for the addition of supplemental water treatment unit processes if water quality results require additional treatment for compliance. The process flow diagram is shown on sheet C-1 in **Appendix D**.

6.2.2 ASR System Components

6.2.2.1 Intake Design and Operation

The intake/discharge structure of the HASR system consists of pre-cast concrete box sections having an internal dimension of 12-ft^2 with 12-in thick walls that house the recharge and recovery sluice gates, the recharge pump, and the aeration process. The top of the box is constructed out of fiberglass grating supported by steel beam framing. Sluice gate operators for recharge and recovery are mounted on the grating framework and allow the flow of water into and out of the concrete pumping "box" chamber to be controlled.

The foundation of the intake/discharge structure is a 5.5-ft thick tremie concrete plug. This application is often used in wet, sandy, or unconsolidated foundations for better setting of the structure. The design of the intake structure allows the option for future retrofitting with bolt-on flanged filter sections. Water quality sensors are installed in the process piping to monitor turbidity and specific conductance. Sensor data are stored electronically inside the control building. Water quality samples can be collected at the intake/discharge structure via a hinged access hatch through the top grating (PBS&J, 2005). Original design drawings associated with the intake structure are illustrated on sheets G-2, C-7, C-8, and C-9 in **Appendix D**.

The intake screen is a Tee-Screen (model 3610; Hendrick Screen Company, Owensboro, KY). This screen mesh size prevents entrainment of fish larvae. The screen admits water through the intake point at a low, uniform velocity which allows for water to pass through the intake screen slots while aquatic life and debris remain in the water source. The screen is constructed from Type 304 stainless steel and has an opening area large enough to reduce the intake velocity at a full flow of approximately 4,000 GPM to less than 0.5 feet per second which meets the USFWS intake velocity guidelines for protection of aquatic organisms at this site (PBS&J, 2005).

The screen is cleaned periodically using an air scour system consisting of a short blast of high pressure air that dislodges material, and is controlled by a timer. The screen is 75-in long and 24-in in diameter and incorporates a funnel-shaped debris deflector on the screen end that is pointed upstream in the canal. The flanged intake pipe is 18-in in diameter. The air inlet is also flanged and is 2-in in diameter. The air requirements are satisfied with a 5-HP air compressor unit having a working pressure of 120-psi and a 200-gallon air receiver. The compressor and tank unit is mounted in the electrical control room to protect it from the elements. The screen unit is installed at a centerline elevation of 3.0-ft and is submerged approximately 3-ft when the canal water surface is at an elevation of 7-ft NGVD29. The determining factors influencing screen opening size are protection of aquatic organisms and the ability of the recharge pump to pass solids of a particular size. In the case of the recharge pump selected for the HASR, the vertical turbine pump cannot pass debris larger than 1.4-in (PBS&J, 2005).

The screen is mounted outside of the pre-cast concrete box and is protected from canal bottom debris accumulation by the addition of a 6-in thick reinforced concrete slab directly under the screen. The screen is attached to the intake structure via an 18-in, 125-lb flange connection (PBS&J, 2005). A typical Tee-Screen is shown in Figure **6-13**.

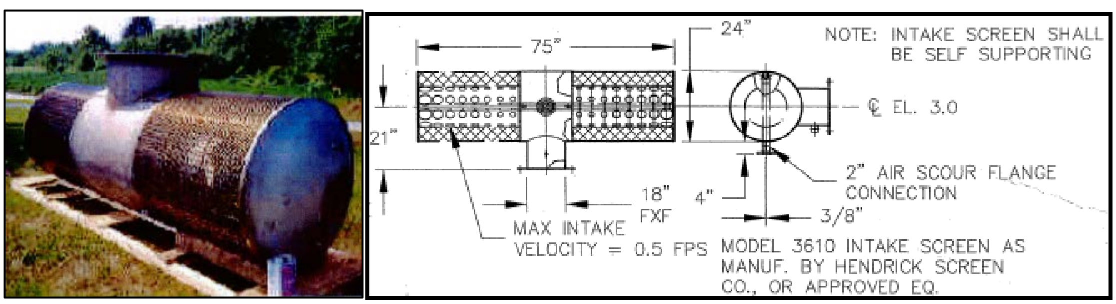

Figure 6-13 -- Typical tee-screen.

6.2.2.2 Recharge Pump

The recharge pump **(**Figure **6-14)** is mounted in the intake structure to convey water from the canal into the ASR well. The recharge pump HASR (14x16RGLC; Goulds, City of Industry, CA) is a 3-stage vertical turbine pump typically used for water well supply applications. The recharge pump design criteria required a pump to deliver approximately 4000 gpm (5.76-MGD) at approximately 163-ft of head. It requires approximately 200 brake HP to reach the pump design flow and head, and is fitted with a 250-HP, 480-V, 1800-rpm, three phase electric motor. The pump is 85 percent efficient at the design point and the motor is 94 percent efficient. The speed of pump is 1,770-rpm, and the diameter of the intake pipe is 18.5-in. The diameter of the discharge pipe is 14-in. To reduce current draw and minimize unnecessary wear on the motor, it is fitted with a soft start-stop feature.

Figure 6-14 -- Recharge pump at the intake structure.

The constant speed pump also requires protection from water hammer and other system forces. This protection includes a pump check valve, filtration isolation valve and a motor overload system. The check valve protects the pump from water hammer and other variables due to interruption in flow from power outages and flow termination. This system is critical as large amounts of energy are delivered by this pump and this must be dissipated in a safe manner. The motor overload system is required as conditions such as impeller clogging, unbalanced phases and low voltage can cause conditions that damage the motor.

The recharge pump system has both high and low level system alarms. The water level is measured via a pressure module that converts the level to a 4-20 mA signal. This signal links to a programmable control that stops the pump during low water conditions. Wet well levels and pump discharge pressure can be monitored locally and at the control panel.

The recharge pump process and instrumentation diagram is shown on Sheet I-2 of the HASR As-Built Drawings **(Appendix D)**. Sheet I-1 in **Appendix D** shows the general symbols and abbreviations for all the process and instrumentation diagrams referenced in this document (PBS&J, 2005)

6.2.2.3 Filtration

Filtration at HASR is accomplished by the use of automatic screen-type filters (Amiad Water Systems, Ltd., Galil Elyon, Israel; Figure **6**-**15**). The filtration system consists of eight screen filters (14-in diameter), though the skid has been constructed to accommodate four additional units if needed in the future. Multiple filter units were used with 30-µm internal screens initially. The size of the screens was increased to 80-µm after early tests showed filter clogging. The filters are backwashed when the pressure differential across the screens exceeds 6- to 7-psi. For the purpose of the filter design, it was assumed that two filters would backwash simultaneously at 150-GPM each. However, the filters at HASR are set to backwash based on interval or demand conditions that are input directly into the unit controls and are not continuously backwashed. The filter units are installed together and arranged so that they can filter both influent source water from the canal and effluent water from the ASR well prior to discharge. These flows are divided uniformly across the eight units of the filtration system. The number of filter units was determined by the manufacturer and the design engineer, and was based on flow and water quality test results and experience from other Amiad filtration system installations. All of the filter units are identical with interchangeable screens and are rated for the anticipated maximum recharge process flow of 5.7-MGD (Figure **6**-**15**; PBS&J, 2005).

Figure 6-15 -- Amiad filtration system.

For improved source water filtration, the tee-screen described in Figure **6**-**13** was selected for use in pre-filtration screening. The tee-screen filters suspended solids, and then the Amiad filtration manifold filters smaller particles (PBS&J, 2005). However, due to the small size of most particles in the source water (≤ 1-µm), the filtration system at the HASR was not able to reduce the concentration of those colloidal-sized particles. The original instrumentation diagram for the filter system is located on Sheet I-2 of **Appendix D**.

6.2.2.4 UV Disinfection System

Disinfection of the canal water prior to aquifer storage is performed by UV radiation. The UV system (model Inline 7500; Aquionics Inc., Erlanger, KY**; Figure 6-16**) consists of two single units in series. The system was constructed so that an additional unit can be added if microbial inactivation is not effective. The two units connect in the process pipeline between the flowmeter and the well via 14-in flanged connections. Two units were selected to ensure maximum coliform inactivation at the design dosage (40 mJ/cm^2). During cycle test 1, the system performed as anticipated, achieving slightly above a 2-log (99 percent) inactivation rate. During cycle tests 2 and 3, the units were not effective for microbe inactivation. Additional discussion of UV disinfection system issues is found in **Section 6.3.1**.

Reducing biofilm growth within the Aquionics 7500 unit is critical for effective microbe inactivation. This model has an automatic cleaning mechanism (wiper assembly) that cleans the silicate sleeve for maximum UV transmittance. Each unit also has a separate power and control module cabinet. Each cabinet is a floor-mounted enclosure approximately 7-ft tall by 2.5-ft^2 housing the power supply and controls. Each unit has an adjustable power level feature, so that it functions at low, medium, or high lamp power. The electrical requirements for each unit are 480-V, 3-phase with a power consumption of 45-kilowatts at the highest power level. Each unit has 12 bulbs that have a service life of 5000 hours. The control cabinets are epoxy coated steel, and both cabinets are housed in the control building, along with other electrical project components (PBS&J, 2005).

Figure 6-16 -- A single chamber of the UV disinfection unit.

The UV system can be operated automatically by the PLC or manually. Besides the three power settings, UV sensors control flow into the ASR well. When the UV dose transmitted to the flow diminishes to a specific setting, a butterfly valve closes to reduce flow. These two components are interlocked with the UV sensor for safety, as interlocking prevents untreated water from recharging the aquifer. Other safety settings include a low flow switch that terminates power to the UV system so that the unit does not overheat. Other safety overrides are in place related to temperature, amperage, and low voltage.

During testing, the UV units were run on the highest power level at all times and induced several high temperature fault signals. In some cases, bulb replacement was more frequent than the 5000 hour stated service life. Overall, the UV systems were insufficient at meeting desired disinfection and inactivation rates during cycle tests 2 and 3. The UV disinfection systems specifications are presented in **Table 6-11**. The original design process and instrumentation diagram for the UV disinfection system is on sheet I-3 included in **Appendix D**.

Table 6-11 -- UV Disinfection System Specifications

Treatment Chamber		**Power and control modules**	
No. of UV disinfection units	2	Number per system	1 per lamp (12 per unit)
Installation type	In-line	Lamp power level 1	2650 W
Stages	Series	Lamp power level 2	3100 W
Dose	40 mJ/cm^2 *20 mJ/cm^2 per unit*	Lamp power level 3	3750 W
Transmittance	25 percent	Power level control	Manual
Capacity	3500 gpm		
No. of lamps per UV unit	12		

6.2.2.5 Recovery Pump

The recovery pump (14x16RGLC; Goulds, City of Industry, CA**, Figure 6-17**) is a 3-stage, vertical turbine similar to the recharge pump with the same manufacturer, model number, and horsepower. Use of similar pumps with identical model numbers and horsepower requirements streamlines the operation and maintenance efficiency for both pump systems. The recovery pump design point is 4500-GPM at 146-ft TDH. The pump is powered by a vertically mounted Siemens, 250-HP, 480-V, 1800-rpm, 3- phase motor at a pump efficiency of 73 percent and a motor efficiency of 94 percent, using a 9.6-in diameter impeller. The pump is located 155.5-ft deep within the ASR well and has 3 bowls (Goulds O&M Manual, 2006).

Figure 6-17 -- ASR well recovery pump.

Figure 6-18 -- Backwash quarry pit.

During recovery, this pump delivers groundwater to the intake/discharge structure for aeration and final discharge to the Hillsboro Canal. The flow is modulated by a check valve that protects the pump from water hammer by closing slowly. This valve also serves to prevent motor overloading due to low head requirements as it has a control arm with weights that permits adjustment to ensure a minimum head. Finally, it closes during reverse flow conditions so it prevents loss of stored water by the artesian flow from the FAS. The pump has both high and low level alarms. The water level is measured by a titanium mechanical sensor and at a specified (low) level, the pump initiates shut down. Redundancy to the ultrasonic sensor is provided with a water level float switch. The ASR well water level and pump pressure can be monitored manually at the wellhead and at the control panel. The original design for the recovery pump process and instrumentation diagram is shown on sheet I-4 in **Appendix D**.

6.2.2.6 Backwash Pond

Turbid groundwater and backwash from the filtration system flow into a quarry pit located adjacent to the ASR system on the Site 1 impoundment footprint **(Figure 6-18)**. The filter backwash line has a 3-in diameter, and extends from the filters and connects to a 6-in diameter backwash line that leads to the quarry pit. The backwash discharge pipe is installed below grade with a minimum 30-in cover, and terminates at a concrete headwall at the edge of the quarry pit. During test operation, backwash flows were as needed or set to specific intervals using local controls on the Amiad filtration system. Backwash flow rates were estimated to be 50- to 100-GPM. The original design instrumentation diagram including the quarry pit is located on sheet I-3 in **Appendix D**.

6.2.2.7 Aeration

A gas infuser (model FFTLES22 Liqui-Jet Gas Infuser, Elmridge Jet Apparatus, Livonia, MI; Sheet C-7, **Appendix D**) aerated recovered water from the ASR well. The trumpet-like infuser device is constantly submerged and constructed of carbon steel. The aeration device is a simple design and utilizes no moving parts. It operates on the Venturi Principle and imparts air into a high velocity water stream within the unit. The unit requires a minimum of 10-psi of water to operate; however, higher aeration efficiencies are achieved with higher inlet water pressures. The calculated water pressure designed for the HASR system is approximately 25-psi. This pressure level allows operational flexibility and is adequate for the discharge aeration requirements. An 8-in diameter flanged ductile iron extension pipe is attached to the infuser device and extends vertically to approximately 12-in below the intake/discharge structure grating, allowing air to be sucked into the discharge flow stream. Using manufacturer-provided design tables, approximately 140-scfm (standard cubic feet per minute) of air per minute can be imparted to the discharge flow at 25-psi discharge pressure (PBS&J, 2005). Additional calculations show that this rate of air transfer consistently yields a DO concentration greater than 7 mg/L in the effluent, which exceeds the target DO concentration of 5 mg/L for the facility design. If corrosion becomes a concern during the service life of the aeration device, magnesium sacrificial anodes can be attached to the unit and periodically replaced.

6.2.2.8 Flow Control

The flow control and valve diagrams specify the locations and the position of the valves for different phases of the cycle test. A detailed instrumentation diagram of the original design of the flow control and monitoring mechanisms is located on sheets I-2 through I-4 of **Appendix D**.

6.2.2.9 Fittings and Valves

Air release valves, check valves, gate valves, pressure gauges, sample taps, and blind flange tees are located as shown on sheet M-1 of **Appendix D**. The tees are installed to facilitate installation of an in-line metals removal treatment component if needed. Sample taps consist of threaded taps, brass nipples, and stainless steel ball valves. Pneumatically-operated butterfly valves are located at the ASR wellhead as a safety measure to close automatically should the facility lose electrical power. The pneumatic valves are powered by the air scour system compressed air supply and controlled by pneumatic solenoid valves. The pneumatic valves are isolated from the ASR wellhead by manually operated butterfly valves so that future maintenance on the pneumatic valves can be accomplished. Other control valves at this facility are manually operated but are fitted with limit switches and connected to a PLC that ensures failsafe operation during recharge, recovery, and flushing modes (PBS&J, 2005). Valve positions for recharge, storage, full recovery and filtered recovery are shown below in **Table 6-12.**

Table 6-12 -- Valve Positions During Recharge, Storage, and Recovery Phases

Valve ID	Function	Actuation	Recharge Position	Storage Position	Recovery Position (Full/Filtered)
1	Recharge Solenoid Isolation Valve, Solenoid Controlled Butterfly Valve (14 in.)	Pneumatic	Open	Closed	Closed/Closed
2	Recovery Solenoid Isolation Valve, Solenoid Controlled Butterfly Valve (14 in.)	Pneumatic	Closed	Closed	Open/Open
3	Recharge Isolation Valve	Manual	Open	Closed	Closed/Closed
4	Filter Isolation Valve	Manual	Open	Closed	Open/Closed
5	Canal Discharge Valve	Manual	Closed	Closed	Open/Open
6	Flush Valve	Manual	Closed	Closed	Closed/Closed
7	Recovery Filtration Valve	Manual	Closed	Closed	Closed/Closed
8	Recharge Pump Head Isolation Valve (Manual BFV)	Manual	Open	Closed	Closed/Closed
9	Recovery Pump Head Isolation Valve (Manual BFV)	Manual	Closed	Closed	Open/Open

6.2.2.10 In-line Monitoring Components

Magnetic Flowmeter. The magnetic type flowmeter installed at the HASR is bi-directional and accurately measure flows into and out of the ASR well during recharge and recovery phases, respectively. PBS&J (2005) designed a flow through type magnetic meter for the 14-in process line. The flowmeter is a flanged, one piece spool section of pipe specially designed with internal sensors so that maintenance and inspection are simplified. The benefits of using this type of meter include low pressure drop, high accuracy, and high adjustment ranges. An electronic flow totalizer typically is used for these meters, and is mounted inside of the control building. Another magnetic flowmeter has been installed to monitor backwash volumes. These flowmeters are able to communicate with remote operations and are included in the original design process and instrumentation diagram on sheet I-3 in **Appendix D**.

Pressure Transducers/Indicators. The in-line ASR system is equipped with local pressure indicators at the pumps and filtration systems. If pressure readings differ significantly from those expected, the line can be shutoff to ensure system stability. The units included within the ASR in-line facility do not currently have remote telemetry.

Level Transducers. Level transducers are located in the stilling well inside the intake/discharge structure and in the ASR well. These transducers signal the water level within the respective wells to ensure water availability and correct facility timing for pump system operation. These units do not currently have inclusive remote telemetry.

Water Quality Sensors. Water quality sensors have been installed in this facility to monitor specific attributes including dissolved oxygen concentrations, specific conductance, and turbidity. The specific conductance and turbidity sensors were installed to monitor water quality and compare data between pre-filter and post-filter water within the facility as well as data at the facility discharge. An example meter is shown below in **Figure 6-19.** These meters currently do not communicate with remote operations but can be monitored locally.

A dissolved oxygen (DO) sensor is located inside the stilling well where the re-oxygenated water is held before being discharged into the Hillsboro Canal. DO monitoring is performed confirm that target concentration is being met in the effluent. If effluent DO concentration is below 5 mg/L, then the effluent can be redirected into the quarry pit instead of Hillsboro Canal (PBS&J, 2005). The DO sensors currently do not have remote telemetry included but can be monitored locally.

Figure 6-19 -- Water quality monitoring components.

6.2.2.11 Power Supply

Electrical power is sourced from existing electrical supply located along Loxahatchee Road on the south side of Hillsboro Canal. Directional drilling was performed beneath the canal to source electricity to the HASR facility. The lines to the facility carry primary voltage to the utility transformer located at the ASR site via two, 6-in conduits. Lines are 480-V, 3-phase power, as well as 125-V single phase power at the HASR system. A secondary transformer located outside the electrical building was also installed to produce the 125-V single phase (PBS&J, 2005).

6.2.2.12 Operational Control and SCADA

The facility design is streamlined to allow efficient operation by operation and maintenance personnel. The pushbutton controls on the main panel located inside the control building allow for semi-automatic operation. However, as a cost-saving measure, a number of electrically-controlled valves were changed to manual and pneumatically-controlled operating valves. Both the manual and electric valves have limit switch controls to protect the system from operating when a valve is in an improper position for the operational mode selected (PBS&J, 2005).

This simplicity of operation is accomplished with a highly integrated, logical control system. HASR operations are controlled through the ASR control panel, which is comprised of both remote terminal units (RTUs) and PLCs. These are connected to the indication instrumentation for facility process valves, machinery, and equipment, including all in-line flow monitoring equipment such as the transducers, flowmeters, and water quality probes (PBS&J, 2005). Most of this equipment does transmit to the local HMI, however most of the equipment does not communicate with remote operation facilities or SCADA with the exception of the flow meters and the recharge and recovery pneumatic valves adjacent to the ASR well. Lack of SCADA communication limited data acquisition during cycle testing at HASR.

The facility was designed to allow initial pumping to waste in both recovery and recharge modes by use of various control valves, with conveyance of this water to the onsite quarry pit. Upon pressing START on the recharge panel, the PLC automatically checks the limit switch positions on the butterfly valves. If these positions satisfy the controller, the UV disinfection system energizes, along with the air compressor, the intake screen controller, and the soft starter on the recharge pump. After the first flush completes its cycle which is set through a timer, the system shuts down to allow the butterfly valves to be manually reset for normal recharge operation. Following valve reset, the system is re-started in the "Normal Recharge" mode. Again, the PLC checks the limit switch settings for correct valve position before energizing the recharge pump. When the PLC verifies the limit switch positions, it energizes the flowmeter and filter control panel and allows the recharge pump to restart and begin normal operation by pumping filtered, disinfected water into the ASR well (PBS&J, 2005). Both the recharge and recovery operations have a common ALL STOP switch. A schematic of the operational controls and panels is located on sheet E-7 of **Appendix D**.

6.2.2.13 Site Layout

The HASR surface facility consists of appurtenances, an electrical control building, a modular personnel building, filtration and UV disinfection systems, and an intake/discharge feature that includes aeration **(Figure 6-20)**. The surface facility is surrounded by a 6-ft tall chain link perimeter fence and a double 10-ft gate (20-ft clear opening) allowing vehicle access for equipment maintenance and repair. Should the motors or pumps need to be temporarily removed for repair, a small hydraulic boom crane can easily accomplish the required tasks, operating either inside the fenced compound or over the perimeter fencing. A gravel parking area has been built at this location as well. A small non-potable water supply well has been installed in the southeastern comer of the fenced compound. This well supplies water via a small hydro-pneumatic tank. A small swale has been installed to direct stormwater runoff around the site to be discharged into the quarry pit (PBS&J, 2005).

Electrical Control Building. A precast concrete electrical control building houses the electrical controls, starters, switchgear, water quality monitoring, and telemetry equipment. The building is a set-in-place type of structure, fully wired with light fixtures and constructed with double louvered doors (no windows). A wall vent (instead of the originally designed exhaust fan) is installed in the control building. The building size is 10-ft by 20-ft. The concrete floor of the electrical control building was poured in place in the field following installation of conduit to facilitate and simplify the installation and placement of conduit as well as provide a secure building foundation on a pre-prepared gravel base (PBS&J, 2005).

Figure 6-20 -- Aerial photograph showing the surface facility at HASR.

Modular Personnel Building. A modular, pre-assembled 430 ft^2 personnel office building is set on a compacted, prepared gravel pad in the northeast comer of the project fenced compound. The building is furnished with air conditioning, heating, non-potable water, and an inactive restroom that was not connected due to permitting restrictions and easement requirements. The personnel building provides an on-site facility for record keeping as well as a base for facility operations for SFWMD and/or contract personnel (PBS&J, 2005).

Pipe. The process pipeline at this facility is flanged ductile iron, 14-in diameter with 125-lb flanges. Gaskets for flanged pipe, fittings and valves are the Torruseal-type. Underground piping is factory bitumastic coated (external) and epoxy lined (internal). Underground fittings, where required, are of the thrust restrained mechanical joint-type, bitumastic coated and suitable for underground service. Internal coating is epoxy in lieu of unlined or mortar coating due to possible pH or other chemical additions that could possibly react with pipe, especially during water treatment testing (PBS&J, 2005).

6.3 Treatability Testing for UV System Optimization at KRASR

R2T, Inc. conducted water treatability studies to evaluate several methods of organic component and color removal to improve UV system performance. These studies consisted of bench testing, full-scale testing, and jar testing during the KRASR recharge phases of cycle tests 1 and 2. The procedures and summaries of these studies are summarized below.

6.3.1 Water Treatability (Bench- and Full-Scale Tests)

The objective of this study at the KRASR was to investigate the effectiveness of chemical coagulant addition for removal of organic components under various mixing conditions. The low UV transmittance and the extensive biofilm growth in ASR system components due to Kissimmee River water quality caused inadequate coliform inactivation by the UV disinfection system. Therefore, several bench-scale and full-scale tests were employed to determine whether addition of chemical coagulants would be effective. Further detail and data on the jar-scale, bench-scale and full-scale tests are provided in the technical memorandums provided by (R2T Inc., 2009b; **Appendix E**).

6.3.1.1 Ferric Chloride Jar Tests

A series of bench-scale tests were conducted using ferric chloride as the coagulant. When ferric chloride was evaluated during jar testing, results indicated a dose of 50 mg/L (active) was needed to improve UV transmittance values to the target of 37 percent UVT. However, residual iron concentrations were elevated significantly, often exceeding the maximum concentration for iron (0.8 mg/L) defined in the water quality criteria exemption (WQCE) of the UIC permit. In addition, results indicated that additional chemicals, such as sodium bicarbonate or calcium chloride, would be needed to maintain an alkalinity needed for maximum coagulation and reduction of iron residuals. This treatment option also increased solids production. Addition of ferric chloride as a pre-treatment process was not considered feasible at KRASR.

6.3.1.2 Aluminum Chlorhydrate (ACH) Jar Tests

Bench-scale testing with ACH was conducted in August, October and November 2009. Results of initial jar tests indicated that an ACH concentration of 20 mg/L (active) would reduce UVT to 25 percent. However, when this dose was applied under full-scale operations, results were not consistent with the bench-scale results. Additional jar tests showed that the most effective ACH concentration was 40 mg/L (active), resulting in a UVT between 30 and 40 percent. To improve the efficiency of coagulation, the flocculent aid polymer AS100 was added at various dosages following ACH. The AS100 optimum dosage was 1 mg/L when used in conjunction with the coagulant ACH at 20 mg/L. Jar testing using ACH and the addition of hydrochloric acid simulated enhanced coagulation. Acid addition improved UVT, but resultant aluminum concentrations exceeded the secondary drinking water quality criterion of 0.2 mg/L. It was concluded that lower coagulation pH improved UVT but resulted in higher residual aluminum concentrations that exceeded permit criteria (R2T, Inc., 2009b). Subsequently, full-scale testing of ACH addition was performed at KRASR.

6.3.1.3 ACH Full-Scale Tests

Full-scale testing was performed during the recharge phase of cycle test 2 at KRASR. ACH was introduced at different feed points to determine the where coagulation would be most effective. It was determined that the best feed point would be the wet-well, due to the improved resulting UVT (>25 percent) when ACH was introduced at this point. The ACH dosage was varied and results indicated that a dosage of 20 mg/L improved UVT, and resulted in lower turbidity and aluminum concentrations compared to an ACH dose of 25 mg/L. When a flocculent aid was added (1 mg/L AS100) UVT improved but did not differ significantly from the target value of 25 percent.

The addition of ACH during the recharge phase improved percent UVT and overall UV disinfection system performance. However total coliforms were still detected at the ASR well. During the routine cleaning of the UV sleeves and the pipeline, biofilms (algae/biological growth) were abundant. Biofilm growth probably contributed to total coliform detections. Nevertheless, the initial goal was to optimize the plant to provide the minimum design level of UVT consistently as recommended by the manufacturer to sufficiently inactivate coliforms. Our evaluations indicate that a level higher than the design UVT of 25 percent is needed to achieve water treatment goals. In addition, the KRASR system was not able to operate with the high solids load generated with chemical addition.

6.3.1.4 Color Removal by Ion Exchange – Bench Scale Test

Water quality monitoring at the KRASR facility during cycle tests 2 and 3 indicated that the ASR facility did not provide consistent and sufficient coliform inactivation. Results showed the occurrence of bacteria when the influent UVT was at the design value of 25 percent. Following discussions with the USACE, R2T Inc. completed desk top and bench scale evaluation to determine the feasibility of using an anion exchange process to improve the KRASR facility performance and meet the total coliform drinking water criterion (R2T, Inc., 2010; **Appendix E**)

Bench-scale testing was conducted to determine the feasibility of ion exchange to increase influent UVT. Test objectives are: 1) to confirm the feasibility of using ion exchange; 2) to confirm resin type; and 3) to define the recharge cycle and salt usage requirements. The bench-scale testing apparatus was provided by Tonka Equipment Co., and consisted of a packed-bed ion-exchange process in which the resin was stationary within the column while the water flowed through pore spaces, much like a media filter. To avoid excessive head loss in the resin bed, influent filtered water turbidity less than 4 NTU was required.

The color and UVT of the ion exchange effluent water samples varied from 4 to 77 PCU and from 47 to 99 percent respectively during the testing period. The overall improvement in UVT is shown by lower color values. Transmittance values tended to decrease with reduction in resin removal efficiency over time. Even after 6 days of testing, the combined UVT value of the 3RW: 2IEX (3 parts of source water mixed with 2 parts of ion exchange treated water) sample was greater than 25 percent. Review of the bench scale test results data by Tonka Equipment Co. representatives confirmed that the selected resin is optimum for this water quality. A regeneration cycle of 40 hours and 5400-lbs of salt per regeneration cycle would be required. Also, a 40-ton brine tank would be required to maintain a month's supply of salt on hand.

The best water quality was obtained with the 2RW:3IEX (2 parts of filtered water mixed with 3 parts of ion exchange treated water) sample, where the blended transmittance was maintained above 33 percent after the six days of testing. In comparison, the 3RW:2IEX sample resulted in a minimum transmittance of 25 percent after 6 days of testing. It should be noted that the 5RW:2IEX sample resulted in only slightly a less transmittance of 24 percent at the end of the testing period. This result allows the USACE to increase the flow through the combined facility if needed.

6.3.2 Treatability Test Conclusions

Chemical addition and ion exchange processes were evaluated at bench- and full-scales during cycle testing at KRASR. The following are concluded from these treatability tests.

- Ferric chloride addition for coagulation is not effective for color reduction due to exceedance of the drinking water quality criterion for iron, and high solids production rates.

- During bench- and full-scale testing, the use of ACH as a coagulant resulted in minor improvements in the filtered water UVT. The frequency of total coliform detections was reduced, but not eliminated. Ultimately, it was concluded that ACH addition (along with other amendments) was not feasible due to high solids production rate and insufficient reduction of UVT. Total coliforms were still detected after ACH addition as an effluent treatment.

- Ion-exchange using filtrate water: exchange resin ratios of 3RW:2IEX or even the 5RW:2IEX reduced color and increased UVT above 25 percent. The most cost-effective configuration for color removal with ion exchange has a 2 MGD design capacity. A 5 MGD design capacity would not be feasible, so this treatment method is not possible at KRASR.

6.4 ASR System Design Recommendations

Successful completion of four cycle tests at KRASR and three cycle tests at HASR provides some insight on the performance of each ASR system component (pumps, filter, UV disinfection, pond storage, power distribution, and SCADA). While it is beyond the scope of this report to propose design alternatives for new ASR systems,

- **Pressure filters.** The pressure media filter at KRASR was most effective when source water particle loads were high, for example during storm flows. The turbidity of filter effluent was reduced by 50 percent (approximately 60 NTU to 30 NTU) during a high flow event in cycle test 4, with no subsequent well clogging. The filter is less effective for the removal of colloidal particles (1 µm or less). The Amiad screen manifold filter at HASR showed limited effectiveness because the screen mesh size (80 µm) exceeds the colloidal particle size that characterizes the particle load in the Hillsboro Canal. ASR well clogging was a problem at HASR due to organics in the source water. New filtration methods should be investigated for the design of new ASR systems.

- **UV Disinfection System.** For effective disinfection at KRASR, the UVT of treated source water (filter effluent) must exceed the current design value of 25 percent using the existing UV disinfection system. Treatability tests using filter effluent characterized by a UVT of 25 percent still had total coliform concentrations that exceeded 4 CFU/100 mL, even with three in-line UV units. In addition, the UVector sensors did not perform well in an unsheltered outdoor location, resulting in frequent automatic system shut downs during KRASR cycle tests 1 and 2. A shelter was built, and the PLC was reprogrammed to ignore selected UV system shut down commands. These conclusions also apply to HASR, where only two in-line UV units were installed. As long as the disinfection requirement is maintained for UIC permit compliance, it is likely that UV disinfection is the preferred technology because no chemical addition is required. New, more robust UV disinfection technologies should be investigated for the design of new ASR systems.

- **Flow control.** At KRASR, the in-line manual "butterfly" flow control valve was inadequate for controlling flow between the pressure filter and the UV disinfection system. A stronger valve is needed to throttle down the 5 MGD flow.

- **In-line Monitoring.** In-line pH sensors failed repeatedly and should be discontinued. In-line sensors for turbidity, temperature, specific conductance, pressure, and flow were useful attributes of the ASR systems.

- **Pond storage capacity.** After completion of cycle testing at KRASR, the two-pond water management system storage capacity was used infrequently. Solids management and effluent handling probably can be managed in a single pond.

- **SCADA systems and telemetry.** The initial design of the SCADA system at KRASR required significant revision after construction. Modifications included re-programming to integrate all components for remote operation, instrument calibration, and software and hardware upgrades are detailed fully in **Section 8.1.6.4**. However, the result was a fully integrated functional system where each component could be monitored remotely. Future ASR system specifications should include a more detailed SCADA and instrument and controls design. The initial design of the SCADA system at HASR cannot be evaluated because no data were recorded or transmitted by telemetry during the cycle testing program.

- **Power distribution.** The UV disinfection system power supply was re-wired from the subsurface to above-ground conduit due to moisture affecting the cables. Major power supply lines on-site should be designed for above-ground construction due to saturated ground conditions.

7. Permitting and Regulatory Compliance

7.1 Kissimmee River ASR (KRASR) System

The construction and operation of the Kissimmee River ASR system has been subject to a variety of regulations, namely the Safe Drinking Water Act (SDWA) Underground Injection Control (UIC) permit program that addresses injection of water into an underground drinking water source, the Clean Water Act National Pollutant Discharge Elimination System (NPDES) permit program that addresses discharge to a surface water body, and the Comprehensive Everglades Restoration Program Regulatory Act (CERPRA) permit program which covers the construction and operation of CERP facilities. The application, issuance, and maintenance of the three permits (NPDES, UIC and CERPRA) are described below in detail. Copies of permit documents are provided in **Appendix F**. Monthly Operating Reports (MORs) submitted to the FDEP are compiled in **Appendix I**.

7.1.1 National Pollutant Discharge Elimination (NPDES) Permit

The National Pollutant Discharge Elimination System (NPDES) is a major cornerstone of the 1972 Clean Water Act (CWA). It is designed and intended to regulate the discharge of various pollutants into U.S. waters from point and non-point sources. Since the Kissimmee River ASR facility discharges into the Kissimmee River it is necessary to obtain an NPDES discharge permit from the FDEP which has been delegated permitting authority by the United States Environmental Protection Agency (USEPA). The USACE applied for an NPDES Industrial Waste Facility permit in March 2007 and was issued the permit (FL0569071) in August 2007. The application package for this permit included a summary of baseline surface water and groundwater quality, a description of the facility, a description of the water quality monitoring plan, and the operation plan. The permit required water quality sampling and toxicity testing during discharge events and the submittal of monthly discharge monitoring reports (DMRs). The fee for applying for this NPDES Industrial Facilities permit was $5,000. The 5-year renewal fee was also $5,000. The annual permit maintenance fee is $5,800. The permit modification fee is $1,000.

During “shakedown” operational testing in January and February 2008, sampling of the discharge revealed arsenic at concentrations as high as 140 µg/L. As a result of this exceedance of the Class III surface water criteria for arsenic of 50 µg/L, the USACE submitted a request to Florida Department of Environmental Protection (FDEP) for a mixing zone exemption for arsenic. For this request, the USACE prepared a mixing zone analysis to determine the extent of dilution near the discharge outfall. In January 2009, the FDEP issued its first revision of the permit to allow for a mixing zone for arsenic of 50 meters. This revision allowed for a maximum arsenic concentration measured in the discharge of 180 µg/L. A requirement for receiving water mixing flow of a minimum of 30 cfs was added to the permit. The revised permit also required that the USACE sample the effluent for arsenic on a daily basis for the first 14 days during the first discharge event and to sample in the receiving water on a weekly basis for the first 30-days of discharge for subsequent discharge events.

During discharge in April 2009 the recovered water failed the chronic toxicity test for the test species *Pimephales promelas* with an IC25 (inhibition concentration 25 percent) of 79 percent effluent, which is below the standard of 100 percent effluent. During discharge in April 2009, the recovered water failed the chronic toxic for the test species *Ceriodaphnia dubia* with an IC25 of 76 percent effluent. In September 2010, the USACE submitted a request to FDEP for a mixing zone for chronic toxicity. Since no acute toxicity was observed, under NPDES regulations the FDEP was able to develop a mixing zone for chronic toxicity. In May 2011, the FDEP issued its second modification to the permit allowing for a mixing zone for chronic toxicity. The chronic toxicity mixing zone was set to 25 meters (m) which is within the 50 m mixing zone granted for arsenic. The requirement for a minimum mixing flow in the Kissimmee River of 30 cfs during discharge events was not changed in the second revision. The compliance value for chronic toxicity IC25 was set to 60 percent in the second permit revision.

Table 7-1 lists the parameters that must be monitored to comply with the current NPDES permit. In general, the parameters must be measured on a monthly basis with the exception of the toxicity testing which is to be conducted bi-monthly or as required based upon the scheduling of discharge events. In addition to the monthly reports, the permit requires that the following records be maintained on-site and available for inspection: a) records of all compliance monitoring information, including calibration and maintenance records, and a copy of the laboratory certification; b) copies of all reports, data and supporting documentation; c) copy of the permit; and d) copy of record drawings.

Table 7-2 includes the reported arsenic concentrations and toxicity testing results from the shakedown operations and recovery events completed prior to March 2013. This table was initially prepared by the FDEP's NPDES permitting office in West Palm Beach as part of the permit renewal process initiated in June 2012. The FDEP used this table in the renewed permit (September 18, 2012) to illustrate the compliance of the KRASR facility with the two mixing zones granted for the discharge. Compliance with the 50-m mixing zone for arsenic with an allowable concentration of 180 µg/L is demonstrated by the declining arsenic concentrations in the recovered water which all fall well below the mixing zone standard. The chronic toxicity mixing zone allowable condition of no less than 60 percent IC25 concentration is shown to be met with all valid reported tests with the exception of the May 2011 *Ceriodaphnia dubia* test which failed for chronic toxicity with a value of 7.2 percent IC25 concentration. This indicates that during May 2011, a mixture of recovered water and receiving water greater than 7.2 percent would result in measured impact to more than 25 percent of the test population.

Table 7-1-- NPDES Industrial Waste Permit Monitoring Requirements	
Flow	
Flow, Total Volume (Effluent)	Dilution Ratio, Kissimmee River (Total Flow/Effluent Flow)
Upstream Flow, mean daily (Kissimmee River, Total Flow)	Upstream Flow, mean daily (Kissimmee River, Total Flow)
General Water Quality	
Solids, Total Suspended	Turbidity
Specific Conductance (background)	Turbidity (background)
Specific Conductance	Oxygen, Dissolved (DO)
Iron, Total Recoverable	pH
Color	Temperature (C), Water
Arsenic, Total Recoverable	Phosphorus, Total (as P)
Mercury, Total Recoverable	Sulfate, Total
Methyl Mercury	Chloride (as Cl)
Solids, Total Dissolved (TDS)	
Toxicity Testing	
Chronic Whole Effluent Toxicity, 7-Day IC25 (*Ceriodaphnia dubia)*	Chronic Whole Effluent Toxicity, 7-Day IC25 (*Pimephales promelas*)

Table 7-2 -- Point of Discharge (POD) Arsenic and Toxicity Sampling Results Reported for NPDES Permit for Cycle Tests 1 through 4

Cycle Test	Reporting Period (month/year)	Arsenic, Total Recoverable (µg/L)	Acute Toxicity (LC50 percentage)		Chronic Toxicity (IC25 percentage)	
			Ceriodaphnia dubia	***Cyprinella leedsi***	***Ceriodaphnia dubia***	***Pimephales promelas***
Shake down	January 2008	**138**	not conducted	not conducted	No test	No test
Shake down	February 2008	**64**	not conducted	not conducted	No test	No test
1	March 2009	**75**	LC 50 > 100	LC 50 > 100	03/10/2009 IC 25 > 100% 03/17/2009 (footnote "a") 03/24/2009 (footnote "b")	03/24/2009 IC 25 >100% 03/31/2009 (footnote "c")
1	April 2009	**37**	LC 50 > 100	LC 50 > 100	IC 25 > 100	**IC25 = 79.17**
2	October 2009	3.7	LC 50 > 100	LC 50 > 100	IC 25 > 100	(footnote "d")
2	November 2009	2.1	LC 50 > 100	LC 50 > 100	IC 25 > 100	(footnote "d")
2	December 2009	2	LC 50 > 100	LC 50 > 100	**IC 25 = 76.41**	(footnote "d")
2	January 2010	< 2	LC 50 > 100	LC 50 > 100	(footnote "e")	(footnote "d")
3	January 2011	**18**	LC 50 > 100	LC 50 > 100	IC 25 > 100	IC 25 > 100
3	February 2011	3.9	LC 50 > 100	LC 50 > 100	No test	No test
3	March 2011	3	LC 50 > 100	LC 50 > 100	No test	No test
3	May 2011	2.8	**LC 50 = 83.92**	LC 50 > 100	**IC 25 = 7.2**	IC 25 > 100
3	June 2011	2	LC 50 > 100	LC 50 > 100	IC 25 > 100	IC 25 > 100
4	January 2013	10, 3.3	LC 50 > 100	LC 50 > 100	IC 25 > 100	IC 25 > 100
4	February 2013	2.4, 1.4	No test	No test	**IC 25 = 83.9**	IC 25 > 100
4	March 2013	1.9	LC 50 > 100	LC 50 > 100	**IC 25 = 76.2**	IC 25 > 100
4	April 2013	1.6	No test	No test	IC 25 > 100	IC 25 > 100
4	May 2013	1.0	LC 50 > 100	LC 50 > 100	IC 25 > 100	IC 25 > 100
4	June 2013		LC 50 > 100	LC 50 > 100	IC 25 > 100	IC 25 > 100

Footnotes:
a - DMR/March 10, 2009 IC25 > 100 result not revealed in lab report provided to Department.
b - DMR/March 24, 2009 IC25 = 95.52 result not revealed in lab report provided to Department.
c - DMR/March 31, 2009 IC25 > 100 result not revealed in lab report provided to Department.
d - No Observed Effect Concentration (NOEC) result instead of IC25 result was reported.
e - Test was invalid due to problem with control test. Test not repeated due to cessation of discharge.

7.1.2 Underground Injection Control (UIC) Permit

Injection (recharge) of water in an underground source of drinking water (USDW) is regulated by the USEPA under the Safe Drinking Water Act (SDWA). A USDW is defined in the SDWA as an aquifer where the total dissolved solids concentration is less than 10,000 mg/L. In Florida, administration of the UIC permitting program has been delegated to the FDEP by the US Environmental Protection Agency (USEPA). ASR wells are regulated as Class V, Group 7 wells under 62-528 Florida Administrative Code (FAC). For ASR systems, the FDEP first issues a construction and testing permit. This permit can be converted to an operations permit once the testing demonstrates that the facility does not result in harm to the USDW. In general, the UIC rules require that ASR wells can recharge water that meets primary and secondary drinking water standards. However, the applicant can request water quality criteria exemptions (WQCE) to allow exceedances of secondary drinking water standards.

The USACE submitted an application for the UIC permit in March 2005. The application package for this permit included a summary of surface and groundwater quality, facility design, monitor well design and location, as well as preliminary operational testing and water quality monitoring plans. The Kissimmee ASR surface facility design includes pressurized media filtration and UV disinfection, which are intended to treat the surface water to primary drinking water standards. Since the KRASR surface facility does not include chemical treatment, the plant is not capable of removing excessive concentrations of iron or color. To address exceedance of SDWA secondary water quality criteria, the USACE applied for WQCEs for iron and color. The WQCE included a request to allow iron to be as high as 0.80 mg/L compared to the 0.3 mg/L criterion, and color to be 250 PCU compared to the 15 PCU criterion.

In April 2006, the FDEP issued the UIC permit (200917-003-UC) for the KRASR system. This permit authorized the construction and testing of the KRASR surface facility. In October 2007, the FDEP issued a WQCE granting the USACE request to allow injected water to contain up to 250 PCU and 0.80 mg/L iron. The monitoring requirements of the UIC permit are similar to the NPDES monitoring requirements except that they include the collection of samples from several storage zone monitor wells (350-ft SZMW (MW10), the 1,100-ft SZMW (OKF-100)) and collection of microbe and pathogen samples (total coliform, fecal coliform, etc.) at the ASR wellhead during recharge.

In October 2008, the FDEP issued an administrative order (AO) allowing arsenic concentrations in the groundwater system to exceed the primary drinking water standard of 10 µg/L within the limits of the property boundaries. The AO required that the USACE provide a written report within 90 days of the end of a cycle in the event that arsenic is measured above 10 µg/L in any of the facility monitoring wells. The order also required that the USACE notify nearby groundwater users in the event that exceedance of the arsenic standard is likely to have travelled off-site.

In October 2008, the USACE began shakedown testing of the newly constructed KRASR system to ensure that the recharge pump, pressure media filter, UV disinfection system, and ASR well would operate as designed. Testing for biological activity was done to determine if the disinfection system adequately inactivated pathogens prior to injection into the well. The results of the pathogen testing showed that it was probable that the installed duel UV systems would not provide sufficient UV dose to ensure pathogen inactivation during normal operations. The FDEP reviewed the results and requested that the USACE increase UV dosage and add a bypass pipe to allow for offline testing of the UV system. In response, the USACE contracted for the installation of a third UV unit and a bypass pipe system.

The UIC permit requires that monthly operating reports (MORs) be prepared and submitted to the FDEP. These reports include a summary of the volume of water recharged into the ASR well and the results of water quality monitoring performed during the month. A test report is also required to be submitted

90 days after the completion of an injection, storage, and recovery cycle. The general conditions of the permit require that the following records shall be maintained on-site and available for inspection:

1) All monitoring information including; calibration and maintenance records and all original strip chart recordings for continuous monitoring instrumentation, copies of all reports, and records of all data. Information shall be retained for 3 years from the date of the sample, measurement or report.
2) Records of monitoring information shall include:
    a. The date, place, and time of sampling or measurements
    b. The person responsible for performing the sampling measurements
    c. The dates the analyses were performed
    d. The analytical techniques or methods used
    e. The results of such analyses

Table 7-3 is a summary of non-compliant water quality sampling occurrences that were reported to FDEP as part of UIC compliance activities during all four cycle tests. Arsenic concentrations were measured at concentrations exceeding the SDWA criterion of 10 µg/L on more than 120 occasions. Most of these arsenic exceedances were observed at the 1,100-ft SZMW and the 350-ft SZMW though several of the exceedances occurred at the ASR well. Elevated arsenic was not observed at either of the distal storage zone monitor wells (2,350-FT and 4,200-ft SZMWs). Given the exceedance at the 1,100-ft SZMW, which is very close to the southeastern border of the SFWMD property boundary, it is probable that elevated arsenic concentrations in excess of 10 µg/L migrated off-site during some portion of the cycle testing operations.

Iron concentrations of the source water and in the target aquifer were observed to exceed the WQCE limit of 800 µg/L on six occasions during cycle operations. Two of the iron exceedances (860 µg/L; 1,000 µg/L) were observed at the ASR well during recharge operations. These exceedances were the result of high iron concentrations in the source water. Iron exceedances at concentrations in excess of 1,000 µg/L were observed at the ASR well or 350-ft SZMW during storage or recovery operations and were likely the result of iron oxidation of the well casing.

The average color measurement at the ASR well during all recharge events was in excess of 80 PCU. This exceeds the secondary drinking water standard of 15 PCU. Color was observed to exceed the KRASR WQCE criterion of 250 PCU on only three occasions, which all occurred during cycle test 4 recharge phase. It is possible that the USACE could request a higher WQCE for color; however, recharging during high color events would likely increase the frequency of total coliform exceedances.

Total coliform concentrations were observed to exceed the 4 Colony Forming Units/100 mL (CFU/100 mL) drinking water standard on more than 40 occasions during cycle testing. Most of these exceedances were measured during recharge at the ASR well though there were several detections were measured at the 350-ft and 1,100-ft SZMWs. There were approximately 10 exceedances at the SAS well and APPZ well (OKF-100L), or the Point of Discharge (POD) that are not shown in **Table 7-3**. These exceedances are likely the result of testing contamination rather than a result of ASR operations.

In January 2011, the USACE applied for renewal of the original UIC permit, which was set to expire in April 2011. In August 2011, the FDEP completed its review of the UIC permit and issued permission for the USACE to continue to test the facility through the completion of cycle test 4.

Table 7-3 -- Non-Compliant Water Quality Sampling Occurrences Reported to FDEP for UIC Compliance at KRASR

Operations	Arsenic (DWS = 10 µg/L)		Iron (WQCE = 800 µg/L)		Color (WQCE = 250 PCU)		Total Coliform (DWS = 4 CFU/100 ml)	
	No. of Exceedances	Max Conc. (µg /L)	No. of Exceedances	Max Conc. (µg /L)	No. of Exceedances	PCU Value	No. of Exceedances	Maximum CFU/100 mL
Cycle 1								
Recharge	7	35	0		0		3	220
Storage	9	140	3	7500	0		1	44
Recovery	11	59	0		0		1	16
Cycle 2								
Recharge	9	20	0		0		12	74
Storage	0		0		0		1	17
Recovery	0		0		0		1	12
Cycle 3								
Recharge	32	46	1	860	0		24	59
Storage	39	27	0		0		2	12
Recovery	0		1	950	0		0	
Cycle 4								
Recharge	3	29	1	1000	3	900	8	330
Storage	16	44	0		0		0	
Recovery	0		1	710	0		3	9

7.1.3 Comprehensive Everglades Restoration Plan Regulation Act (CERPRA) Permit

The Comprehensive Everglades Restoration Plan Regulation Act (F.S. 373.1502) requires that projects proposed for construction under the CERP obtain a construction and operations permit prior to initiation. The USACE submitted an application for a CERPRA permit for the KRASR system in August 2004. The permit application submittal included baseline ground and surface water quality data, facility design documents, a draft operating plan, and a draft monitoring plan. As part of the permit application review, the FDEP engaged the SFWMD to develop the consumptive water use permit for the project. Consumptive use conditions were incorporated directly into the CERPRA permit. In December 2005, the FDEP issued the CERPRA permit (0236494-003-GL) that authorized construction and operational testing of the facility through December 2010. In August 2011, the FDEP issued a modification of the permit to extend the duration of the permit through 2015 and to change the monitoring requirements so that they are consistent with the latest versions of the UIC and NPDES permits.

The monitoring, reporting, and record keeping requirements of the CERPRA permit are similar to those found in the UIC and NPDES permits. The FDEP has allowed the USACE to submit copies of the NPDES and UIC monthly reports to comply with the reporting requirements of the CERPRA. Because the CERPRA permit covers the UIC and NPDES requirements as well as the construction phase of the facility, failure to comply with either of these permits during operations is effectively a failure to comply with the CERPRA permit. For this reason compliance discussions are limited to the NPDES and UIC permits.

7.1.4 Permit Compliance

During cycle testing at the KRASR, the USACE and its operating contractor (R2T, Inc.) acted to maintain the facility and its operations in compliance with the NPDES, and UIC permit conditions. When numerical exceedances of either the drinking water or surface water quality standards were observed, the USACE would notify the FDEP via email usually within 24 hours of receiving the certified laboratory results or as part of the monthly reporting. The USACE and R2T, Inc. would hold a teleconference to determine what actions would be necessary to alleviate the exceedance and the action plan would be transmitted to FDEP for comment and/or concurrence. In general, the facility was not in compliance with one or more of the permit conditions during much of the cycle testing. During all recharge events, total coliform was observed at the ASR well in excess of the 4 CFU/100 mL standard on one or more occasions. The USACE kept FDEP informed of these occurrences on a timely basis and implemented remedial action plans during operations to reduce or eliminate total coliform exceedances. For instance, after cycle test 1 recharge, the USACE began a program to sanitize the pressure filter and pipe network with chlorine prior to recharge, and on a monthly basis during recharge events. Chlorinated water was then released to the backwash equalization pond, and not the ASR well or the Kissimmee River. To address total coliform exceedances during cycle test 2, the effective dose from the UV disinfection system was increased by 20 percent by reducing the inflow rate from 5 MGD to less than 4 MGD; however, this was not effective for total coliform inactivation, and the recharge flow rate was increased to 5 MGD for subsequent cycle tests. The USACE directed the contractor to perform chemical dosing tests during cycle test 2 recharge to determine whether the addition of Aluminum Chlorhydrate (ACH) would improve pathogen inactivation by the UV disinfection system **(Section 6.3)**. The results of this testing indicated that chemical dosing would improve the performance of the disinfection system; however, coliform exceedances would likely still occur without significant modification and addition to the treatment plant (Appendix E). Prior to cycle test 3 recharge, the UV system was dismantled and refurbished by replacing the glass lamp sleeves and all of the UV lamps. During both cycle tests 3 and 4 recharge events, source water quality was severely degraded due to high color and iron concentrations. Reduced UV transmittance through the source water resulted in frequent exceedances of total coliform at the ASR well and the 350-ft SZMW. During a period of particularly low UV transmittance that occurred during cycle test 4 recharge, the USACE decided to cease operations for approximately one week until surface water quality conditions improved as indicated by lower color and iron concentrations.

The facility was largely in compliance with the terms of the NPDES permit. To address the exceedance of arsenic in the discharge water that occurred early in the cycle testing, the NPDES permit was modified to include a 50-m mixing zone; however, subsequent testing of recovered water indicated low concentrations of arsenic below the surface water quality standard (50 µg/L). Toxicity testing results at the KRASR system indicated that chronic toxicity conditions exist occasionally in the recovered water. Interestingly, the incidents of chronic toxicity seem to occur not during the final week of recovered water discharge when specific conductance in the recovered water was highest, but two to four weeks prior to the end of a discharge event. To address the chronic toxicity exceedances, the FDEP modified the NPDES permit to allow for a 30-m mixing zone for chronic toxicity.

As discussed above, compliance with the NPDES permit required that the USACE be granted mixing zones to accommodate arsenic and chronic toxicity. The mixing zones require that adequate mixing water be available in the receiving water body. At the KRASR, adequate mixing water volume was provided by arranging with the SFWMD to open the S65E structure to pass a minimum of 30-cfs continuously during ASR recovery operations to meet the dilution ratio requirement of 3.9 stated in the NPDES permit. Because the KRASR system was operated as a pilot testing facility with a limited flow volume (5-MGD), it was not difficult to arrange for sufficient mixing flow from upstream structures. Given that NPDES permit conditions address many surface water quality exceedances through the issuance of mixing zones, future CERP ASR facilities should be located at sites where adequate mixing water is available.

Compliance with the UIC permit was not constant due to exceedances of the total coliform criterion in the source water during recharge, and due to periodic exceedances of the 10 µg/L standard for arsenic in the aquifer as indicated by sampling at the two proximal SZMWs. If ASR operations are to continue going forward at the KRASR, modifications to the water treatment plant for a more robust UV disinfection process would be necessary to provide assurance that total coliform counts remain below the standard (4 CFU/100 mL) during recharge.

The administrative order (AO) for arsenic exceedances in the aquifer that FDEP issued to this facility in 2011 required that operations cease if elevated arsenic concentrations were observed to leave the boundaries of the facility. Based upon the arsenic results at the 1,100-ft SZMW, it is likely that the ASR operations at the Kissimmee ASR facility periodically violated the terms of the (AO) since the 1,100-ft SZMW is adjacent to the limits of the SFWMD lands where the facility is sited. Given that arsenic concentrations in the aquifer during ASR operations appear to be trending downward it is possible that future operations at this site would comply with all of the terms of the arsenic administrative order.

7.2 Hillsboro ASR System

The HASR system required NPDES, UIC, and CERPRA permits analogous to those at the KRASR system. The requirements of these permits are very similar to those issued for the KRASR, although characteristics of the FAS and the receiving water body (Hillsboro Canal) differ from KRASR system. Permit documents are provided in **Appendix F**. MORs and supporting SFWMD technical memos are compiled **in Appendix J**.

7.2.1 NPDES Permit

The SFWMD applied for an NPDES Industrial Waste Facilities permit in February of 2006 and the FDEP issued the NPDES permit (FL0484890) in June of 2006 and its renewal in June of 2011. The monitoring and reporting requirements for this permit are very similar to the requirements of the first version of the NPDES permit issued for the KRASR operations. The permit requires acute toxicity testing but does not include provisions for mixing zones for arsenic or chronic toxicity. The renewed permit is very similar to the original version since water quality records from cycle tests 1 and 2 indicated that recovered water largely meets surface water quality standards. The reporting and record keeping requirements of this permit are similar to that of the Kissimmee ASR NPDES permit.

During the three recovery events at this facility, the discharged water met the receiving water quality requirements for all parameters except arsenic. Arsenic was measured as high as 102 µg/L during the first recovery event. The maximum arsenic concentration during the second and third recovery events was less than the 50 µg/L surface water quality criteria. Toxicity testing conducted during the three recovery events all indicated that the water was not acutely toxic. Chronic toxicity testing was not required because discharged water largely met the receiving water quality criteria. In accordance with the NPDES permit conditions, recovery during cycle tests 2 and 3 was terminated before the specific conductance of the recovered water exceeded 1,275 mhos/cm.

7.2.2 UIC Permit

The SFWMD applied for the UIC permit for the HASR system in 2005. The FDEP issued the UIC permit (0153872-002-UC/5X) in 2006. A water quality criteria exemption was issued for the HASR system in conjunction with the UIC permit issuance. This WQCE allows the water injected into the aquifer to have a maximum value of 230 PCU for Color, in excess of the secondary drinking water standard of 15 PCU. In March 2010, the FDEP issued an AO allowing exceedances of the 10 µg/L arsenic standard in the aquifer. This AO is identical to the one issued for the KRASR. It also requires the SFWMD provide a written report within 90 days of the end of a cycle in the event that arsenic is measured above 10 µg/L in any of the system monitoring wells. The order also requires that the SFWMD notify nearby groundwater users in the event that exceedance of the arsenic standard is likely to have travelled offsite. In 2011, the FDEP issued an extension to the UIC permit to allow facility operation through 2016.

During the three recharge and storage phases, there were several drinking water standard exceedances observed either in the source water during recharge, or at the monitor wells. Gross alpha exceedances were measured at one or more monitor wells during cycle test 3. The highest gross alpha observation (25 picocuries/liter; pCi/L) was measured at the PBF-10R monitor well. Three arsenic exceedances were observed during cycle test 3 recovery at two of the monitor wells. During cycle test 1, total coliform values in the recharge water remained from "below detection level" to 10 CFU/100 mL (one sample) during the entire recharge period, indicating that the UV disinfection system operated as designed and intended. During cycle test 2, total coliform values in the recharge water ranged between 2 to 20 CFU/100 mL, with occasional concentrations of up to 190 CFU/100 mL. There were no exceedances for color during any cycle test. HASR operational performance was documented in the cycle tests 1 and 2 Summary Technical Memoranda that were submitted to the FDEP and project team subsequent to each cycle **(Appendix J)**. Exceedances to the UIC permit are summarized in **Table 7-4.**

During the initial four weeks of recharge during cycle test 3, total coliform values ranged from 17 to >200 CFU/100 mL. During this same time, the UV disinfection system began reporting faults and inconsistent operation. Upon notification of this, the ASR system was turned off and the UV disinfection system underwent a diagnosis and repair. This period of inactivation extended from December 4, 2011 to January 17, 2012, which was reported to the FDEP in the monthly project MORs. The system was subsequently reactivated and operated without incident from January 18, 2012 to the end of recharge period of cycle test 3, on March 7, 2012. During this second period of recharge, total coliform counts ranged from 15 to > 200 CFU/100 mL, indicating that the UV disinfection system was not operating as intended. Based on this operational performance, future consideration should be given to increasing the UV dosage at the system or augmenting the disinfection process with higher filtration or additional pre-treatment of the recharge water.

Table 7-4 -- Non-Compliant Water Quality Sampling Occurrences Report to FDEP for UIC Compliance at HASR

Operations	**Arsenic (DWS = 10 µg/L)**		**Total Coliform (DWS = 4 CFU/100 ml)**	
	No. of Exceedances	Max Conc. (µg /L)	No. of Exceedances	Maximum CFU/100 mL
Cycle 1				
Recharge	0		3	10
Storage	0		0	
Recovery	4	102	0	
Cycle 2				
Recharge	4	19	16	190
Recovery	0		1	430
Cycle 3				
Recharge	2	35	17	>200
Storage	0		1	10
Recovery	1	48	0	

7.2.3 CERPRA Permit

The SFWMD applied for the CERPRA permit for the HASR system in June 2004. The FDEP issued the permit (01543872-003) in September 2005. This permit authorized the construction and testing of the facility through September 2010. The FDEP issued a minor modification of the permit in December 2010 that authorized operation of the facility through September 2015. The monitoring and record keeping requirements of this CERPRA permit are similar to those of the KRASR system. A mixing zone for specific conductance was authorized to enable recovery to background FAS water quality conditions only during cycle test 1. This mixing zone extended 800 m downstream in the Hillsboro Canal.

7.2.4 Permit Compliance

The SFWMD was responsible for ensuring compliance with the three permits issued for the HASR system. Reporting of all constituent concentrations of regulatory and scientific interest during cycle tests 1 and 2 was documented in Summary Technical Memorandums prepared by the SFWMD, and submitted to the FDEP and project team **(Appendix J)**. The most significant permit compliance issues associated with operations at the HASR system were the frequent exceedances of total coliform criterion in the source water during recharge, and the elevated concentrations of arsenic that were observed in monitor wells during storage and recovery. Arsenic exceedances observed in the facility groundwater samples indicate that the terms of the AO may have been violated since it is possible that arsenic exceedances in the FAS occurred off of the project lands. If future ASR operations are to go forward at the HASR system, it is likely that additional treatment functionality will be required to ensure that total coliform values in the recharge water are maintained below the 4 CFU/100 mL standard. Given the declining concentrations of arsenic observed at the HASR and KRASR systems, it is probable that exceedances of the drinking water standard for arsenic during future ASR operations will be infrequent. The probability that elevated arsenic will leave the property boundaries also should decrease.

8. Construction of ASR Pilot Systems

8.1 Kissimmee River ASR Pilot System

8.1.1 Procurement

A request for proposal entitled "Surface Facilities for Lake Okeechobee ASR Pilot Projects, Kissimmee River Site" was posted on or about 15 December 2005 on the USACE FedBizOps web site. This construction project was authorized as a "full and open" competition. Source selection and all required approvals were completed in April 2006, leading to an award on 3 May 2006 to Harry Pepper and Associates, Inc. A "Notice to Proceed" (NTP) was issued on 7 June 2006 for construction of the surface facility of the ASR system. This award included construction of all surface water treatment and conveyance features. Monitor wells were constructed by separate contracts. The ground-breaking for the Lake Okeechobee ASR Pilot Project was held in the Okee-Tantie Campground, approximately 1 mile from KRASR, on 29 June 2006 (Palm Beach Post, 30 June 2006).

8.1.2 Surface Facility Construction Sequence and Duration

Construction was initiated in July 2006, commencing with clearing and grubbing, and grading the site to ensure that surface runoff would not enter the Kissimmee River. The ASR system construction began at the river, with the intake (wet well, wing walls, bulkhead, intake piping, and intake structure **(Figure 8-2 A, B)** and outflow features (cascade aerator and piping). Simultaneously, the subsurface plumbing of the ASR system (intake to filter to ASR well) was installed. With great effort, the pressure filter (Tonka's largest) was installed on the surface facility pad **(Figure 8-2 C, D)**.

A. Cofferdam for wet well construction. **B. Wet well, wing wall, and raw water influent pipe.**

Figure 8-1 (A through F) -- Photographs showing the KRASR pilot system under construction.

C. Installing the pressure filter.

D. Influent and effluent pipes on pressure filter.

E. ASR system construction in progress – June 2007. Drill rig in lower left is constructing the 350-ft SZMW**.**

F. Team ASR. USACE and Harry Pepper Associates Inc. (construction contractor) construction management team. From left to right: Erasmo Rivera (USACE field engineer), Kirk Watson (HPA Project Manager), Bill Meier (HPA Quality Control Officer), Chuck Wilburn (USACE Resident Engineer), and Lee "Stump" Lightsey (HPA Field Engineer).

Figure 8-2 (A through F) *continued* -- Photographs showing the KRASR pilot system under construction.

After a significant portion of intake and outflow plumbing was constructed, grading and construction of berms around the flow equalization and solid settling ponds, and the final access road were initiated **(Figure 8-2 E)**. The backwash decant pump station, to transfer effluent between these ponds also was completed. As these features were established, the working areas of the site were developed. The working areas include foundation, pads, structures and conduit for electrical and operations buildings, and all of the water treatment components of the surface facility. The progress of construction went well due to the solid team work of USACE and our Contractor **(Figure 8-2 F)**. However, it might have been helpful to have the design engineer of record (CH2M Hill) available through separate contract to provide oversight that the facility was constructed as designed. Construction duration was 437 days (1.2 years) from NTP to acceptance. **Figure 8-3** shows the sequence of major construction tasks and their estimated durations.

8.1.3 Surface Facility Construction Cost

The award for construction contract W912EP-06-C-0010 was $5,788,862.69, which included construction and operational testing of the surface facility. This cost does not include real estate purchase, contract modifications, construction of the monitor wells. During construction, modifications to the project totaled $349,391.10, for a total project cost of $6,138,253.79. This cost does not include real estate, as that was contributed by the SFWMD. Construction contract and modification costs are listed in **Table 8-1.**

Several of these modifications merit further explanation. Modification P00008 ($50,264.843) was to install dolphin pilings and warning signs around the bollards and intake structure. During installation, it was clear that the bollard structure (known as "the shark cage") was a potential hazard to navigation.

Installation of pilings and signs reduced that risk. Modification P00011 ($37,416.25) extended the 16-inch discharge pipe further into the Kissimmee River. The years 2006-2007 were exceptionally dry, as shown by low river and lake levels. The discharge pipe was extended further from the cascade aerator to prevent erosion by discharge during low water levels. Modification P00014 ($189,677.76) was to satisfy a FDEP-UIC disinfection requirement. The existing 2-unit UV disinfection system did not result in 4-log inactivation of coliforms prior to recharge into the FAS. Therefore, FDEP required installation of 14-inch bypass piping to connect the filter effluent line (post-UV) to the 14-inch pipe that discharges to the backwash equalization pond. This bypass piping enabled further testing of the UV system without recharging through the ASR well into the UFA. This requirement delayed the commencement of cycle testing by approximately one year.

Table 8-1 -- KRASR Construction Contract and Modifications Costs				
Contract Item	**Contract/Mod. No.**	**Title/Purpose**	**Award Date**	**Amount**
Notice to Proceed	W912EP-06-C-0010	Construction contract	6/7/2006	$ 5,788,862.69
Modification	P00005	FP&L power line relocation, survey, ROW easement documentation to SFWMD	4/11/2007	$ 11,647.79
Modification	P00007	No-cost mod to extend time addl 45 days for FP&L relocation		$ -
Modification	P00008	Installation of dolphins and warning signs on bollard cage around intake	9/24/2007	$ 50,264.83
Modification	P00009	Additional chain link fence to enclose monitor well MW-10	9/24/2007	$ 3,823.20
Modification	P00010	Cost of additional discharge monitoring	9/29/2007	$ 12,098.00
Modification	P00011	Extension of 16" discharge pipe farther into Kissimmee River	9/29/2007	$ 37,416.25
Modification	P00012	Additional 30 days of maintenance and security	11/1/2007	$ 18,176.92
Modification	P00013	Topographic Survey	11/12/2007	$ 3,926.51
Modification	P00014	Construction of bypass around ASR well as per FDEP directive	7/12/2007	$ 189,677.76
Request for Equitable Adjustment	P00015	REA for additional performance testing of system after bypass construction		$ 22,359.84
		CONTRACT CONSTRUCTION COST		**$ 5,788,862.69**
		MODIFICATIONS COST		**$ 349,391.10**
		TOTAL COST		**$ 6,138,253.79**

8.1.4 ASR Well and Monitor Well Construction Costs

The KRASR system was constructed among several pre-existing wells: the ASR well (EXKR-1; CH2M Hill, 2004), OKH-100 (Intermediate Confining Unit well), OKS-100 (surficial aquifer well), and OKF-100 (now the dual-zone 1,100-ft SZMW). These wells were constructed by SFMWD, and no construction cost information is available for these wells. All other wells on-site were constructed by the USACE. Well construction costs include drilling, geophysical characterization of the borehole, casing and grouting, well development, pressure testing, completion of the wellhead, and water quality analyses as required by the UIC permit. Despite the existence of a SFWMD surficial aquifer well (OKS-100) already constructed, this well was located beyond the 150-ft radius required by the UIC permit. Therefore, a second surficial aquifer well (MW-17) was constructed. Well construction costs borne by USACE are shown in **Table 8-2**.

Table 8-2 -- Costs for USACE-Constructed Monitor Wells at KRASR				
WELL	**DESCRIPTION**	**COMPLETION DATE**	**REPORT REFERENCE**	**TOTAL COST**
OKF-100	Convert single-zone FAS well into dual-zone well, with upper (UFA) and Lower (APPZ) zones. Becomes 1,100-ft SZMW.	Nov-06	Golder Associates, 2006	$ 350,798.70
MW-10	Construct a new 350-ft SZMW in the UFA, as required by UIC permit	Aug-07	Golder Associates, 2007	$ 641,468.19
MW-17	New surficial aquifer well within FDEP-required radius from ASR well	Oct-07	Challenge Engineering and Testing, Inc., 2007	$ 14,685.00
MW-18	Construct a new 2,350-ft SZMW in the UFA	Jul-10	Entrix, 2010a	$ 373,104.90
MW-19	Construct a new 4,200-ft SZMW in the UFA	Jul-10	Entrix, 2010b	$ 361,114.50
TOTAL CONSTRUCTION COST FOR USACE MONITOR WELLS				**$1,741,171.29**

8.1.5 Integrating Well Construction and Surface Facility Construction

One of the reasons for choosing this site for ASR system construction was the existence of four wells constructed previously by SFWMD: EXKR-1, OKH-100, OKS-100, and OKF-100. When completed, EXKR-1 had a nominal 22-inch diameter borehole in the open interval, which was suitable for ASR well construction. Additional wells, some required by the UIC permit, were constructed by the USACE during 2006-2007 while the surface facility was under construction. Sometimes the site was occupied by multiple drill rigs, cranes, and flatbed trucks. Coordination among the field engineers and our contractors ensured that work could progress on all tasks simultaneously. Two additional monitor wells were constructed during operational testing (2010). No problems arose during this later episode of well construction.

ID	Task Name	Start	Finish
1	Notice to Proceed	Wed 6/7/06	Wed 6/7/06
2	Ground Breaking	Thu 6/29/06	Thu 6/29/06
3	Surface Facility Construction	Fri 7/7/06	Mon 11/26/07
4	Clearing and Grubbing	Tue 7/11/06	Fri 7/28/06
5	Grading	Fri 7/21/06	Mon 8/21/06
6	Raw Water Intake Construction	Mon 8/21/06	Tue 6/19/07
7	Cofferdam installation	Mon 8/21/06	Tue 10/3/06
8	Wet Well structure	Thu 10/5/06	Tue 2/6/07
9	Intake Piping	Fri 12/15/06	Thu 1/18/07
10	Bulkhead and Wing Walls	Fri 12/15/06	Mon 3/12/07
11	Grading for Fabriform Erosion protection	Tue 1/23/07	Tue 1/30/07
12	Bollard Structure assembly and installation	Tue 1/23/07	Mon 3/12/07
13	Intake "saddle" assembly and installation	Wed 2/7/07	Wed 3/14/07
14	Recharge Pump and Valves installation	Tue 5/1/07	Fri 6/15/07
15			
16	Cascade Aerator and Outflow Construction	Fri 12/15/06	Wed 3/7/07
17	Cascade Aerator	Fri 12/15/06	Fri 1/26/07
18	Inflow and Outflow piping	Fri 1/5/07	Fri 2/16/07
19			
20	Flow Equalization and Solids Settling Pond	Fri 1/5/07	Fri 4/20/07
21	Grading for Berms	Mon 1/15/07	Wed 3/7/07
22	Sump Earthworks	Tue 1/23/07	Tue 2/6/07
23	Transfer pump structure	Mon 1/15/07	Fri 4/20/07
24	Tramsfer pump and appurtanances	Mon 4/2/07	Fri 4/20/07
25			
26	Water Treatment Foundation Construction	Wed 1/3/07	Fri 5/25/07
27	ASR Well Pad and Plumbing appurtanances	Wed 1/3/07	Wed 2/21/07
28	Filter Pad and plumbing appurtanances	Wed 1/3/07	Wed 2/7/07
29	Electrical Building pad and conduit	Thu 2/1/07	Fri 3/30/07
30	Electrical Building Installed	Fri 3/30/07	Sat 4/7/07
31	Operations Building Pad	Mon 4/9/07	Wed 4/18/07
32	Ops Building Installed	Tue 5/1/07	Fri 5/25/07
33			
34	Erosion Control and Access Road	Thu 3/15/07	Mon 4/23/07
35	Fabriform installation	Thu 3/15/07	Thu 4/5/07
36	Grading for drainage swales	Wed 3/21/07	Fri 4/20/07
37	Access Road grading	Mon 4/2/07	Thu 4/19/07
38	Sodding berms	Mon 4/16/07	Fri 4/20/07
39			
40	Surface Facility Treatment Components Installation	Mon 4/30/07	Tue 6/26/07
41	Pressure filter installation, piping, and media placment	Mon 4/30/07	Fri 5/25/07
42	ASR well recovery pump and valves installation	Mon 6/11/07	Tue 7/17/07
43	UV Installation (2 units)	Mon 8/27/07	Tue 9/25/07
44			
45	Performance Testing	Mon 8/6/07	Mon 11/5/07
46	ASR pump test complete	Tue 8/7/07	Tue 8/7/07
47	UV Disinfection system	Mon 8/27/07	Mon 8/27/07
48	Pressure filter backwash system	Thu 9/27/07	Thu 9/27/07
49	Complete ASR system	Tue 10/2/07	Mon 10/15/07
50	Final Acceptance of the Surface Faciility	Mon 11/26/07	Mon 11/26/07

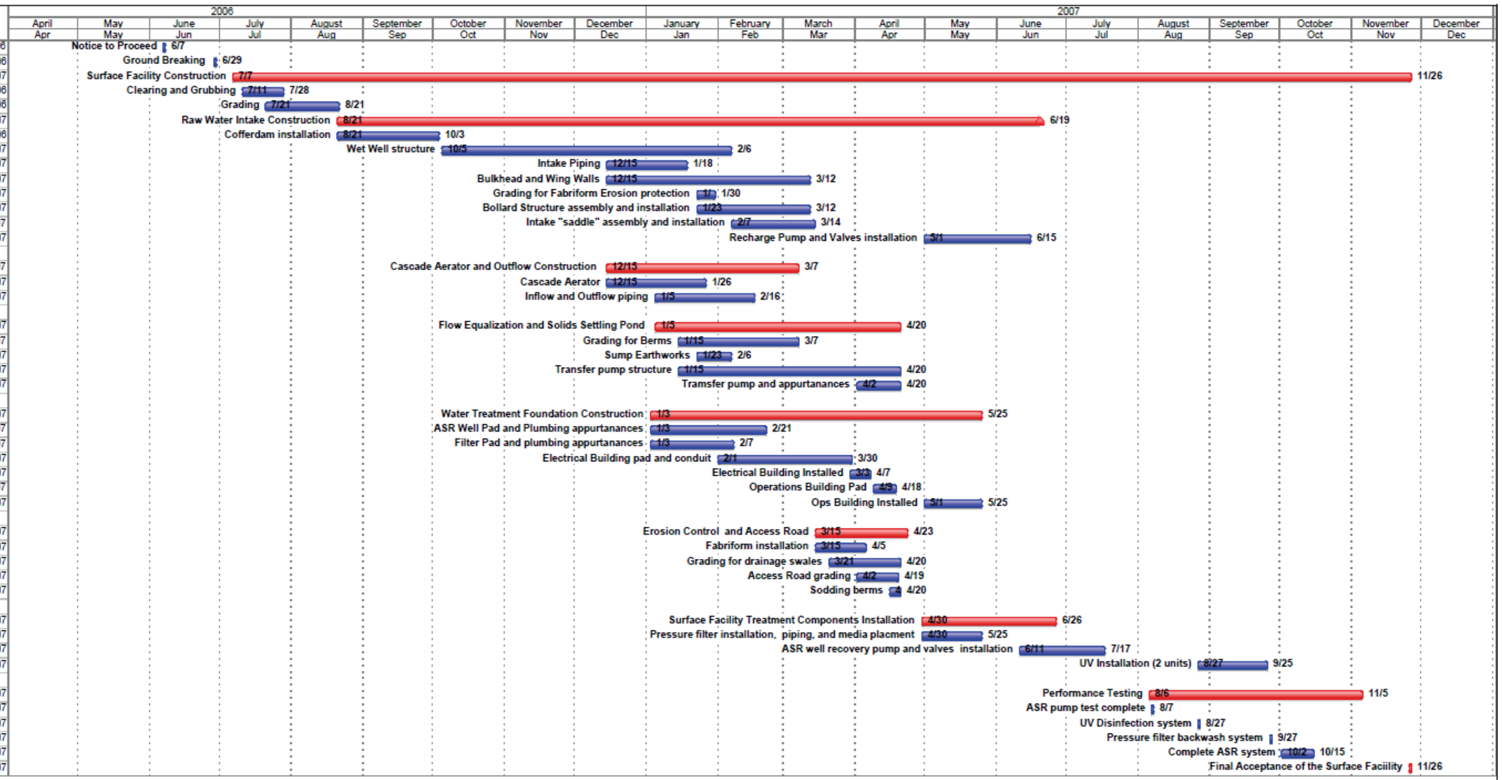

Figure 8-3 -- Gantt chart showing the sequence of major construction tasks at KRASR.

8.1.6 Engineering During Construction

The engineering during construction (EDC) phase tasks include modifications to the plans and specs, completion of detailed design reports, preparation of engineering considerations, instructions to field personnel, and submittal reviews. Other plans and reports include an embankment surveillance plan, and development of an operation and maintenance (O&M) manual (now completed; R2T, Inc., 2011). A few issues arose that required more detailed engineering input, and these are discussed below.

8.1.6.1 Evaluation of Bank Erosion and Erosion Control Measures

Erosion along swales that drain the site became apparent in late spring 2007 **(Figure 8-4)**. As part of a cumulative repair to control erosion of sands in along the toe of the embankment and also along the drainage swales, Harry Pepper Associates was retained after the site was accepted, to perform additional repair tasks. Work during 2008 extended the fabriform apron to the 8-ft NGVD29 elevation. The fabriform was also extended around along the base of the drainage swales, where surface runoff discharges into the Kissimmee River. Swales were partially filled with #57 stone for stability and to reduce runoff flow velocity. By October 2008, river levels rose to the range of design stage, the toe of the embankment became vegetated, a fence bounding the river was installed. The drainage swales became vegetated and stabilized. No piping was observed on the site foundation, and no further disruption of the fabriform apron has been observed throughout the project duration.

In August 2006, the Contractor submitted Request for Information (RFI) #0008 requesting clarification on the extent of the fabriform ("grout bag") apron that protects the Kissimmee River bank from erosion. In the plans, the fabriform apron was designed for a normal water elevation of 14 ft NGVD29, with low water at 10.7 ft and high water at about 18 ft. At this time, Kissimmee River and Lake Okeechobee water levels were approaching a historical low, at 8.79 ft NGVD29, exposing the toe of the fabriform apron. Subsequently, cavities appeared beneath the toe so there was a concern that piping could develop if significant erosion occurred beneath the apron. The remedy was to infill the eroded margin with silt, and vegetate the area **(Figure 8-5)**.

Figure 8-4 -- Embankment erosion control before (left) and after (right).

Figure 8-5 -- Erosion control along drainage swales, before (left) and after (right).

8.1.6.2 Disinfection Effectiveness and Coliform Inactivation – Endurance Testing

The initial phase of endurance testing was conducted from 3-10 October 2007. Endurance testing is conducted to show that the facility can be operated as designed, and that all components of the system are functional. The initial recharge flow rate was 5.1 MGD, the system design flow rate, but this resulted in wellhead pressure (80 psi) that exceeded the UIC permit criterion (66 psi). Therefore, the endurance test was conducted at a slower flow rate of 4 MGD.

UV performance problems were apparent early during the October 2007 endurance test. The performance problems included: 1) the inability to quantify the UV dose; 2) the inability to transfer UV performance data from the UV sensors to the SCADA system; and 3) incomplete activation (2-3 log reduction) of total coliforms. After these data were evaluated, more detailed endurance testing was conducted in December 2007 to optimize flow rate through the UV system so that total coliform inactivation would meet the construction contract performance specification of 4-log reduction. Flow rate reduction (4.0 MGD to 2.5 MGD) did not improve total coliform inactivation during the December 2007 tests. The USACE then elected to install an additional in-line UV disinfection unit, for a total of 3-units, to be completed during the summer 2008. USACE briefed the FDEP-UIC group on 10 January 2008 regarding the possibility of initiating cycle testing once the third UV unit was installed. The FDEP-UIC group indicated that this would not be satisfactory, and also required construction of a by-pass around the ASR well to the recovered water effluent pipe, so that the newly configured UV unit could be tested without recharging the FAS. Modification P00014 included plans and specs for all erosion control repairs, and construction of the 14-inch by-pass piping was awarded on 4 August 2008. The third UV unit was installed in October 2008, after our facility operators (R2T, Inc.) were under contract **(Figure 8-6)**.

The expanded 3-unit UV disinfection system was tested in November 2008 under different flow rates and UV power settings (USACE, 2008). Regulatory compliance (defined as total coliform concentrations less than 4 CFU/100 mL) as measured at the ASR wellhead during recharge) usually was achieved with 5.0 MGD flow rate and with all three UV units operating at medium or high power settings. The demonstration of complete inactivation of coliforms by the upgraded UV system was the final hurdle to be cleared for cycle testing to begin.

8.1.6.3 Endurance Testing of Other ASR System Components

Endurance tests are performed prior to USACE acceptance of a facility, to ensure that the facility operates as specified. Some individual components were tested prior to the full system performance test. The sequence of testing events was: 1) field testing of system components (vertical turbine pump performance test, pressure media filter, ultraviolet (UV) disinfection system test; 2) Phase I ASR system performance test; 3) Phase II ASR system performance test.

Figure 8-6 -- Completed by-pass piping (left), completion of 3-unit, in-line UV disinfection system (right).

Field testing of individual ASR system components was performed during July and August 2007. Vertical turbine pumps at the raw water intake and ASR wellhead pump performance were tested from 0830 to 1250, 7 August 2007. Previously, the ASR wellhead pump (FloWay vertical turbine pump, 150 HP) had been tested successfully in the factory on 3 May 2007, with EN-DM oversight. The vertical turbine pump performance tests were conducted at the ASR system to confirm performance after installation, and to ensure that there were no leaks, vibration, banging noises, or unusual heat generated during operation. For the raw water intake pump, surface water was pumped through the pressure filter through piping to the cascade aerator (no recharge). For the ASR wellhead pump, groundwater was pumped from the aquifer, through the ASR surface facility to the cascade aerator while flow and operational measurements were made. Flow rate could not be confirmed yet because the meter had not yet been calibrated. However, relative changes in flow rate were only partially accomplished using the in-line butterfly valve located between the pressure filter and the UV system. The performance tests were successful because there were no leaks, vibration, banging noises or unusual heat generated.

8.1.6.4 Electrical, SCADA, and Communications Issues

A few significant issues arose with the electrical system and SCADA system after construction was complete (July 2008) through completion of cycle test 1 (March 2009). During cycle test 1, there were frequent automatic system shut-downs initiated by poor performance of the UV system. Trouble-shooting by R2T, Inc. identified the cause of these system shut-downs resulting from an inadequate power supply to the UV units. The power supply to the UV disinfection system components extended from the electrical building to the UV system via buried 3-inch schedule 40 PVC conduit. Visual examination and testing of the cables revealed: 1) the cables were saturated inside the conduit; 2) the insulation on the cables (installed as designed) was 15-mil PVC; 3) megger testing on the cables (after drying) showed resistance on the cable greater than 1 ohm. The insulated cables became waterlogged resulting in high resistance measurements. The problem was solved by re-wiring the UV system to the electrical building through a series of overhead PVC-coated rigid conduits. This task was completed between cycle tests 1 and 2, for a total subcontracted cost of $15,727.00.

In addition to the UV power supply issue, during the early part of cycle testing, the SCADA system's capability to report alarms from remote locations was very limited. The integration requirements of the SCADA system were not fully specified. The major components of the system did not communicate effectively back to SCADA. This lack of information made it impossible to monitor several components of data necessary for the effective operation of the facility.

Adequate communication between the SCADA and the components to monitor the disinfection process and filtration was needed. A remote and secure internet access to the system was not available and the data backup and redundancy was nonexistent. R2T identified and implemented the following enhancements (R2T, Inc., 2011):

- Provided remote monitoring/control capabilities that are identical to what is available to operators on site.
- Improved integration of vendor provided programmable logic controller (PLCs) and streamlined local and remote capabilities.
- Provided redundant data storage on site to improve system reliability

Below is a list of items which were added or modified on the Instrumentation and Control (I&C) system to improve functionality, communication and versatility:

Instrumentation Calibration

- Integrated the Tonka Filter control panel PLC with SCADA through a category 5 (Ethernet) data connection. Filter operation status, backwash conditions and alarms are displayed. The monitoring of this system was initially not available except for a general alarm condition.
- Integrated Aquionics UV control panel with SCADA through a Modbus serial connection so that the UV system status, lamp condition, faults, lamp hours, intensity, dosage, temperature and power level can be viewed. The units can be turned on/off, alarms can be reset, the transmittance of water can be entered remotely so the dosage calculations become corrected, and power level can be modified.

Hardware Upgrades

- Installed Allan Bradley 13 slot rack for the addition of an analog input module and Modbus serial communication module. This allowed for complete interface of the plant PLC with the Tonka Filter and Aquionics UV system.
- Installed a Fiber Optic Network Solution (FONS; Marlborough, MA) fiber termination box and re-terminated all fiber connections to improve system integrity.

- Installed Virtual Private Network (VPN) Router for remote client login capability.
- Replaced DRUCK (General Electric) pressure sensor with a 300 psi sensor in lieu of a 150 psi sensor. This would allow greater drawdown during recovery and higher pressures during recharge without having to relocate the depth of insertion of the probe to keep pressures within range.

Software Upgrades/Reprogramming

- Set up the remote login and access required software. This allows for secure remote access and control of the SCADA system through a Digital Subscriber Line (DSL) connection. Software installed were:

    a. Netgear FVS338 Prosafe VPN Firewall 50
    b. Prosafe VPN Client Software – 5 users
    c. Win911 Software with Universal Serial Bus (USB) Modem – This software allows for call out of alarm conditions by SCADA to designated phone numbers. The user can access and reset alarms and be made aware of any faulty condition.

- Installed Wonderware Developer and Historian Software on the main computer and on a backup desktop and laptop computer for increased redundancy. These systems can operate and log data independently of each other in the case of the main historian computer failure. Each system is accessible remotely through the VPN as well.
- Revised I&C and electrical drawings to reflect modifications.

8.1.6.5 Lessons Learned During Construction

The design and constructing process for the KRASR system differs somewhat from that of a permanent water control structure because the facility has a short, finite period of operational testing. The facility is fully functional for the intended testing period, and in fact has successfully performed longer (4 cycle tests, 4.5 years) than the original 2-year duration. All construction issues were resolved at extra cost by refining the design and the plans and specs. The most difficult problems that were encountered during the construction phase are:

- Stabilizing the facility foundation and intake structure. This problem was resolved by extending the fabriform apron to a lower elevation in the river, and extending the apron and fill into surface runoff drainage swales.
- Rewiring the UV system above ground. Electrical cables were no longer saturated, and UV performance improved.
- UV disinfection system performance for total coliform inactivation. A more robust UV disinfection system is necessary.

- Revising the SCADA code and modifying the instruments and control system to improve functionality and communication. This system was improved through instrument calibration, hardware upgrades, software upgrades and system reprogramming.
- A stronger butterfly valve is needed for adequate flow control between the pressure filter and the UV disinfection system.
- Retaining the design engineer of record would be helpful during the construction and endurance testing phases.

8.2 Hillsboro ASR Pilot System

8.2.1 Procurement

Bids to construct the surface facilities at the Hillsboro ASR Pilot Project were opened on May 23, 2005. Harry Pepper Associates, Inc. was the apparent low bidder. The low bidder, however, was found to be non-responsible and the construction contract is awarded to GlobeTec Construction, LLC. On July 15, 2005, Harry Pepper Associates, Inc. filed a bid protest. The bid protest was ultimately retracted on September 20, 2005. The Notice to Proceed (NTP) was given to GlobeTec on December 5, 2005 to start construction. This contract was for construction of all surface water treatment and conveyance features. The ASR well and the monitor wells were constructed under separate contracts.

8.2.2 Surface Facility Construction Sequence and Duration

NTP with construction was given on December 5, 2005. The site was cleared, grubbed, and surveyed shortly after the notice was given. On January 9, 2006, the contractor applied for a building permit with Palm Beach County. The County's zoning department delayed issuing the building permit until zoning issues could be resolved. Given the delays in issuance of the building permit, the SFWMD suspended the construction contract on February 10, 2006. The SFWMD reactivated the contract on June 7, 2006 after negotiations with Palm Beach County. Construction of the surface facilities continued through 2006 and 2007, with some delays as a result of Florida Power & Light providing electrical service to the site. Construction ended in 2008 with the installation of the electrical and control components for the site.

8.2.3 Surface Facility Construction Cost

The construction contract for the surface facilities was awarded for $2,240,000. Major components of the surface facilities contract included installation of the intake/discharge structure, filters, UV disinfection units, pumps, piping, valves, and electrical controls. This contract for the surface facilities did not include operational testing of the system, contract modifications, or construction of any wells. Minor change orders to the contract for modifications to the ASR well drop pipe and installation of a flow-control valve resulted in a final construction cost of $2,277,598.30 for the surface facilities. The ASR well and associated monitor wells were constructed under a separate contract. A detailed cost breakdown for the HASR system is shown in **Table 8-3.**

Table 8-3 -- Detailed Construction Cost Breakdown for HASR

CONTRACT TITLE: *HILLSBORO ASR PILOT PROJECT, PALM BEACH COUNTY, FLORIDA*
CONTRACT NUMBER: CN050254
CONTRACTOR: GlobeTec Construction, LLC
STREET ADDRESS: 4774 North Power Line Road
INVOICE DATE: November 30, 2007

ITEM NO.	DESCRIPTION	EST QTY	UNIT	UNIT PRICE ($)	BID AMOUNT ($)	ITEM NO.	DESCRIPTION	EST QTY	UNIT	UNIT PRICE ($)	BID AMOUNT ($)
A	**GENERAL CONDITIONS**					D	**PROCESS SLAB, *continued***				
1	Mobilization	1	LS	2,000.00	2,000.00	81	Miscel. Control Appurtances	1	LS	5,100.00	5,100.00
2	Insurances	1	LS	19,020.00	19,020.00	82	(Mat.) Miscel. Control Appurta	1	LS	5,600.00	5,600.00
3	Bond	1	LS	22,000.00	22,000.00	83	Underslab Utilities	1	LS	7,000.00	7,000.00
4	Site Survey	1	LS	4,000.00	4,000.00	84	(Mat.) Underslab Utilities	1	LS	9,000.00	9,000.00
5	Site Safety (10 Mo.)	1	LS	5,000.00	5,000.00	85	Sta 4+ 37 Slab (Form)	1	LS	2,524.00	2,524.00
6	Photographs (10 Mo.)	1	LS	2,000.00	2,000.00	86	(Mat.) Sta 4+ 37 Slab (Form)	1	LS	1,200.00	1,200.00
7	Demobilization	1	LS	2,000.00	2,000.00	87	Sta 4+ 37 Slab (Rein.)	1	LS	2,100.00	2,100.00
	Subtotals A				56,020.00	88	(Mat.) Sta 4+ 37 Slab (Rein.)	1	LS	2,000.00	2,000.00
B	**SITE WORK**					89	Sta 4+ 37 Slab (Place)	1	LS	2,108.00	2,108.00
8	Clear & Grub	1	LS	16,200.00	16,200.00	90	(Mat.) Sta 4+ 37 Slab (Place)	1	LS	3,105.00	3,105.00
9	(Mat.) Clear & Grub	1	LS	200.00	200.00	91	Sta 3+ 40 Slab (Form)	1	LS	1,170.00	1,170.00
10	Environmental Controls	1	LS	900.00	900.00	92	(Mat.) Sta 3+ 40 Slab (Form)	1	LS	600.00	600.00
11	(Mat.) Environmental Controls	1	LS	900.00	900.00	93	Sta 3+ 40 Slab (Rein.)	1	LS	600.00	600.00
12	Cofferdam Installation	1	LS	40,500.00	40,500.00	94	(Mat.) Sta 3+ 40 Slab (Rein.)	1	LS	1,600.00	1,600.00
13	(Mat.) Cofferdam Installation	1	LS	3,600.00	3,600.00	95	Sta 3+ 40 Slab (Place)	1	LS	1,800.00	1,800.00
14	Cofferdam Excavation	1	LS	27,420.00	27,420.00	96	(Mat.) Sta 3+ 40 Slab (Place)	1	LS	1,124.00	1,124.00
15	(Mat.) Cofferdam Excavation	1	LS	200.00	200.00	97	Concrete & Pipe Pedestals	1	LS	13,688.00	13,688.00
16	Cofferdam Rental (2 Mo.)	1	LS	5,000.00	5,000.00	98	(Mat.) Concrete & Pipe Pedes	1	LS	3,300.00	3,300.00
17	Dewatering (1Mo.)	1	LS	6,200.00	6,200.00	99	System(s) Testing & Start Up	1	LS	1,400.00	1,400.00
18	(Mat.) Dewatering	1	LS	4,000.00	4,000.00	100	(Mat.) System(s) Testing & St	1	LS	500.00	500.00
19	Cofferdam Backfill	1	LS	6,570.00	6,570.00		*Subtotals D*				841,466.00
20	(Mat.) Cofferdam Backfill	1	LS	200.00	200.00	E	**FILTER SLAB**				
21	UG DIP to Process	1	LS	7,400.00	7,400.00	101	Slab Prep	1	LS	6,910.00	6,910.00
22	(Mat.) UG DIP to Process	1	LS	5,200.00	5,200.00	102	(Mat.) Slab Prep	1	LS	300.00	300.00
23	UG DIP to Quarry	1	LS	10,300.00	10,300.00	103	Underslab Utilities	1	LS	4,450.00	4,450.00
24	(Mat.) UG DIP to Quarry	1	LS	8,800.00	8,800.00	104	(Mat.) Underslab Utilities	1	LS	4,000.00	4,000.00
25	UG Elec. Load Side	1	LS	6,100.00	6,100.00	105	Slab (Form)	1	LS	1,400.00	1,400.00
26	(Mat.) UG Elec. Load Side Mat	1	LS	11,000.00	11,000.00	106	(Mat.) Slab (Form)	1	LS	600.00	600.00
27	Water System	1	LS	4,000.00	4,000.00	107	Slab (Rein.)	1	LS	1,000.00	1,000.00
28	(Mat.) Water System	1	LS	6,000.00	6,000.00	108	(Mat.) Slab (Rein.)	1	LS	1,870.00	1,870.00
29	Final Site Restore	1	LS	7,000.00	7,000.00	109	Slab (Place)	1	LS	1,900.00	1,900.00
30	(Mat.) Final Site Restore	1	LS	2,900.00	2,900.00	110	(Mat.) Slab (Place)	1	LS	1,725.00	1,725.00
31	Fence & Gate	1	LS	4,000.00	4,000.00	111	Filter System	1	LS	11,140.00	11,140.00
32	(Mat.) Fence & Gate	1	LS	5,000.00	5,000.00	112	(Mat.) Filter System	1	LS	392,045.00	392,045.00
	Subtotals B				189,590.00	113	DIP & Fittings	1	LS	18,880.00	18,880.00
C	**AKE & DISCHARGE STRUCTURE**					114	(Mat.) DIP & Fittings	1	LS	85,000.00	85,000.00
33	Precast Structure	1	LS	26,620.00	26,620.00	115	BFValve	1	LS	900.00	900.00
34	(Mat.) Precast Structure	1	LS	21,000.00	21,000.00	116	(Mat.) BFValve	1	LS	1,400.00	1,400.00
35	Miscellaneous Metals	1	LS	2,500.00	2,500.00	117	Turbidity Meters	1	LS	1,000.00	1,000.00
36	(Mat.) Miscellaneous Metals	1	LS	22,000.00	22,000.00	118	(Mat.) Turbidity Meters	1	LS	4,000.00	4,000.00
37	DIP	1	LS	6,000.00	6,000.00	119	System(s) Testing & Start Up	1	LS	1,400.00	1,400.00
38	(Mat.) DIP	1	LS	7,000.00	7,000.00	120	(Mat.) System(s) Testing & St	1	LS	500.00	500.00
39	Screen Equipment	1	LS	2,140.00	2,140.00		*Subtotals D*				540,420.00
40	(Mat.) Screen Equipment	1	LS	39,000.00	39,000.00	F	**ECTRICAL CONTROL BUILDING**				
41	Lower Level Slab (Form)	1	LS	760.00	760.00	121	Slab Prep	1	LS	3,000.00	3,000.00
42	(Mat.) Lower Level Slab (Form	1	LS	100.00	100.00	122	(Mat.) Slab Prep	1	LS	300.00	300.00
43	Lower Level Slab (Rein.)	1	LS	375.00	375.00	123	Underslab Utilities	1	LS	7,000.00	7,000.00
44	(Mat.) Lower Level Slab (Rein.	1	LS	150.00	150.00	124	(Mat.) Underslab Utilities	1	LS	18,750.00	18,750.00
45	Lower Level Slab (Place)	1	LS	1,080.00	1,080.00	125	Precast Bldg.	1	LS	1,800.00	1,800.00
46	(Mat.) Lower Level Slab (Place	1	LS	200.00	200.00	126	(Mat.) Precast Bldg.	1	LS	43,884.00	43,884.00
47	Gates(2)	1	LS	2,560.00	2,560.00	127	Floor Slab	1	LS	1,700.00	1,700.00
48	(Mat.) Gates(2)	1	LS	28,500.00	28,500.00	128	(Mat.) Floor Slab	1	LS	900.00	900.00
49	Pump (1- 150 Hp)	1	LS	2,560.00	2,560.00	129	MCC	1	LS	1,650.00	1,650.00
50	(Mat.) Pump (1- 150 Hp)	1	LS	25,000.00	25,000.00	130	(Mat.) MCC	1	LS	15,000.00	15,000.00
51	Coatings	1	LS	2,500.00	2,500.00	131	Elec. Panels / Transformer	1	LS	2,800.00	2,800.00
52	(Mat.) Coatings	1	LS	4,260.00	4,260.00	132	(Mat.) Elec. Panels / Transfor	1	LS	6,000.00	6,000.00
53	Tremie	1	LS	3,300.00	3,300.00	133	(Mat.) Systems Control Panel	1	LS	4,200.00	4,200.00
54	(Mat.) Tremie	1	LS	7,575.00	7,575.00	134	Systems Control Panel(s)	1	LS	800.00	800.00
55	Dissolved Oxygen System	1	LS	1,000.00	1,000.00	135	RTU & Antenna	1	LS	4,500.00	4,500.00
56	(Mat.) Dissolved Oxygen Syste	1	LS	5,000.00	5,000.00	136	(Mat.) RTU & Antenna	1	LS	29,000.00	29,000.00
57	Stilling Well	1	LS	2,000.00	2,000.00	137	Interior Lighting & Finishes	1	LS	2,200.00	2,200.00
58	(Mat.) Stilling Well	1	LS	1,000.00	1,000.00	138	(Mat.) Interior Lighting & Finis	1	LS	2,000.00	2,000.00
	Subtotals C				214,180.00		*Subtotals F*				145,484.00
D	**PROCESS SLAB**					G	**PERSONNEL BUILDING**				
59	ASR Well Pump	1	LS	7,300.00	7,300.00	139	Slab Prep	1	LS	15,610.00	15,610.00
60	(Mat.) ASR Well Pump	1	LS	52,000.00	52,000.00	140	(Mat.) Slab Prep	1	LS	6,300.00	6,300.00
61	UV System	1	LS	3,000.00	3,000.00	140	Foundation	1	LS	9,200.00	9,200.00
62	(Mat.) UV System	1	LS	414,000.00	414,000.00	141	(Mat.) Foundation	1	LS	13,900.00	13,900.00
63	Flow Meter	1	LS	1,000.00	1,000.00	142	Underslab Utilities	1	LS	4,000.00	4,000.00
64	(Mat.) Flow Meter	1	LS	24,000.00	24,000.00	143	(Mat.) Underslab Utilities	1	LS	2,000.00	2,000.00
65	Mechanical Specialties	1	LS	1,000.00	1,000.00	144	PreFab Bldg.	1	LS	19,800.00	19,800.00
66	(Mat.) Mechanical Specialties	1	LS	6,825.00	6,825.00	145	(Mat.) PreFab Bldg.	1	LS	111,000.00	111,000.00
67	BFValve (Solenoid Pneumatic	1	LS	4,500.00	4,500.00	146	Interior Build Out	1	LS	3,900.00	3,900.00
68	(Mat.) BFValve (Solenoid Pneu	1	LS	12,864.00	12,864.00	147	(Mat.) Interior Build Out	1	LS	3,880.00	3,880.00
69	BFValve (Pneumatic)	1	LS	2,300.00	2,300.00	148	Interior Lighting & Finishes	1	LS	1,800.00	1,800.00
70	(Mat.) BFValve (Pneumatic 3,	1	LS	25,728.00	25,728.00	149	(Mat.) Interior Lighting & Finis	1	LS	2,000.00	2,000.00
71	BFValve	1	LS	1,700.00	1,700.00	150	Lighting Protection & Groundi	1	LS	1,850.00	1,850.00
72	(Mat.) BFValve (8 & 9)	1	LS	3,000.00	3,000.00	151	(Mat.) Lighting Protection & G	1	LS	2,800.00	2,800.00
73	DIP & Fittings	1	LS	28,980.00	28,980.00	152	Exterior Lighting & Finishes	1	LS	700.00	700.00
74	(Mat.) DIP & Fittings / Eductor	1	LS	151,000.00	151,000.00	153	(Mat.) Exterior Lighting & Finis	1	LS	800.00	800.00
75	Check Valve	1	LS	2,000.00	2,000.00	154	Holding Tank	1	LS	1,300.00	1,300.00
76	(Mat.) Check Valve	1	LS	13,650.00	13,650.00	155	(Mat.) Holding Tank	1	LS	2,000.00	2,000.00
77	Conductivity Meters	1	LS	1,000.00	1,000.00		*Subtotals G*				202,840.00
78	(Mat.) Conductivity Meters	1	LS	4,000.00	4,000.00		**TOTALS**				2,190,000.00
79	Slab Prep	1	LS	15,400.00	15,400.00						
80	(Mat.) Slab Prep	1	LS	700.00	700.00	1	Allowance Account For FPL	1	LS	50,000.00	50,000.00
							TOTAL CONTRACT AMOUNT				**2,240,000.00**

8.2.4 ASR Well and Monitor Well Construction Cost

Each of the wells at the Hillsboro ASR Pilot Project was constructed under SFWMD contracts. The ASR well and two Floridan Aquifer SZMWs were constructed by the SFWMD prior to the surface facility under separate contracts. The Floridan Aquifer SZMWs, which include the dual-zone SZMW (PBF-11/PBF-12) and the single-zone 330-ft SZMW (PBF-10R), were constructed in 1999 under a single contract for a total cost of approximately $650,000. That contract included a change order to construct a large-diameter exploratory well (the ASR well). Construction of the exploratory ASR well was completed in 2000 for a cost of approximately $980,000. The construction cost for the remaining 1,010-ft SZMW (PBF-14), was $ 430,000. Lastly, a surficial aquifer monitor well (PBS-11) was constructed for $ 21,000.

8.2.5 Lessons Learned During HASR Construction

The Hillsboro ASR Pilot Project was designed and constructed to answer questions related to the potential role of ASR technology as part of the CERP. The design, construction, and operation of the two ASR pilot projects (Kissimmee River and Hillsboro) differed in some ways to test a variety of methods. In general, the KRASR system was designed and constructed with greater operational controls. The HASR system, in contrast, was designed and constructed with the intent of needing less operational oversight and control.

Some of the lessons learned during construction are:

- It would be preferable to have less time between the construction of the ASR well and the surface facilities.
- It is recommended to do a thorough evaluation of potential local permitting issues, such as zoning issues and building permits.
- Reconsider the installation of a “permanent” onsite personnel building, especially if water/wastewater issues for that building are a concern.
- Fully evaluate the purpose and flexibility of any filtration system. Fine-mesh filters were originally installed, only to create operational issues due to clogging.
- Installation of three ultraviolet disinfection units should be specified for highly colored source waters.
- A valve dedicated to regulating water flow to and from the ASR well is recommended. The isolation-type valves, which were in the original design, were not adequate in efficiently controlling the flow.
- Special attention should be paid to the in-line water quality monitors such as those for specific conductance and dissolved oxygen. The reliability of those monitors proved to be suspect.
- Better coordination is needed when installing the instrumentation and controls and its connection with the SCADA system.

9. Water Quality Changes During Cycle Testing at CERP ASR Pilot Systems

9.1 Cycle Testing Objectives

Cycle testing is the permitted process through which ASR system performance is evaluated. A cycle test consists of three phases: recharge of treated surface water; storage of surface water in subsurface permeable zones (or aquifers); and recovery of stored water back to the surface for subsequent distribution.

Cycle tests are conducted as part of a permitted operational testing plan consistent with the Underground Injection Control (UIC) regulations of the Safe Drinking Water Act (SDWA). In Florida, existing municipal ASR systems typically are smaller (1 MGD capacity) than either the Kissimmee River ASR (KRASR) or Hillsboro ASR (HASR) systems. These municipal ASR systems typically are connected to potable water treatment plants for drinking water supply. Increasing use is made of reclaimed water for ASR recharge, particularly along the Gulf Coast counties. At reclaimed ASR systems, highly treated wastewater is stored in brackish to saline aquifers (often greater than 10,000 mg/L TDS), then recovered for irrigation water supply. The original CERP ASR cycle test protocols are based on observations from smaller systems at drinking water treatment plants. Knowledge gained from cycle tests at KRASR and HASR have produced results that are appropriate for other larger, non-CERP ASR systems.

Initially, there were several ASR cycle test protocols that are common to both CERP ASR systems. Both systems conducted short “shake-down” tests to ensure that each facility operated as designed. Both ASR systems had identical cycle test durations for cycle test 1, which consisted of one-month recharge, one-month storage, and approximately one-month recovery. After completion of cycle test 1, the protocols differed between KRASR and HASR. Interpretation of early results, and also the availability of funds, enabled additional cycle tests to be conducted at both facilities in order to refine ASR performance for CERP operations.

Goals and objectives of the two Lake Okeechobee ASR pilot projects were defined in USACE (2004). Briefly, the goals of the Lake Okeechobee ASR pilot projects are: 1) to demonstrate ASR feasibility at two locations having different surface water quality characteristics, hydrogeologic conditions, and surface water distribution configurations; and 2) to reduce technical and regulatory uncertainties associated with ASR system operation. The extent to which each ASR system has achieved project objectives will be discussed in the following sections. Specific objectives of each ASR pilot project are summarized in **Table 9-1.**

Table 9-1-- CERP ASR Pilot Project Objectives		
PROJECT OBJECTIVES	**Kissimmee River ASR Pilot System**	**Hillsboro ASR Pilot System**
1. Evaluate the ability to construct and operate an ASR facility with a target capacity of 5 million gallons of water per day and determine a range of feasible recharge and recovery capacities	✓	✓
2. Identify and initiate evaluation of relevant geochemical and ambient groundwater quality changes during ASR cycle testing	✓	✓
3. Identify an appropriate treatment facility for recharge and recovered water. Determine lifecycle costs	✓	✓
4. Evaluate the inter-relationships of recharge and recovery rates, storage volumes and recoverability	✓	✓
5. In coordination with the ASR Regional Study, evaluate the effect of ASR on the affected ecosystem	✓	✓
6. Evaluate the extent of pressure changes and the cone of influence during recharge and recovery operations	✓	✓
7. Identify and evaluate the effects of ASR on existing Floridan Aquifer users	✓	✓
8. Design, construct, and test a three-well cluster to assist in future, large-scale ASR system design involving optimum well spacing, evaluating pressure effects, etc.		
9. Evaluate ASR system performance from a geographic perspective around Lake Okeechobee	✓	
10. Operate project in accordance with Adaptive Management guidance developed by RECOVER for CERP	✓	✓

9.2 Kissimmee River ASR Pilot System

9.2.1 Water Quality Monitoring Programs

The Kissimmee River is classified as a State of Florida Class III surface water, with designated uses that include fish consumption, recreation, and propagation and maintenance of a healthy, well-balanced population of fish and wildlife. The Floridan Aquifer is classified as an underground source of drinking water (USDW), characterized by TDS less than 10,000 mg/L. Therefore, any ASR cycle testing program must be in compliance with State and Federal regulations that protect both surface and groundwater quality. Surface water quality criteria and regulations for discharge of recovered water into the

Kissimmee River are defined within the National Pollution Discharge Elimination System (NPDES) of the Clean Water Act (CWA), and the F.A.C. 62-302.530 (State of Florida Surface Water Quality Criteria). Ground water quality criteria are defined within the Underground Injection Control (UIC) program of the Safe Drinking Water (SDWA), by F.A.C. 62-528 (Underground Injection Control), and F.A.C. 62-550 (Drinking Water Standards, Monitoring and Reporting). Surface water (recharge water) and native groundwater are characterized prior to the onset of cycle testing so that water quality changes in groundwater or recovered water can be identified.

9.2.1.1 Recharge Water Quality

The Kissimmee River is the source of recharge water to the KRASR system. Land use in the lower Kissimmee River watershed is primarily agriculture and pasture (51.2 percent), rangeland (15.8 percent) and wetlands (22 percent), with the remainder consisting of forested upland, open water, built environment, and barren land (FDEP, 2006). Sections of the lower Kissimmee River basin have been identified as impaired, primarily due to eutrophic conditions characterized by elevated nutrient and chlorophyll *a* concentrations (FDEP, 2012). The section of the Kissimmee River adjacent to KRASR also is designated as an impaired surface water body due to elevated mercury concentrations in fish tissue (FDEP, 2012)

Recharge water quality characterization is important because these waters exert a major control on reactions between water and rock in the Floridan Aquifer during an ASR cycle test. At KRASR, water quality is characterized using ASR wellhead samples obtained during the recharge phase of cycle tests 1 through 4. Cycle test 1 had the shortest duration (4 weeks, 4 sampling events), but analyses were extensive and included many trace elements, and stable and radioactive isotopes. A few analyses of Kissimmee River surface water samples (N=7; quarterly sampling during 2002; USACE, 2005; Golder 2009) also are included in the dataset. Generally, samples were analyzed for primary and secondary inorganic and organic constituents, and microorganisms required for SDWA compliance. Additional analytes (primarily nutrients and metals) were added to the analytical protocol for geochemical modeling and interpretation.

Considering major and trace inorganic constituents, recharge water at KRASR is oxic, and has neutral pH, low carbonate alkalinity, low total dissolved solids (TDS), and concentrations of most inorganic constituents. Recharge water shows relatively high concentrations of total and dissolved organic carbon, iron, and color. A descriptive statistical compilation of major and trace inorganic constituent concentrations, and field parameters is shown in **Table 9-2.**

Table 9-2 -- Major and Trace Inorganic Constituents in Recharge Water from the Kissimmee River, Baseline (2002) and Cycle Tests 1 through 4 (2009-2012)

Constituent or Parameter	Unit	Criteria	Value					
			Mean	Std Dev	Median	Maximum	Minimum	N
Temperature	º C		25.5	5.8	28.3	31.6	15.4	56
Specific Conductance	µS/cm	1275	223	50	204	365	97	61
pH	Std	6 to 8	6.7	0.6	6.7	9.6	5.6	61
ORP	mV		132	58	123	333	38	56
Dissolved Oxygen	mg/L	> 5.0	4.4	2.4	4.1	8.8	0.8	61
Turbidity	NTU	< 29	2.2	1.1	2.1	5	0.8	61
Total dissolved solids	mg/L		208	321	150	2,000	52	59
Total suspended solids	mg/L		5.1	0.3	5	6.5	< 5.0	34
Color	PCU		122	138	90	900	20	57
Hardness	mg/L		82	33	65	170	51	12
Calcium	mg/L		19	4.7	14.5	30	13	56
Magnesium	mg/L		6.9	11.9	4.7	84	3.3	56
Sodium	mg/L		16	3.8	14.5	29	11	58
Potassium	mg/L		4.0	0.7	4.1	6.1	2.6	56
Sulfate	mg/L		16	7.3	14.5	43	0.6	58
Sulfide	mg/L		0.1	0.3	0.01	1	< 0.01	52
Bromide	mg/L		0.083	0.019	0.089	0.100	0.048	6
Chloride	mg/L		30.6	8	28	59	19	59
Fluoride	mg/L	< 10	0.1	0.025	0.10	0.16	0.07	9
Silica	mg/L		1.2	0.2	1.2	1.9	0.9	4
Tot Alkalinity as $CaCO_3$	mg/L	> 20	48	45	37.5	370	28	58
Total Cyanide	mg/L	< 0.0052	<0.005	0.001	< 0.005	< 0.005	< 0.0025	5
Diss. Organic Carbon	mg/L		15.7	1.6	16	18	12	19
Total Organic Carbon	mg/L		17.4	2.9	17	27	15	20
Aluminum	µg/L		91	29	89	150	42	12
Antimony	µg/L	< 4,300	0.21	0.13	0.17	0.4	0.09	7
Arsenic	µg/L	< 50	1.0	0.7	0.84	4.0	< 0.37	59
Barium	µg/L		18.5	3	19.5	23	14	10
Beryllium	µg/L	< 0.13	--	--	--	< 0.05	--	1
Boron	µg/L		38	3	39	40	34	4
Cadmium	µg/L	< 0.23	<0.7			< 1	< 0.02	7
Chromium	µg/L	< 73	1.0	0.7	0.9	2.3	0.3	7
Cobalt	µg/L		0.14	0.01	0.14	0.15	0.12	4
Copper	µg/L	< 7.9	0.98	0.48	0.80	1.7	0.42	6
Iron	µg/L		256	141	245	1000	59	54
Lead	µg/L	< 2.5	0.29	0.09	0.26	0.44	0.19	5
Manganese	µg/L		5.3	3.6	4.2	17	1.4	51
Mercury (Ultrace)	ng/L	12	2.01	0.91	1.8	5.65	0.99	61
Methyl Mercury	ng/L		0.35	0.51	0.23	3.02	0.02	61
Molybdenum	µg/L		4.0	10.8	1.2	40.0	0.5	13
Nickel	µg/L	44.2	0.74	0.36	0.79	1.2	0.2	5
Selenium	µg/L	< 5.0	0.94	0.28	0.89	1.4	0.58	7
Silver	µg/L	< 0.07	--	--	--	< 0.50	< 0.01	6
Strontium	µg/L		367	137	400	580	150	9
Thallium	µg/L	< 6.3	--	--	--	< 0.50	< 0.10	5
Uranium	µg/L		0.26	0.09	0.3	0.33	0.11	6
Vanadium	µg/L		--	--	--	< 0.20	--	4
Zinc	µg/L	< 101	44.7	61.6	16.8	190	3.7	10

Note: Most samples were collected at the ASR wellhead (EXKR-1) after filtration and UV disinfection, during recharge of cycle tests 1 through 4. Five surface water samples from the Kissimmee River (USACE, 2005) near the site are included for completeness for some constituents. Concentrations reported as "<" are below the method detection limit. N, no. of samples. ORP, oxidation-reduction potential. Units: mg/L, milligram per liter; µg/L, microgram per liter; ng/L, nanograms per liter; pCi/L, picocuries per liter; º C, degrees Celsius; µS/cm, microsiemens per cm; PCU, platinum cobalt units; NTU, nephelometric turbidity units; mV, millivolts. Surface Water Quality Criteria are from Florida F.A.C. 62-302.530. Cadmium, chromium, copper, lead, and zinc are site-specific standards calculated for a hardness concentration of 82 mg/L. Primary and secondary inorganic criteria of the SDWA also are listed.

The Kissimmee River flows through an agricultural landscape, so agricultural chemicals (herbicides, pesticides, nematicides) and other industrial compounds (volatile organic compounds, semi-volatile organic compounds) are a potential concern for recharge water quality. Primary and secondary organic constituents were analyzed in surface water samples (N=5) prior to cycle testing (2002; reported in Tetra-Tech, 2005). A single ASR wellhead sample also was analyzed (2011) during cycle 3 recharge for primary and secondary organic constituents. Primary and secondary organic constituents analyzed in 2002 and 2011 are shown in **Table 9-3.**

Table 9-3 -- Primary and Secondary Organic Constituents Analyzed in Recharge Water from the Kissimmee River (2002, 2011)

Volatile Organic Compounds		
1,2-Dibromoethane	Chlorobenzene	Styrene
1,2-Dichlorobenzene	Chloroform	Tetrachloroethene
1,2-Dichloroethane	Chloromethane	Toluene
1,2-Dichloropropane	cis-1,2-Dichloroethene	trans-1,2-Dichloroethene
1,4-Dichlorobenzene	Dibromochloromethane	Trichloroethene
Benzene	Dichlorodifluoromethane	Trichlorofluoromethane
Bromodichloromethane	Ethylbenzene	Trihalomethanes
Bromoform	Freon 113	Vinyl Chloride
Carbon tetrachloride	Methylene chloride	Xylenes (total)
Semi-Volatile Organic Compounds		
2,4,6-Trichlorophenol	Benzo(a)pyrene	Pentachlorophenol
2,4-Dichlorophenol	bis(2-Ethylhexyl)phthalate	Phenol
2,4-Dinitrophenol	Fluoranthene	Pyrene
2,4-Dinitrotoluene	Fluorene	Total carc-PAHs
2-Chlorophenol	Hexachlorobenzene	Total PAHs
Acenaphthene	Hexachlorobutadiene	Total Phathalate esters
Anthracene	Hexachlorocyclopentadiene	Total Phenolics

Pesticides				
4,4'-DDT	Chlordane	Endothall	Malathion	
Alachlor	Deethylatrazine	Endrin	Methoxychlor	
Aldrin	Di(2-ethylhexyl)adipate	Ethion	Metolachlor	
Ametryn	Dieldrin	gamma-BHC	Norflurazon	
Atrazine	Diquat	Glyphosate	Oxamyl	
beta-BHC	Endosulfan I	Heptachlor	PCBs	
Bromacil	Endosulfan II	Heptachlor epoxide	Simazine	
Carbofuran	Endosulfan sulfate	Hexazinone	Toxaphene	
Herbicides				
2,4,5-TP	2,4-D	Dalapon	Dinoseb	Picloram

Few anthropogenic organic constituents were detected in recharge water samples. In the 2002 quarterly sampling events, total trihalomethanes (0.84 µg/L) and xylene (0.33 µg/L) were detected in a single sample. Toluene (0.23 µg/L and 0.62 µg/L) was detected in two samples. These concentrations are all below SDWA regulatory criteria. All other compounds listed on **Table 9-3** were not detected.

Waterborne microorganisms are common constituents of Florida surface water and stormwater, especially where the predominant land use is agriculture, pasture, and rangeland (Betancourt and Rose, 2005). Representative and indicator microorganisms and viruses (bacteriophages) were analyzed in ASR wellhead samples during the recharge phase of cycle tests 1 through 4. Bacteria include total and fecal coliforms, *Escherichia coli*, enterococci, *Clostridium perfringens* and cyanobacteria. Total and fecal coliform and enterococci data serve as indicators for the possible presence of other enteric pathogens such as *E. coli*. *C. perfringens* is an anaerobe found in the soil and water, but also can occur in wastewater. Cyanobacteria are photosynthesizing bacteria that occur commonly in surface water, but can cause extensive blooms in the presence of elevated nutrient concentrations in the Kissimmee River and Lake Okeechobee (SFWMD, 2012d). Coliphages are non-hazardous viruses that inhabit host coliform bacteria, and can serve as tracers of surface water. *Cryptosporidium parvum* and *Giardia lamblia* are protozoan parasites that inhabit mammalian intestines. Their presence in surface water indicates a sewage source.

Bacteria were detected most frequently in recharge water samples. Of these, fecal coliforms, enterococci, and *E. coli* are most directly associated with mammalian waste sources in the watershed. Cyanobacteria were detected in every recharge water sample obtained during cycle tests 1 through 3 (cyanobacteria were not measured during cycle test 4). Cyanobacteria samples were quantified as number of cells, but cells were not identified to genus. Cyanobacteria, green algae (Chlorophyta), diatoms, and other phytoplankton were identified during cycle test 1 for periphyton analysis (Golder Associates, 2009; see **Section 10**). Protozoan pathogens *C. parvum* and *G. lamblia* were rare or absent. There is only a single unequivocal detection of *C. parvum* in recharge water, and no detections of *G. lamblia* throughout the entire cycle testing period. Microorganism abundances measured in recharge water samples are shown in **Table 9-4.**

Total phosphorus (TP) is the most important constituent of concern in the Kissimmee River watershed and Lake Okeechobee (FDEP, 2006). TP loads result from agricultural runoff. Reducing TP loads (less than 140 million tons/year) to Lake Okeechobee by 2015 is an FDEP restoration target (SFWMD, 2012d). Total nitrogen (TN) load (sum of nitrate, nitrite, ammonia and total Kjeldahl nitrogen, TKN) also degrades surface water quality, but currently does not have defined restoration targets. Nutrient concentrations in recharge water are shown in **Table 9-5.**

Table 9-4 -- Microorganisms in Recharge Water from the Kissimmee River, Cycle Tests 1 through 4 (2009-2012)

Microbe or Pathogen	Unit	No. samples with Positive Detection	Total No. of Samples (N)	Per-cent Detect	Mini-mum Value	Maxi-mum Value	Geo-metric Mean	Std Dev	Med-ian
Total Coliform	CFU/100 mL	42	61	69	1	330	7	57	7
Fecal Coliform	MPN/100 mL	0	61	0	2	2			
E. coli	CFU/100 mL	1	18	6	1	2	1	0	1
Enterococci	MPN/100 mL	3	12	25	1	40	2	11	1
Clostr. perfringens	CFU/100 mL	6	14	43	1	53	4	17	1
Coliphage	PFU/100 mL	0	12	0	1	1			
Giardia lamblia	oocysts/100mL	1	14	0	1.3	8.5			
Crypto. parvum	oocysts/100mL	1	14	7	1.3	21	4	5	3.1
Cyanobacteria	cells/mL	7	7	100	3	8253	95	3992	17

Note: All samples from the ASR wellhead, EXKR-1, after filtration and UV disinfection, during recharge of cycle tests 1 through 4.

TP concentrations in recharge water reported here generally are lower than TP and TN concentrations reported for adjacent sub-basins of the lower Kissimmee River watershed (SFWMD, 2012d). The 2012 average TP concentration in the L-59E basin is 0.245 mg/L, and that in the lower Kissimmee sub-watershed is 0.458 mg/L (versus 0.067 mg/L for KRASR recharge). The 2012 average TN concentration in the L-59E basin is 2.65 mg/L, and that in the lower Kissimmee sub-watershed is 1.13 mg/L (versus 1.25 mg/L for KRASR recharge).

Table 9-5 -- Nutrients in Recharge Water from the Kissimmee River, Cycle Tests 1 through 4 (2002, 2009-2012)

Nutrient	Unit	Criteria	Value					
			Mean	Std Dev	Median	Maximum	Minimum	N
Nitrate N	mg/L	10	0.15	0.115	0.100	0.47	< 0.015	43
Nitrite N	mg/L	1	0.016	0.006	0.02	0.05	< 0.010	40
Total Kjeldahl N	mg/L		1.10	0.43	1.00	2.74	0.15	40
Ammonia, Total	mg/L		0.09	0.07	0.08	0.41	0.03	40
Total N	mg/L		1.25	0.55	1.24	3.08	0.22	44
Phosphorus, Total as P	mg/L	40	0.067	0.042	0.055	0.250	< 0.0044	54
ortho-Phosphorus as P	mg/L		0.029	0.014	0.026	0.080	< 0.016	30

Note: Most samples were collected from the ASR wellhead (EXKR-1) after filtration and UV disinfection, during recharge of cycle tests 1 through 4. Five surface water samples from the Kissimmee River (Tetra Tech, 2005) near the site are included for completeness. Concentrations reported as "less than" are below the method detection limit. N, number of samples. Surface Water Quality Criteria are from State of Florida F.A.C. 62-302.530. The total phosphorus standard is based on TMDL loading to Lake Okeechobee. Primary and secondary inorganic criteria of the SDWA also are listed.

Selected radionuclides were analyzed in Kissimmee River recharge water. Gross alpha activity measurements serve as a general indicator of the presence of uranium, thorium, and radium radionuclides in a sample. Radium isotopes were analyzed in ASR wellhead samples (N=5) during cycle test 1 recharge, and again during cycle test 3 recharge. All radionuclide activities were detected at levels far below regulatory criteria. Radium-228 values nearly always were below the uncertainty level, and thus most analyses were J-flagged. Radionuclide data are shown in **Table 9-6.**

Table 9-6 -- Radionuclides in Recharge Water from the Kissimmee River, Cycle Tests 1 through 4 (2009-2012)

Radionuclide	Unit	Criteria	Mean Value	Std Dev	Uncertainty (+/-) of Mean Value	Median	Maxi-mum	Mini-mum	No. of samples (N)
Gross Alpha	pCi/L	15	0.71	0.48	1.52	0.60	2.00	0.04	55
Radium-226	pCi/L	5	0.24	0.07	0.16	0.20	0.32	0.18	5
Radium-228	pCi/L		0.28	0.11	0.35	0.38	0.42	0.20	5

Note: All samples were collected from the ASR wellhead (EXKR-1) after filtration and UV disinfection, during recharge of cycle tests 1 and 3. Radium-226 and Radium-228 isotopes were quantified separately, but the SDWA criterion is the sum of Radium-226+Radium 228 activities.

9.2.1.2 Native Floridan Aquifer Water Quality – Upper Floridan Aquifer and Avon Park Permeable Zone

Native water quality characteristics of two permeable zones within the Floridan Aquifer System in the vicinity of KRASR are presented. The Upper Floridan Aquifer (UFA) is the storage zone for the KRASR system; the Avon Park Permeable Zone (APPZ; Reese and Richardson, 2008) underlies the storage zone. Water quality characterization of the surficial aquifer at the site is found in **Section 9.2.1.3.**

Water quality of the UFA in the vicinity of KRASR is fresh, having low concentrations of major inorganic constituents (TDS, calcium, magnesium, sodium, potassium, sulfate, and chloride), especially compared to locations further south. Groundwater in the UFA is in contact with limestone aquifer matrix, so carbonate alkalinity is low to moderate (75 to 85 mg/L) and pH is slightly alkaline (7.6 to 8.3). UFA groundwater has low but measureable dissolved and/or total organic carbon concentrations (1 to 2 mg/L), which is surprising given that groundwater now in the vicinity was recharged approximately 18,000 to 25,000 years ago (Morrissey et al., 2010). The redox condition is sulfate-reducing, with measureable dissolved sulfide (1.0 to 1.4 mg/L). Dissolved inorganic trace constituent concentrations are also low, with most metals ranging from 70 μg/L to below the method detection limit (MDL; typically less than 0.2 μg/L). The native UFA is iron-poor, with concentrations typically below the MDL (less than 24 μg/L); nutrient-poor (nitrogen and phosphorus species typically are below the MDL); and has low radium radionuclide activity (less than 5 pCi/L). Major and trace inorganic constituent and nutrient concentrations and radionuclide activities from the native UFA are summarized in **Table 9-7.**

A suite of organic constituent compounds identical to those listed in **Table 9-3** was analyzed in groundwater samples from KRASR ASR and SZMWs (350-ft and 1,100-ft SZMWs) in prior to cycle testing (2008). No organic constituents were detected in samples from the ASR well and the 350-ft SZMW. Bis(2-ethylhexyl)phthalate, a common volatile laboratory compound associated with plastic, was detected (0.54 µg/L, lower than the practical quantitation limit) in a single sample from the 1,100-ft SZMW. No other organic constituents were detected.

Water quality of the Avon Park Permeable Zone (APPZ) in the vicinity of KRASR shows many similar water quality characteristics to the UFA, because groundwater is in contact with a dolomitic limestone or dolostone (Reese and Richardson, 2008). At KRASR, only the uppermost APPZ is sampled, because the open interval of the OKF-100L well is at elevations between -982.5 ft and -1031.8 ft NGVD1929. The depth of the APPZ in the KRASR area typically extends from approximately -1000 ft to -1800 ft NGVD1929 (Reese and Richardson, 2008). The APPZ groundwater is slightly brackish, having moderate concentrations of major dissolved inorganic constituents (TDS, calcium, magnesium, sodium, potassium, sulfate, and chloride), especially compared to locations further south. Groundwater in the APPZ is in contact with dolomitic limestone, so carbonate alkalinity is low to moderate (72 mg/L) and pH is slightly alkaline (8.2). The redox condition is mixed ferric-iron and sulfate-reducing, with measureable dissolved sulfide and iron (<1.0 mg/L and 220 µg/L respectively). Dissolved inorganic trace constituent concentrations also are low, with measureable barium (41µg/L), boron (66 µg/L), and strontium (12 mg/L) concentrations. All other metal concentrations are below the MDL (typically less than 0.2 µg/L). Nutrient nitrogen species concentrations are below the MDL. Phosphorus concentration is 17 µg/L. Gross alpha and radium radionuclide activity are below their regulatory criteria (less than 5 pCi/L). Organic compounds were not measured in any APPZ sample. Major and trace dissolved inorganic constituent and nutrient concentrations and radionuclide activities from the native APPZ are summarized in **Table 9-8.**

Table 9-7 -- Major and Trace Dissolved Inorganic Constituents, Nutrients, and Radionuclides in the Native Upper Floridan Aquifer at KRASR (All Wells), 2004 - 2009

Constituent or Parameter	Unit	Criteria	OKF-100 U			MW-10			EXKR-1 (ASR)			MW-18			MW-19		
			Mean	Std Dev	N	Mean	Std Dev	N	Mean	Std Dev	N	Mean	Std Dev	N	Mean	Std Dev	N
Temperature	º C		25.8	0.6	7	25.9	1.5	3	25.5	0.31	3	25.3	0.88	3	25.3	0.39	3
Spec Conduct.	in µS/cm		1386	212	6	1306	201	3	1269	137	3	1005	20	3	1383	29	3
pH	std unit	6.5 - 8.5	8.19	0.35	7	7.91	0.30	3	7.82	0.2	3	7.59	0.49	3	7.95	0.09	3
ORP	mV		-231	73	2	-268		1	-283		1	-289	122	3	-221	25	3
Diss. Oxygen	mg/L		0.44	0.47	6	0.02		1	0.29		1	0.23	0.25	3	0.34	0.42	3
Turbidity	NTU		0.33	0.47	3	1.08	1.65	3	0.49	0.54	2	0.20	0.23	3	0.19	0.18	3
Tot. Diss. Solids	mg/L	500	810	164	7	727	83	3	762	105	3	540		1	800		1
Tot. Susp. Solids	mg/L		5		1	5		1									
Color	PCU	15	6.7	2.9	3	5		1	< 5		2						
Hardness	mg/L		237	12	3												
Calcium	mg/L		48.2	8.7	6	48.0	7.1	2	51.5	2.2	2	42.7	12.7	3	41.7	12.7	3
Magnesium	mg/L		33.7	2.8	6	39.5	2.1	2	38.7	1	2	33.7	3.2	3	37	3.5	3
Sodium	mg/L	160	183	56	5	140	10	3	141	20.1	3	78.7	17.0	3	143	29	3
Potassium	mg/L		6.7	0.9	6	7.9	0.9	2	7.6	1.1	2	5.1	0.4	3	9.2	0.8	3
Sulfate	mg/L	250	168	18	7	180	10.0	3	185	22.0	3	187	20.8	3	203	15	3
Sulfide	mg/L		0.9	0.14	2	1.37		1	0.8		1	1.1	0.1	3	1.2	0.1	3
Bromide	µg/L		740	20	2	790		1	750		1	510		1	510		1
Chloride	mg/L	250	281	66	7	237	25	3	228	26	3	150	10	3	267	12	3
Fluoride	mg/L	4.0	0.49	0.03	3	0.52	0.1	3	0.52	0.1	3	0.55		1	0.6		1
Silica	mg/L		5.4		1	5.1		1	14.1	0	2						
Total Alkalinity	mg/L as CaCO3		77.7	9.7	6	87.5	2.1	2	89.5	2.1	2	84.3	1.04	3	87	1.0	3
Total Cyanide	mg/L	200	< 0.005		1	< 0.005		2	< 0.005		2						
Diss. Org. Carbon	mg/L		1.2	0.2	2	1.6		1	< 1.0		1						
Tot. Org. Carbon	mg/L					1.7	0.0	2	< 1.0		1						
Aluminum	µg/L	50	< 20		3	11.3	9.7	3	< 20		3	< 0.13		1	< 0.13		1
Antimony	µg/L	6	< 2.3		3	<0.31		2	< 3		3	< 0.24		1	0.24		1
Arsenic	µg/L	10	< 2.6		3	2.8	1.7	3	5.4	5.8	3	1.5	0.6	3.0	1.6	0.3	3
Beryllium	µg/L	4	< 1		2				< 0.12		2	< 0.066		1	< 0.066		1
Barium	µg/L	2	36.3	6.7	3	31.5	6.4	2	31.6	7.5	3	28		1	25		1
Boron	µg/L		69		1	95		1									
Cadmium	µg/L	5	< 0.7		3	< 0.084		3	< 0.70		3	< 0.071		1	< 0.071		1
Chromium	µg/L	100	< 7.2		3	8.0	13	3	< 1.8		3	0.86		1	1.2		1
Cobalt	µg/L		< 1		2	< 0.12		1	< 1		1						
Copper	µg/L	1000	1.47	1.1	3	1.2	0.9	3	1.5	0.4	3	2.3		1	0.45		1
Iron	µg/L	300	46	18.5	3	199	223	3	92	110	3	23.7	0.6	3	< 24		3
Lead	µg/L	15	< 3		3	< 0.25		3	< 3		3	< 0.029		1	< 0.029		1
Manganese	µg/L	50	3.9	0.3	3	7.3	6.8	3	< 3.8		3	3.6	0.6	2	3	4.2	2
Mercury (Inorg)	µg/L	2	0.07	0.01	2	< 0.5		1	< 0.080		1						
Mercury (Ultrace)	ng/L	2000	< 0.15		1	< 0.15		1									
Methyl Mercury	ng/L		< 0.02		1	< 0.02		1									
Molybdenum	µg/L		40		1	66		1				3.3	0.6	2	< 2.8		2
Nickel	µg/L	100	1.49	0.73	2	0.53		1	< 2		2	0.18		1	0.11		1
Selenium	µg/L	50	1.9	1.3	3	2.8	2.9	2	< 2.1		2	< 0.52		1	< 0.52		1
Silver	µg/L	100	< 1		2	< 0.34		1	5.7	7.5	2	< 0.10		1	< 0.10		1
Strontium	µg/L		16,500	4,950	2	14,000		1	16,900	4,384	2						
Thallium	µg/L	2	< 1		1	0.12		1	< 1		2	<0.053		1	< 0.053		1
Uranium	µg/L	30	0.07	0.07	2	< 0.058		1	0.0198		1						
Vanadium	µg/L								< 0.04		1						
Zinc	µg/L	5000	7.53	5.6	3	29.4	41.2	3	8.2	5.2	3	2.3		1	1.2		1
Ammonia	mg/L		0.22		1				0.21	0	2						
Nitrate N	mg/L	10	< 0.01		3	< 0.047		3	< 0.1		2	< 0.003		1	< 0.003		1
Nitrite N	mg/L	1	< 0.05		3	< 0.025		3	< 0.05		2	< 0.0022		1	< 0.0022		1
N, Tot Kjeldahl	mg/L		0.28		1				0.36	0.01	2						
Tot. Phosphorus	mg/L		< 0.01		3	0.03	0.02	3	< 0.010		2						
ortho-Phosphorus	mg/L		< 0.01		1				< 0.05		1	0.0085		1	0.0085		1
Gross Alpha	pCi/L	15	4.7	1.7	2	5.3		1	5.87		1	2.8		1	2.9		1
Ra-226	pCi/L	5	2.1	0.3	2	1.48		1	2.37		1						
Ra-228	pCi/L		< 1.3		2	< 0.33		1	< 1.26		1						

Note: All samples collected from the wellhead prior to the onset of cycle testing. Concentrations reported as "less than" are below the method detection limit. N, number of samples. ORP, oxidation-reduction potential. Units: mg/L, milligram per liter; µg/L, microgram per liter; ng/L, nanograms per liter; pCi/L, picocuries per liter; º C, degrees Celsius; µS/cm, microsiemens per cm; PCU, platinum cobalt units; NTU, nephelometric turbidity units; mV, millivolts. Primary and secondary drinking water criteria are from State of Florida F.A.C. 62-520.400 and the Federal SDWA.

Table 9-8 -- Major and Trace Dissolved Inorganic Constituents, Nutrients, and Radionuclides in the Native Avon Park Producing Zone (OKF-100L) Groundwater, 2007-2009

Constituent or Parameter	Unit	Criteria	Value					
			Mean	Std Dev	Median	Maxi-mum	Mini-mum	N
Temperature	º C		26.7	0.4	26.6	27.3	26.4	6
Spec.Conductance	in µS/cm		1684	235	1614	2064	1444	5
pH	std unit	6.5 - 8.5	8.18	0.15	8.15	8.40	8.00	6
ORP	mV		-160					1
Dissolved Oxygen	mg/L		0.41	0.63	0.15	1.68	0.01	6
Turbidity	NTU		0.05					1
Total Diss. Solids	mg/L	500	902	182	921	1163	630	6
Total Susp.Solids	mg/L		< 5					1
Color	PCU	15	10					1
Hardness	mg/L asCaCO3		269	4	270	272	264	4
Calcium	mg/L		49.4	3.0	49.9	52.1	44.0	6
Magnesium	mg/L		34.1	2.2	34.6	36.4	30.0	6
Sodium	mg/L	160	208	50	215	287	150	6
Potassium	mg/L		6.7	1.7	6.2	9.2	5.2	6
Sulfate	mg/L	250	177	30	167	237	160	6
Sulfide	mg/L		< 1.0					1
Bromide	µg/L		870					1
Chloride	mg/L	250	356	115	342	569	245	6
Fluoride	mg/L	4	0.5					1
Silica	mg/L		5.6					1
Total Alkalinity	mg/L asCaCO3		71.5	11.4	71.5	87.0	53.0	6
Total Cyanide	mg/L	200	< 0.005					1
Diss. Org.Carbon	mg/L		< 1.0					1
Total Org.Carbon	mg/L		< 0.5					1
Aluminum	µg/L	50	< 4.5					1
Antimony	µg/L	6	< 0.082					1
Arsenic	µg/L	10	1					1
Beryllium	µg/L	4						0
Barium	µg/L	2	41					1
Boron	µg/L		66					1
Cadmium	µg/L	5	<0.058					1
Chromium	µg/L	100	< 0.24					1
Cobalt	µg/L		< 0.12					1
Copper	µg/L	1000	0.54					1
Iron	µg/L	300	220					1
Lead	µg/L	15	<0.054					1
Manganese	µg/L	50	19					1
Mercury (Ultrace)	ng/L	2000	< 0.15					1
Methyl Mercury	ng/L		< 0.02					1
Molybdenum	µg/L		1.6					1
Nickel	µg/L	100	1.1					1
Selenium	µg/L	50	2.7					1
Silver	µg/L	100						0
Strontium	µg/L		13,000					1
Thallium	µg/L	2						0
Uranium	µg/L	30	< 0.0586					1
Zinc	µg/L	5000	< 4.3					1
Nitrate N	mg/L	10	< 0.025					1
Nitrite N	mg/L	1	< 0.01					1
Tot. Phosphorus	mg/L		0.017					1
Gross Alpha	pCi/L	15	4.2	2.6				1
Ra-226	pCi/L	5	1.47	0.28				1
Ra-228	pCi/L		< 0.03	0.22				1

Note: All samples collected from the OKF-100L wellhead prior to the onset of cycle testing. Concentrations reported as "less than" are below the method detection limit. N, number of samples. ORP, oxidation-reduction potential. Units: mg/L, milligram per liter; µg/L, microgram per liter; ng/L, nanograms per liter; pCi/L, picocuries per liter; º C, degrees Celsius; µS/cm, microsiemens per cm; PCU, platinum cobalt units; NTU, nephelometric turbidity units; mV, millivolts. Primary and secondary drinking water criteria are from State of Florida F.A.C. 62-520.400 and the Federal SDWA.

9.2.1.3 Surficial Aquifer Water Quality

Water quality characteristics of the surficial aquifer are defined so that effects resulting from ASR cycle testing can be detected. These effects include leaching of inorganic constituents (such as metals) from on-site backwash equalization and solids ponds, or less likely, the upward migration of groundwater from the storage zone. ASR cycle testing caused no effects on surficial aquifer water quality, which is discussed in **Section 9.9.1.** Therefore, water quality characterization of the surficial aquifer is compiled from all sample data obtained during cycle tests 1 through 4 (cycle test 4 recharge only), from 2009 through 2012.

The surficial aquifer at KRASR is recharged by percolation of rainwater or infiltration of Kissimmee River water, and these sources are reflected in the groundwater quality characteristics. Groundwater in the surficial aquifer is in contact with unconsolidated quartz sand and silts with increasing shell content at depth (Challenge Engineering & Testing, Inc., 2007). The surficial aquifer is brackish, having moderate concentrations of some major dissolved inorganic constituents (primarily sodium and chloride), when compared to other aquifers at KRASR. Carbonate alkalinity is high (375 mg/L) and pH is neutral (7.6). Dissolved and total organic carbon concentrations are high (approximately 8 mg/L). The redox condition is sulfate-reducing, with significant dissolved sulfide (3 to 5 mg/L). Dissolved inorganic trace constituent concentrations are also low, with barium (15 μg/L), boron (585 μg/L), and strontium (45 μg/L) concentrations that differ in proportion compared to limestone aquifer samples. All other metal concentrations are generally low or below the MDL (typically less than 22 μg/L). Nutrient nitrogen species concentrations are below the MDL. Phosphorus concentration averages 24 μg/L. Gross alpha and radium radionuclide activity are below their regulatory criteria (less than 15 and 5 pCi/L, respectively). Anthropogenic organic compounds were not measured in any surficial aquifer sample. Major and trace dissolved inorganic constituent and nutrient concentrations and radionuclide activities from the surficial aquifer are summarized in **Table 9-9.**

Table 9-9 -- Major and Trace Dissolved Inorganic Constituents, Nutrients, and Radionuclides in the Surficial Aquifer (MW-17) Groundwater, 2009-2012

Constituent or Parameter	Unit	Criteria	Value					
			Mean	Std Dev	Median	Maximum	Minimum	N
Temperature	º C		24.2	0.9	24.0	29.1	23.4	128
Specific Conductance	in µS/cm		3291	57	3282	3675	3204	129
pH	std unit	6.5 - 8.5	7.58	0.08	7.59	7.80	7.26	128
ORP	mV		-249	38	-248	-145	-316	127
Dissolved Oxygen	mg/L		0.15	0.18	0.09	1.14	0.01	129
Turbidity	NTU		0.28	0.15	0.26	1.30	0.04	129
Total Diss. Solids	mg/L	500	1815	285	1800	3700	1100	124
Tot. Suspend. Solids	mg/L		5	0	5	5	5	3
Color	PCU	15	34	24	30	250	10	127
Hardness	mg/L as CaCO3							
Calcium	mg/L		29.3	1.0	29.5	30.0	28.0	4
Magnesium	mg/L		30.3	2.2	31.0	32.0	27.0	4
Sodium	mg/L	160	640	34	655	660	590	4
Potassium	mg/L		24.8	14.4	31.0	34.0	3.3	4
Sulfate	mg/L	250	285	80	270	518	4	48
Sulfide	mg/L		3.0	2.7	3.0	4.9	1.1	2
Bromide	µg/L		2000	141	2000	2100	1900	2
Chloride	mg/L	250	675	97	680	950	51	126
Fluoride	mg/L	4	1.0	0.3	1.0	1.2	0.8	2
Silica	mg/L		18.5	0.7	18.5	19.0	18.0	2
Total Alkalinity	mg/L as CaCO3		375	7	375	380	370	2
Total Cyanide	mg/L	200	<0.005					3
Diss. Organ. Carbon	mg/L		7.7	0.2	7.7	7.8	7.5	2
Tot. Organic Carbon	mg/L		8.2	0.3	8.2	8.4	8.0	2
Aluminum	µg/L	50	22	0	22	22	22	2
Antimony	µg/L	6	< 0.41					2
Arsenic	µg/L	10	0.85	0.71	0.57	3.7	< 0.37	31
Beryllium	µg/L	4						
Barium	µg/L	2	15	0	15	15	15	2
Boron	µg/L		585	21	585	600	570	2
Cadmium	µg/L	5	< 0.29					2
Chromium	µg/L	100	0.8	0.6	0.8	1.2	0.3	2
Cobalt	µg/L		< 0.6					2
Copper	µg/L	1000	< 1.3					2
Iron	µg/L	300	< 26					4
Lead	µg/L	15	0.27					2
Manganese	µg/L	50	5.3	1.3	5.3	6.6	3.9	4
Mercury (Ultrace),	ng/L	2000	< 0.15					3
Methyl Mercury	ng/L		< 0.02					3
Molybdenum	µg/L		1.35	0.21	1.35	1.50	1.20	2
Nickel	µg/L	100	0.90	0.28	0.90	1.10	0.70	2
Selenium	µg/L	50	2.75	1.20	2.75	3.60	1.90	2
Silver	µg/L	100						
Strontium	µg/L		455	7	455	460	450	2
Thallium	µg/L	2						
Uranium	µg/L	30	0.47	0.31	0.47	0.69	0.26	2
Zinc	µg/L	5000	< 22					2
Nitrate N	mg/L	10	< 0.25					2
Nitrite N	mg/L	1	< 0.01					2
Phosphorus, Total as P	mg/L		0.024	0.019	0.024	< 0.037	0.010	2
Gross Alpha	pCi/L	15	< 10.5					35
Ra-226	pCi/L	5	0.41	0.06	0.41	0.45	0.37	2
Ra-228	pCi/L		< 0.44					2

Note: All samples collected from the MW-17 well using a submersible pump. Concentrations reported as "less than" are below the method detection limit. N, number of samples. ORP, oxidation-reduction potential. Units: mg/L, milligram per liter; µg/L, microgram per liter; ng/L, nanograms per liter; pCi/L, picocuries per liter; º C, degrees Celsius; µS/cm, microsiemens per cm; PCU, platinum cobalt units; NTU, nephelometric turbidity units; mV, millivolts. Primary and secondary drinking water criteria are from Florida F.A.C. 62-520.400 and the Federal SDWA.

9.2.2 Cycle Testing Program

9.2.2.1 Overview

The overall cycle testing goal for KRASR is to evaluate the feasibility of multi-year water storage. Located on the Kissimmee River near its confluence with Lake Okeechobee, this ASR system is intended to operate in progressively longer recharge periods leading to large-volume storage, with subsequent distribution during periods of low water level. The intent of KRASR was to serve as a conceptual model for expanded ASR systems to provide storage north and northwest of Lake Okeechobee. The original schedule did not include long storage periods, opting instead for longer recharge and recovery. This schedule was extended to include an additional cycle with longer duration to better characterize water quality changes during prolonged storage. Four cycle tests were completed at KRASR. Each successive cycle test had longer total duration, with longer recharge phase and therefore larger storage volume. Cycle test 4 was the longest cycle (2 year duration), with the greatest volume in storage (nearly 1 billion gallons), and with the longest storage period (approximately 1 year). Cycle test duration and volume characteristics are summarized in **Table 9-10.** A graphical display of the cycle test history at KRASR is shown in **Figure 9-1**.

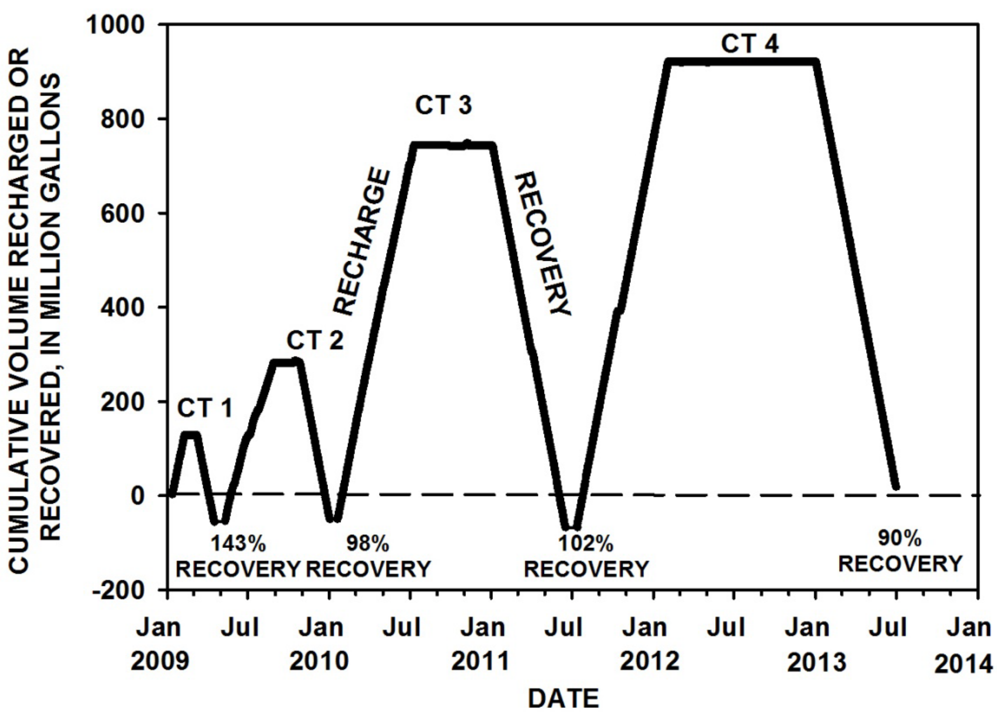

Figure 9-1 -- Cycle test (CT) history at the Kissimmee River ASR system.

Table 9-10 -- Recharge, Storage, and Recovery Pumping Rate, Duration, and Volumes During KRASR Cycle Tests

Phase	Start Date	End Date	No. of Days	Avg. Pumping Rate (MGD)	Volume, in MG		Percent Volume Recovered
					Recharge	Recovery	
Cycle 1							
Recharge	12-Jan-09	9-Feb-09	28	4.7	128.5	__	__
Storage	9-Feb-09	9-Mar-09	28	__	__	__	__
Recovery	9-Mar-09	17-Apr-09	39	4.8	__	183.8	143%
Cycle 2							
Recharge	11-May-09	28-Aug-09	109	3.8	334.3	__	__
Storage	28-Aug-09	28-Oct-09	61	__	__	__	__
Recovery	28-Oct-09	2-Jan-10	66	4.0	__	331.5	98%
Cycle 3							
Recharge	19-Jan-10	9-Jul-10	171	5.0	793.1	__	__
Storage	9-Jul-10	4-Jan-11	178	__	__	__	__
Recovery	4-Jan-11	17-Jun-11	164	5.0	__	805.5	102%
Cycle 4							
Recharge	11-Jul-11	3-Feb-12	217	5.0	998.4	__	__
Storage	3-Feb-12	2-Jan-13	333	__	__	__	__
Recovery	2-Jan-13	1-July-13	181	5.0	__	902.2	90.4%

9.2.2.2 Cycle Test 1

The inaugural cycle test at KRASR was initiated on 12 January 2009 and completed on 17 April 2009. Cycle test 1 consisted of recharge, storage, and recovery phase durations of approximately 1 month. The recovery phase was extended for two weeks (39 days total duration) so that groundwater quality would be restored to near-native conditions, characterized by arsenic concentrations below the 10 µg/L regulatory criterion in all monitoring wells. To do this, the volume of water recovered during cycle test 1 exceeded the volume recharged by 43 percent **(Table 9-10).** The average daily recharge pumping rate was 4.69 million gallons per day (MGD); the average daily recovery pumping rate was 4.82 MGD. During recharge, wellhead pressures rose from approximately 55 psi to 60 psi, suggesting that borehole clogging was occurring. However, recharge pumping proceeded with minimal interruption (one half-day) to purge the well. The UIC-permitted wellhead pressure (66 psi) was never exceeded at recharge flow rates of 4.6 to 4.8 MGD.

The most extensive suite of water quality and geochemical analytes was obtained during cycle test 1. This suite includes constituents and parameters that are required for permit compliance, but also includes constituents that enable detailed geochemical evaluation of water quality changes during an ASR cycle test. The analytical suite includes field parameters, major and traces inorganic (metals) constituents, radionuclides, stable isotopes, microbes, and nutrients. Groundwater samples were collected weekly from all wells including the ASR well. Recovered water quality was evaluated at the ASR wellhead for geochemical interpretations, at the point of discharge (cascade aerator) and in the

Kissimmee River to document compliance with the NPDES permit. The most important geochemical issue to be evaluated during ASR cycle tests are: 1) controls on the release, mobility, and sequestration of transition metals primarily arsenic, iron, and molybdenum; 2) the fate of nutrients (phosphorus and nitrogen species); and 3) evaluation of mercury methylation potential. Additional detailed water quality data were acquired at MW-10 (350-ft storage zone monitor well, SZMW) using a submersible water quality sensor. The SeaCat Profiler (model SBE19plusV2; Sea-Bird Electronics, Inc. Bellevue, WA) is an oceanographic-type battery powered sensor that can measure water quality characteristics (temperature, pressure, pH, specific conductance, ORP, dissolved oxygen concentration) hourly in equilibrated samples, then store data for quarterly downloads. This sensor is particularly important for characterization of changing aquifer redox conditions that control arsenic mobility during a cycle test. The sensor was deployed prior to initiation of cycle test 1 on 28 December 2008. SeaCat Profiler data collected during cycle test 1 is the most complete dataset through most of a cycle. Unfortunately, a crack in the battery compartment caused a leak, and the probe was returned to the manufacturer for repair. As a result, no data were obtained between 28 December 2008 (before cycle test 1 recharge), and 17 January 2009 (week 1 recharge). Characterization of water quality changes during ASR cycle testing is consistent with objective 2 **(Table 9-1)**. Detailed discussions of water quality changes, including the "first flush" characterization of water and solids from the ASR well at the onset of recovery, are found in **(Section 10).** Hydrogeologic analysis is presented in **Section 5**.

An extensive program of toxicity testing was conducted during cycle test 1 recharge and recovery phases. These tests consisted of toxicity testing for CERPRA and NPDES permit compliance to evaluate the effects of recharge and recovered water on test organisms **(Table 9-11)**. In addition, several on-site ecotoxicological studies were initiated with recharge water to define baseline (pre-cycle testing) effects on target organisms. Results of these studies are discussed in **Section 10**.

Cycle test 1 operation proceeded continuously, with exception of brief stoppages during ASR well purging or power loss during storms. However, it became clear during cycle test 1 that the ultraviolet (UV) disinfection system did not provide consistent and sufficient coliform inactivation during recharge (**Table 9-4**). Two technical memoranda were submitted by the operators of the surface facility (R2T, Inc.) with suggestions to improve UV performance, and these approaches are summarized in **section 6.3**. Technical Memorandum 1 (R2T, Inc., 2009a; Appendix E) evaluated application of coagulants to reduce color, and therefore improve UV transmittance. Memorandum 2 (R2T, Inc., 2009b) evaluated coagulant dose in jar tests to quantify color reduction and mass of residuals generated. Optimizing surface facility operations during ASR cycle testing is consistent with objectives 1 and 3 **(Table 9-1)**.

Table 9-11 -- Toxicity Testing for Permit Compliance, and Ecotoxicity Studies Conducted During Cycle Test 1 at KRASR				
Test or Study	**Endpoint**	**Permit or Purpose**	**Test Organism**	
7-day chronic static renewal	Survival and reproduction	NPDES	*Ceriodaphnia dubia*	water flea
7-day chronic static renewal	Survival and teratogenicity	NPDES	*Pimephales promelas* embryo	fathead minnow
96-hr LC50 acute static renewal	Survival	NPDES and CERPRA	*Ceriodaphnia dubia*	water flea
96-hr LC50 acute static renewal	Survival	NPDES and CERPRA	*Cyprinella leedsi*	bannerfin shiner
21-day chronic static renewal	Survival and reproduction	Ecotox	*Daphnia magna*	water flea
96-hour chronic non-renewal	Growth	Ecotox	*Selanastrum capricornutum*	green algae
96-hour FETAX assay	Embryo survival and teratogenesis	Ecotox	*Xenopus* embryo	frog
Bioconcentration - metals	Concentration in tissue	Ecotox	*Lepomis macrochirus*	bluegill
Bioconcentration - radium-226 228	Concentration in tissue	Ecotox	*Elliptio buckleyi*	freshwater mussel
Periphyton	Density and diversity	Ecotox	various alga, protozoans, diatoms	

During cycle test 1, a geotechnical evaluation of rock fracturing potential was initiated. Samples from the Ocala Limestone, Avon Park Formation, and Lower Hawthorn Group sediments in cores from all CERP ASR pilot sites were obtained from the Florida Geological Survey and submitted for geotechnical analysis (Mactec, 2008). These data were interpreted, resulting in an evaluation of hydraulic fracturing of representative storage zone lithologies (Geibel and Brown, 2012). Characterization of pressures that resulting in hydraulic fracturing during ASR cycle testing are discussed further in **Section 5.5**, and this work is consistent with objective 3 **(Table 9-1)**.

9.2.2.3 Cycle Test 2

Each successive cycle test increased the volume of stored water during a longer recharge phase. The storage duration also increased with each successive cycle test. The second cycle test was initiated on 11 May 2009, less than one month after completion of cycle test 1, and was completed on 2 January 2010. The recharge phase duration was 109 days (3.5 months), which included approximately 16 days when the surface facility was shut down. The storage phase duration was 2 months, and the recovery phase duration was 66 days (2.2 months). Cycle test 2 showed a 98 percent recovery by volume. The average daily recharge pumping rate was 3.52 MGD; the average daily recovery pumping rate was 4.98 MGD. During recharge, wellhead pressures continued to rise, which required pumping rate to be reduced to approximately 3 MGD so that wellhead pressures would not exceed the UIC-permitted criterion of 66 psi.

The suite of water quality analytes was decreased in number during cycle test 2, to focus on specific water quality and geochemical reactions instead of broad characterization of surface and groundwater.

However, all monitor wells were sampled weekly through recharge, storage, and recovery. The ASR well (EXKR-1) was sampled weekly during recharge and recovery only. The SeaCat Profiler continued to collect in-situ data at a depth of approximately -550 ft NGVD29. The DO sensor data are invalid due to drift or failure between 11 August 2009 (end of cycle test 2 recharge) and 19 January 2010 (cycle test 3). Additional discussion of specific water quality changes during ASR cycle testing is found in **Sections 9.4** through **9.8.**

The most detailed examination of ecotoxicological effects from recovered water was conducted during cycle test 2 recovery phase **(Table 9-12)**. Many of the bioassays conducted during cycle test 1 (with source water, Kissimmee River surface water) were repeated with mixtures of surface and recovered water. Comparison of ecotoxicological effects of surface water with recovered water are discussed in **Section 10**. Ecotoxicological studies of recharge and recovered water are consistent with objective 5 **(Table 9-1).**

Table 9-12 -- Toxicity Testing for Permit Compliance, and Ecotoxicity Studies Conducted During Cycle Test 2 at KRASR

Test or Study	Endpoint	Permit	Test Organism	
7-day chronic static renewal [1]	Survival and reproduction	NPDES	*Ceriodaphnia dubia*	water flea
7-day chronic static renewal	Survival and teratogenicity	NPDES	*Pimephales promelas* embryo	fathead minnow
96-hr LC50 acute static renewal	Survival and reproduction	NPDES and CERPRA	*Ceriodaphnia dubia*	water flea
96-hr LC50 acute static renewal	Survival and reproduction	NPDES and CERPRA	*Cyprinella leedsi*	bannerfin shiner
96-hour chronic non-renewal	growth	Ecotox	*Selanastrum capricornutum*	green algae
96-hour FETAX assay	embryo survival and deformation	Ecotox	*Xenopus* embryo	frog
Bioconcentration - radium-226 + 228 and metals	Concentration in tissue	Ecotox	*Elliptio buckleyi*	freshwater mussel

1 *C. dubia* test did not produce sufficient broods in the control, and is therefore invalid.

Cycle test 2 operation proceeded with some of the same issues identified during cycle test 1 recharge phase: inconsistent performance of the UV disinfection system resulting in coliform detections at the ASR wellhead, and increasing wellhead pressure. The ASR system was offline approximately 14 of 109 days during recharge, primarily due to automatic "high temperature" shutdown prompts from the UV system to the SCADA, or storm-induced power outages. Operations staff pursued many options to improve UV system performance during this and subsequent cycle tests. The immediate solution for both issues was to reduce the recharge flow rate to approximated 3.5 MGD, despite the design criterion of 5 MGD. Treated recharge water at the ASR wellhead showed detectable (> 4 CFU/100 mL) total coliforms in 6 of 16 samples and frequent detection of cyanobacteria during monthly extended microbiological sampling. Operations staff also suspected that the ASR wellbore was starting to clog as a result of calcium carbonate precipitation, biofilm growth, or entrainment of aquifer particulates. The first of two ASR well rehabilitations was conducted during cycle test 2 storage phase (Cardno-ENTRIX Inc., 2011a). The ASR wellbore was treated with dilute hydrochloric acid solution to dissolve minerals and organics without removing the pump. Comparison of pre- and post-rehabilitation specific capacity values (38 gpm/ft and 61 gpm/ft, respectively) showed that the treatment improved well performance over 60 percent (Cardno-ENTRIX Inc., 2011a).

The monitoring wellfield at KRASR was expanded starting in October 2009 (cycle test 2 storage). The construction of two additional storage zone monitor wells (MW-18 and MW-19; Cardno-ENTRIX, 2010a, 2010b) enabled hydrologic, hydraulic and water quality evaluations at greater distances from the ASR well. MW-18 is located 2,350-ft from the ASR well, and MW-19 is located 4,200-ft from the ASR well. Construction of these distal wells was justified because recharge water was already observed to pass through the 1,100-ft storage zone monitor well. Because the recharge volumes of cycle tests 3 and 4 would be greater than that of cycle test 2, it becomes important to detect distal effects during CERP-like (large volume, long storage duration) ASR operations. Justification for an expanded monitoring wellfield is consistent with objectives 2 and 6 **(Table 9-1).**

9.2.2.4 Cycle Test 3

Cycle test 3 was the first test to resemble inter-annual ASR operations proposed in CERP. This cycle was longer (6 months each recharge, storage, and recovery), and resulted in a larger volume in storage (792.1 MG). The cycle test was initiated on 19 January 2010, less than three weeks after completion of cycle test 2. Recharge proceeded nearly uninterrupted for 6 months, at an average pumping rate of 4.86 MGD. There were a total of approximately 8 days of ASR system down-time during the course of the 171-day recharge phase. These system shut-downs were related to monthly chlorination events or storm-induced power outages. ASR wellhead pressures declined through the recharge phase, from 32 psi to 24 psi, well below the UIC-permitted criterion (66 psi). Recovery proceeded with only one day of site shut-down over 5 months, with an average pumping rate of 4.98 MGD.

The suite of water quality analytes was similar to those measured during cycle test 2, with a few important changes. Molybdenum, a trace inorganic constituent, was added to the suite because there was evidence of mobilization during recharge. Additional nutrients were added during cycle test 3. Phosphorus was measured in recharge water and groundwater during storage and recovery. Cycle test 2 data suggested that phosphorus concentrations declined during storage, so sampling was expanded during cycle test 3 to better quantify this process. The nitrogen species (nitrate, nitrite, total Kjeldahl nitrogen, and ammonia) analytes also were added. Only nitrate and nitrate were analyzed during cycle tests 1 and 2. Nitrogen species were analyzed in recharge water and also groundwater during cycle test 3 to evaluate the potential for nitrogen reduction during cycle testing. SeaCat Profiler data collection continued, except for DO data. Unfortunately, the failure of the DO sensor during cycle test 2 was not recognized until Cycle 3. No DO data were obtained from 11 August 2009 (cycle 2 recharge) through 13 February 2010 (Cycle 3 recharge). The SeaCat profiler was retrieved and returned to the manufacturer on 13 February 2010, and redeployed on 30 March 2010 (cycle 3 recharge). Due to an unanticipated draw on electrical power related to the probe attempting to communicate with the SFWMD SCADA system no data were obtained between 29 June 2010 (cycle test 3 recharge) and 29 August 2010 (cycle test 3 storage). Monthly downloads were initiated to have better understanding of probe performance. The SeaCat Profiler was again retrieved for recalibration on 7 May 2011 (cycle test 3 recovery), and redeployed in preparation for cycle test 4 on 25 June 2011.

Ecotoxicological testing of Kissimmee River ASR effluent was reduced during cycle test 3, to include only tests that were required by NPDES and CERPRA permits. Of the tests listed in **Table 9-12**, only the following tests were performed: 1) 96-hr LC50 acute static renewal using test organisms *C. dubia and C. leedsi*; and 2) the 7-day chronic static renewal using test organisms *C. dubia and P. promelas*. The 7-day chronic static renewal test using *P. promelas* was conducted with larval r organisms, with survival and growth endpoints. This differs slightly than the 7-day static renewal tests that were conducted during cycle tests 1 and 2 **(Table 9-11, Table 9-12)**, in that embryonic *P. promelas* was the test organism, and the endpoints were survival and teratogenicity. Evaluation of the ecotoxicological effects of recovered water are discussed in **Section 10**.

Cycle test 3 operation proceeded consistently, although UV disinfection system performance remained inadequate. Treated recharge water at the ASR wellhead showed detectable total coliforms in 21 of 24 samples. *Clostridium perfringens*, enterococci, and cyanobacteria were detected frequently during monthly extended microbiological sampling. Operational changes to improve UV disinfection system performance, such as slower pumping rate and adjustments to the UVector sensors, were not successful. In order to improve compliance with the UIC permit requirement of zero total and fecal coliform detections, operations staff initiated monthly chlorination events in which the filter and recharge lines were soaked in dilute sodium hypochlorite for one day, then purged prior to resumption of recharge. Purged water was diverted to the ponds, not the Kissimmee River. Additional discussions on UIC permit compliance and fate of microbes in the subsurface are found in **Sections 7.1.2 and 9.4**, respectively.

9.2.2.5 Cycle Test 4

Cycle test 4 is intended to evaluate reproducible hydrogeologic performance during successive large-volume cycle tests. Cycle test 4 recharge commenced on 11 July 2011, less than one month after completion of cycle test 3. Recharge proceeded nearly uninterrupted for 7 months (217 days) with few system shut-downs. The average recharge pumping rate was 4.81 MGD, and the average wellhead pressure was 22.2 psi. Wellhead pressures have slowly declined since the second well rehab event, reflecting development of the aquifer during cycle testing. After a one-year storage duration, recovery was initiated on 2 January 2013 and ceased on July 1, 2013, with a recovery of 90 percent by volume and an average pumping rate of 5.02 MGD. Cycle testing ended early due to contractual constraints. The specific conductance of recovered water never exceeded the 1275 µS/cm maximum during recovery. Nearly one-billion gallons of treated surface water was recharged, stored, and recovered through a single well during cycle test 4 making this one of the largest single-well cycle tests conducted to date in Florida.

Fewer water quality analytes were measured during cycle test 4. Water quality sampling was performed biweekly for the first two months, then replaced by monthly sampling frequency during recharge and recovery. Storage phase monitoring was restricted to analytes required by the UIC permit. Most of the water quality analytes measured during cycle test 3 also were measured during cycle test 4 recharge and recovery, with two exceptions. Manganese was deleted from the trace inorganic constituents because this metal was not detected in most samples during cycle tests 1 through 3. Cyanobacteria analysis was deleted from the microbiological suite because it is not required by permit, and sufficient data were obtained during cycle tests 1 through 3. All major and trace inorganic constituents and nutrient analytes were measured at the ASR well and the storage zone monitor wells that are open to the upper Floridan Aquifer. During the storage phase, wells were sampled only for analytes required for UIC permit compliance. This reduction of samples and analytes during storage resulted in lower cost, but the ability to sufficiently define water quality changes during a long storage phase remained.

In-situ monitoring using down-hole sensors was expanded during cycle test 4. In addition to the SeaCat Profiler deployed in the 350-ft SZMW (MW-10), two additional CTD (conductivity, temperature, depth/pressure) sensors were deployed in the 2,350-ft SZMW (MW-18) and the 4,200-ft SZMW (MW-19). These data are important for calibration of the inset groundwater flow and transport model at KRASR, and provide more detail about the direction and rate of recharge water flow through the aquifer. The SeaCat Profiler was re-installed on 25 June 2011, just prior to initiation of cycle test 4 on 11 July 2011. Sensor data collection continued uninterrupted until 4 January 2012 (cycle test 4 recharge), when the DO sensor failed. Data collection continued without the DO sensor through 6 May 2012 (cycle test 4 storage), when it was retrieved for re-calibration by the manufacturer. The SeaCat Profiler was re-deployed on 7 July 2012 for data collection through cycle test 4 storage and recovery phases.

Ecotoxicological testing of Kissimmee River ASR effluent during cycle test 4 was identical to that in cycle test 3. Only tests that were required by NPDES and CERPRA permits were performed. Of the tests listed in **Table 9-12** only the following tests were performed: 1) 96-hr LC50 acute static renewal using test organisms *C. dubia and C. leedsi*; and 2) the 7-day chronic static renewal using test organisms *C. dubia and P. promelas*. Evaluation of the permit-required toxicity testing of recovered water is discussed in **Sections 7 and 10**.

Cycle test 4 operations continued smoothly with very few system shut-downs during recharge. The ASR system was shut down for less than one day per month for chlorination of the filter and recharge lines. Other infrequent shut-downs lasting a few hours resulted from storm-induced power outages, or call-outs on the SCADA system due to UV wiper failures or filter valve issues. The UV disinfection system continued to perform inadequately. Recharge water at the ASR wellhead showed detectable total coliforms in 8 of 9 monthly samples, and one detection each of *Clostridium perfringens* and *Cryptosporidium parvum.* Additional discussions on UIC permit compliance and fate of microbes in the subsurface are found in **Sections 7.1.2 and 9.4**, respectively.

9.3 Hillsboro ASR System

9.3.1 Water Quality Monitoring Program

The Hillsboro Canal is classified as a State of Florida Class III surface water, with designated uses that include fish consumption, recreation, and propagation and maintenance of a healthy, well-balanced population of fish and wildlife. This Hillsboro Canal transmits dry-season discharges and regulatory releases from Water Conservation Area-1 and -2 (WCA-1, also known as Loxahatchee National Wildlife Refuge) and features located upstream. The primary downstream user of the Hillsboro Canal is the Lake Worth Drainage District, which draws from the canal for water supply. Excess Hillsboro Canal water (primarily storm flow discharge) is released to tide into the Lake Worth Lagoon.

The Floridan Aquifer is classified as an underground source of drinking water. Therefore, any ASR cycle testing program must be in compliance with State and Federal regulations that protect both surface and groundwater quality. Surface water quality criteria, and regulated discharge of recovered water into the Hillsboro Canal are defined within the National Pollution Discharge Elimination System (NPDES) of the Clean Water Act (CWA), and F.A.C. 62-302.530 (State of Florida Surface Water Quality Criteria). The Hillsboro Canal east of the S-39 structure is beyond the Everglades Protection Area, so phosphorus concentrations need not comply with F.A.C. 62-302.540 (State of Florida Water Quality Standards for Phosphorus in the Everglades Protection Area). The appropriate surface water quality guideline for phosphorus concentrations is not well-defined at this site, but discharge from HASR must not degrade surface water quality in the Hillsboro Canal. Groundwater quality criteria are defined within the Underground Injection Control (UIC) program of the Safe Drinking Water (SDWA) and F.A.C. 62-550 (Drinking Water Standards, Monitoring and Reporting). Surface water (recharge water) and native groundwater are characterized prior to the onset of cycle testing so that water quality changes in groundwater or recovered water can be identified.

9.3.1.1 Recharge Water Quality

The Hillsboro Canal (L-39) is the source of recharge water to the HASR system. Land use in adjacent water conservation areas WCA-1 and WCA-2 are managed freshwater wetlands and swamps. These water conservation areas are remnants of the original central Everglades ecosystem.

Surface water quality in the Hillsboro Basin (WCA-1 and -2) upstream of HASR reflects natural, undeveloped wetland conditions that are largely unaffected by agricultural activities. However, during extreme dry season conditions, Lake Okeechobee water can be routed to the Hillsboro Canal through the L-14 and L-15 canals. This undesirable condition brings nutrient-rich water to the Hillsboro Basin.

Major and trace inorganic constituent concentrations in HASR recharge water are characterized using ASR wellhead samples obtained during the recharge phase of cycle tests 1 through 3 (2010 through 2012). These data are supplemented by quarterly analysis of Hillsboro Canal surface water samples (N=12) that were collected upstream (at S-39), adjacent to, and downstream of the HASR system prior to cycle testing (2002). Generally, the 2002 surface water samples were analyzed for primary and secondary inorganic, organic constituents, and microorganisms required for SDWA compliance.

Additional analytes (primarily nutrients and metals) were added to the analytical protocol for geochemical modeling and interpretation.

Considering major and trace inorganic constituents, recharge water at HASR is oxic, and has neutral pH, moderate carbonate alkalinity, and low-to-moderate total dissolved solids (TDS) and chloride concentrations. Major inorganic constituent concentrations such as calcium, magnesium, and carbonate alkalinity are greater than those in the Kissimmee River at KRASR, reflecting contact with surficial limestone in the Hillsboro Basin. Most Hillsboro Canal inorganic constituent concentrations are twice those of Kissimmee River surface water samples. HASR recharge water shows relatively high concentrations of total and dissolved organic carbon and color. A descriptive statistical compilation of major and trace inorganic constituent concentrations and field parameters is shown in **Table 9-13**. Surface water flows through wetlands of the undeveloped Hillsboro Basin upstream of HASR, so the occurrence of agricultural chemicals (herbicides, pesticides, and nematicides) and other industrial compounds (volatile organic compounds, semi-volatile organic compounds) is rare. Primary and secondary organic constituents were analyzed in surface water samples (N=12) prior to cycle testing (2002; Tetra Tech, 2005). A single ASR wellhead sample also was analyzed during cycle test 1 (2010) recharge for primary and secondary organic constituents. Primary and secondary organic constituents analyzed in 2002 and 2010 are shown in **Table 9-14**.

Few anthropogenic organic constituents were detected in recharge water samples. The most common detections were of the "BTEX" compounds (benzene, toluene, ethylbenzene, and total xylenes), which are fuel components. In the 2002 data set, BTEX compounds were detected in four of 12 samples, at concentrations as follows: benzene, 0.14 to 0.17 µg/L; toluene, 0.36 to 3.1 µg/L; ethylbenzene, 0.19 to 0.36 µg/L; total xylenes, 0.7 to 1.1 µg/L. These concentrations are all below SDWA regulatory criteria. Pesticide compounds simazine (5 µg/L) and toxaphene (8 µg/L) were detected in a single surface water sample, and these concentrations exceed the SDWA criteria of 4 µg/L and 3 µg/L, respectively. All other compounds listed on **Table 9-14** were not detected.

Waterborne microorganisms in Hillsboro Canal surface water at HASR are most likely naturally occurring or reflect non-point sources. The HASR intake structure is approximately 700-ft downstream of water control structure S-39, which controls flow out of L-40 and WCA-1 and -2. Representative and indicator microorganisms and viruses (bacteriophages) were analyzed in ASR wellhead samples during the recharge phase of cycles 1 through 3. Bacteria include total and fecal coliforms, *Escherichia coli*, enterococci, *Clostridium perfringens* and cyanobacteria. Bacteria were detected most frequently in recharge water samples. Of these, fecal coliforms, enterococci, and *E. coli* are most directly associated with mammalian waste sources in the watershed. Cyanobacteria were detected in every recharge water sample. Cyanobacteria samples were quantified as number of cells, but cells were not identified to genus in recharge water sample. Protozoan pathogens *C. parvum* and *G. lamblia* were absent. Microorganism abundances measured in recharge water samples are shown in **Table 9-15.**

Table 9-13 -- Major and Trace Dissolved Inorganic Constituents in Recharge Water from the Hillsboro Canal, Baseline (2002) and Cycle Tests 1 through 3 (2010-2012)

Constituent or Parameter	Unit	Criteria	Value					
			Mean	Std Dev	Median	Maximum	Minimum	N
Temperature	º C		25.1	5.1	25.0	31.8	9.7	45
Specific Conductance	µS/cm	1275	653	165	678	960	217	45
pH	Std units	6 to 8	7.6	0.3	7.7	8.2	6.9	46
ORP	mV		32	65	23	156	-142	44
Dissolved Oxygen	mg/L	> 5.0	5.7	2.2	6.0	10.6	0.6	45
Turbidity	NTU	< 29	2.4	1.7	1.9	11	0.9	46
Total dissolved solids	mg/L		396	98	383	640	130	45
Tot. suspended solids	mg/L		3.7	3.2	2.1	10	0.1	18
Color	PCU		71	26	69.5	130	20	44
Hardness	mg/L		227	71	240	310	68	12
Calcium	mg/L		61.7	15.0	64.0	78.7	19.0	26
Magnesium	mg/L		15.6	5.5	15.8	27.0	3.9	26
Sodium	mg/L		69.1	21.0	73.6	100	16.0	25
Potassium	mg/L		7.1	2	7	9.7	1.5	25
Sulfate	mg/L		30.1	19.8	23.9	120	3.0	44
Sulfide	mg/L		0.05	0.05	0.02	0.16	< 0.01	7
Bromide	mg/L		0.30	0.09	0.32	0.39	0.12	9
Chloride	mg/L		90	30	81	190	25	45
Fluoride	mg/L	< 10	0.3	0.11	0.34	0.42	0.08	13
Silica	mg/L		11.1	--	--	--	--	1
Tot Alkalinity asCaCO3	mg/L	> 20	184	46.9	188	260	48	24
Total Cyanide	mg/L	< 0.0052	--	--	--	<0.010	< 0.005	11
Diss. Organic Carbon	mg/L		22.8	5.4	21.5	30	13	12
Total Organic Carbon	mg/L		24.5	20.1	18.4	90.2	8.0	17
Aluminum	µg/L		62	12	62	80	50	7
Antimony	µg/L	< 4,300	5	0	5	5	< 4	5
Arsenic	µg/L	< 50	2.0	1.4	1.4	5.6	0.91	41
Barium	µg/L		44	14	42	68	22	13
Beryllium	µg/L	< 0.13	--	--	--	< 0.5	< 0.050	12
Boron	µg/L		66.8	--	--	--	--	1
Cadmium	µg/L	< 0.23	1	0	1	1	< 0.050	4
Chromium	µg/L	< 73	2	0	2	2	< 0.050	4
Cobalt	µg/L		2	0	2	2	< 0.050	4
Copper	µg/L	< 7.9	2.5	0.8	2.3	3.8	< 0.93	9
Iron	µg/L		52	33	42	176	13	34
Lead	µg/L	< 2.5	--	--	--	< 3	< 0.050	13
Manganese	µg/L		10.1	4.9	11	16	3.5	7
Mercury (Ultrace)	ng/L	2	1.0	0.45	0.88	2.49	0.51	39
Methyl Mercury	ng/L		0.154	0.106	0.125	0.536	0.026	38
Molybdenum	µg/L		0.98	0.30	0.95	1.48	0.53	13
Nickel	µg/L	44.2	3.9	2.2	50	5.0	0.68	4
Selenium	µg/L	< 5.0	3.8	1.6	5.0	5.0	2.0	5
Silver	µg/L	< 0.07	--	--	--	< 1	< 0.050	13
Strontium	µg/L		1384	470	1400	2000	300	13
Thallium	µg/L	< 6.3	--	--	--	< 2	< 0.050	13
Uranium	pCi/L		< 0.729	--	--	--	--	1
Vanadium	µg/L		2.3	1.6	1.3	4.0	0.7	9
Zinc	µg/L	< 101	83.9	49.7	50.0	160	50.0	9

Note: Most samples are from the ASR wellhead, PBF-13, after filtration during recharge of cycle tests 1 through 3 (N=33). These data are supplemented by surface water samples collected at HASR before cycle testing (N=12). Concentrations reported as "<" are below the method detection limit. N, no. of samples. ORP, oxidation-reduction potential. Units: mg/L, milligram per liter; µg/L, microgram per liter; ng/L, nanograms per liter; pCi/L, picocuries per liter; º C, degrees Celsius; µS/cm, microsiemens per cm; PCU, platinum cobalt units; NTU, nephelometric turbidity units; mV, millivolts. Surface Water Quality Criteria are from State of Florida F.A.C. 62-302.530. Cadmium, chromium, copper, lead, and zinc are site-specific standards calculated for an estimated hardness concentration of 82 mg/L.

Table 9-14 -- Primary and Secondary Organic Constituents Analyzed in Recharge Water from the Hillsboro Canal (2002, 2010)

Volatile Organic Compounds		
1,2-Dibromoethane	Chlorobenzene and Trichlorobenzene	Tetrachloroethane
1,2-Dichlorobenzene	Chloroform	Tetrachloroethene
1,2-Dichloroethane	Chloromethane	Toluene
1,2-Dichloropropane	cis-1,2-Dichloroethene	trans-1,2-Dichloroethene
1,2- and 1,4-Dichlorobenzene	Dibromochloromethane	Trichloroethane
1,2-Dibromo-3-chloropropane	Dichlorodifluoromethane	Trichloroethene
Benzene	Ethylbenzene	Trichlorofluoromethane
Bromodichloromethane	Freon 113	Trihalomethanes
Bromoform	Methylene chloride	Vinyl Chloride
Carbon tetrachloride	Styrene	Xylenes (total)
Semi-Volatile Organic Compounds		
2,4,6-Trichlorophenol	Benzo(a)pyrene	Pentachlorophenol
2,4-Dichlorophenol	bis(2-Ethylhexyl)phthalate	Phenol
2,4-Dinitrophenol	Fluoranthene	Pyrene
2,4-Dinitrotoluene	Fluorene	Total carc-PAHs
2-Chlorophenol	Hexachlorobenzene	Total PAHs
Acenaphthene	Hexachlorobutadiene	Total Phthalate esters
Anthracene	Hexachlorocyclopentadiene	Total Phenolics

Pesticides			
4,4'-DDT	Chlordane	Endothall	Malathion
Alachlor	Deethylatrazine	Endrin	Methoxychlor
Aldrin	Di(2-ethylhexyl)adipate	Ethion	Metolachlor
Ametryn	Dieldrin	gamma-BHC	Norflurazon
Atrazine	Diquat	Glyphosate	Oxamyl
beta-BHC	Endosulfan I	Heptachlor	PCBs
Bromacil	Endosulfan II	Heptachlor epoxide	Simazine
Carbofuran	Endosulfan sulfate	Hexazinone	Toxaphene

Herbicides				
2,4,5-TP	2,4-D	Dalapon	Dinoseb	Picloram

Table 9-15 -- Microbes and Pathogens in Recharge Water from the Hillsboro Canal, Cycle Tests 1 through 3 (2010-2012)

Microbe or Pathogen	Unit	No. samples with Positive Detection	Total No. of Samples	Per-cent Detect	Mini-mum Value	Maxi-mum Value	Geo-metric Mean	Std Dev	Med-ian
Total Coliform	CFU/100 mL	28	32	88	1	> 200	28	76	21
Fecal Coliform	MPN/100 mL	14	31	45	1	79	3.7	18	2
E. coli	CFU/100 mL	6	13	46	1	65	3.3	19	1
Enterococci	MPN/100 mL	3	3	100	1	35	3	20	1
Clostr. perfringens	CFU/100 mL	3	3	100	9	27	17	9	22
Coliphage	PFU/100 mL	1	3	33		1			
Giardia lamblia	oocysts/100 mL	0	3	0					
Crypto. parvum	oocysts/100 mL	0	3	0					
Cyanobacteria	cells/mL	3	3	100	1	39	9	19	23

Note: All samples from the ASR wellhead, PBF-13, after filtration during recharge of cycle tests 1 through 3. For all microorganisms, "detections" are data that are not "U" flagged (analyzed but not detected); "I" flagged values (value > MDL but < PQL) are reported as detections.

Total phosphorus (TP) is the most important constituent of concern in the Water Conservation Areas and Hillsboro Canal. TP loads result from non-point sources in WCA-1 and -2. Total nitrogen (TN) load (sum of nitrate, nitrite, ammonia and total Kjeldahl nitrogen, TKN) also degrades surface water quality, but currently does not have a defined regulatory criterion. Nutrient concentration data in recharge water samples at the HASR system during cycle testing is sparse for all species except phosphorus. Therefore, the nutrient composition of recharge water is characterized using surface water data measured at the S-39 structure during the period from 2000 to 2012 (DBHydro database). Nutrient concentrations in recharge water are shown in **Table 9-16**. Total phosphorus concentrations in recharge water reported here are statistically similar compared to average historical surface water TP measurements at S-39. Although there is only one wellhead sample measurement, total ammonia concentration (0.44 mg/L) is significantly higher than average historical surface water ammonia measurements at S-39 (0.023 +/- 0.021 mg/L). All nitrate and nitrite measurements (ASR wellhead and surface water) were in compliance with the SDWA regulatory standard.

Table 9-16 -- Nutrients in Recharge Water from the Hillsboro Canal: Surface Water (2000 - 2012) and Cycle Tests 1 through 3 (2010-2012)

Nutrient	Unit	Criteria	Value					
			Mean	Std Dev	Median	Maximum	Minimum	N
Nitrate N – ASR WH	mg/L	10	0.25	--	--	--	--	1
Nitrate N – SW at S-39			0.067	0.142	0.021	0.734	0.004	64
Nitrite N – ASR WH	mg/L	1	< 0.025	--	--	--	--	1
Nitrite N- SW at S-39			0.011	0.022	0.004	0.141	0.002	60
Tot. Kjeldahl N – ASR WH	mg/L	none	--	--	--	--	--	-
Tot. Kjeldahl N SW at S-39			1.47	0.35	1.43	2.71	0.77	206
Total Ammonia - ASR WH	mg/L		0.44	--	--	--	--	1
Total Ammonia - SW at S-39			0.023	0.021	0.018	0.167	0.008	151
Total Nitrogen – ASR WH	mg/L	none	--	--	--	--	--	-
Total Nitrogen SW at S-39			1.76	0.55	1.63	3.67	0.96	45
Total Phosphorus – ASR WH	mg/L		0.042	0.076	0.021	0.350	0.0026	28
Total Phosphorus SW at S39			0.026	0.017	0.021	0.132	0.008	206
ortho-Phosphorus ASR WH	mg/L	none	0.0043	--	--	--	--	1
ortho-Phosphorus SW at S39			0.011	0.013	0.006	0.075	0.002	118

Note: Wellhead (WH) samples were collected from the ASR wellhead (PBF-13) after filtration and UV disinfection, during recharge of cycle tests 1 through 3. Surface water samples were collected at S-39. Concentrations reported as "less than" are below the method detection limit. N, number of samples. Surface Water Quality Criteria are from Florida F.A.C. 62-302.530. Primary and secondary inorganic criteria of the SDWA also are listed.

Selected radionuclides (radium-226 and radium-228) were analyzed in Hillsboro Canal surface water samples, supplemented by gross alpha analyses at the ASR wellhead. Gross alpha activity measurements serve as a general indicator of the presence of uranium, thorium, and radium radionuclides in a sample. All radionuclide activities were detected at levels below regulatory criteria. Radionuclide data are shown in Table **9-17**.

Table 9-17 -- Radionuclides in Recharge Water from the Hillsboro Canal: Surface Water (2002) and Cycle Test 3 (2012)

Radionuclide	Unit	Criteria	Mean Value	Std Dev	Median	Maxi-mum	Mini-mum	No. of samples (N)
Gross Alpha	pCi/L	15	3.4	4.2	1.93	13.6	1.4	8
Radium-226	pCi/L	5	0.391	0.131	0.387	0.589	0.229	11
Radium-228	pCi/L		1.69	0.77	1.40	2.95	0.12	11

Note: All samples were collected from the ASR wellhead (PBF-13) after filtration and UV disinfection, during recharge of cycle tests 1 and 3, supplemented by surface water measurements (2002) in the Hillsboro Canal (USACE, 2005). Radium-226 and Radium-228 isotopes were quantified separately, but the SDWA criterion is the sum of Radium-226+Radium 228 activities.

9.3.1.2 Native Floridan Aquifer Water Quality

Native water quality characteristics of two permeable zones within the Floridan Aquifer System in the vicinity of HASR are presented. The Upper Floridan Aquifer (UFA) is the storage zone for the HASR system; the Avon Park Permeable Zone (APPZ; Reese and Richardson, 2008) underlies the storage zone. Water quality characterization of the surficial aquifer at the site is found in **Section 9.3.1.3.**

Water quality of the Upper Floridan Aquifer in the vicinity of HASR is brackish, having relatively high concentrations of major inorganic constituents (TDS, calcium, magnesium, sodium, potassium, sulfate, and chloride), especially compared to more northerly, upgradient locations. Groundwater in the UFA is in contact with limestone, so carbonate alkalinity is moderate (120 to 280 mg/L) and pH is slightly alkaline (7.1 to 7.9). UFA groundwater has low but measureable dissolved and/or total organic carbon concentrations (2 to 3 mg/L), which is surprising given that groundwater now in the vicinity was recharged greater than 25,000 years ago (Morrissey et al., 2010). The redox condition is sulfate-reducing, with measureable dissolved sulfide (2.8 to 4.6 mg/L). Inorganic trace constituent concentrations also are low, with most metals ranging from 20 μg/L to below the MDL (typically less than 0.2 μg/L). The native UFA is iron-poor, with concentrations typically below the MDL (less than 24 μg/L); nutrient-poor (nitrogen and phosphorus species typically are below the MDL); and has low radium radionuclide activity (less than 5 pCi/L). Major and trace dissolved inorganic constituent and nutrient concentrations and radionuclide activities from the native UFA are summarized in **Table 9-18.**

A suite of anthropogenic organic compounds similar to those listed in **Table 9-3** was analyzed in a single groundwater samples from the upper UFA during construction of the ASR well (PBF-13; Bennett et al., 2000) prior to the onset of cycle testing. There were no detections of anthropogenic organic compounds (VOCs, semi-volatile organic compounds, pesticides, herbicides, and drinking water compounds) in this sample. Anthropogenic organic compounds were analyzed in an annual water quality characterization sample from storage zone monitor well PBF-10R, but this was obtained during (not prior to) cycle test 1 (March 22, 2010). There were no detections of anthropogenic organic compounds (VOCs, semi-volatile organic compounds, pesticides, herbicides, and drinking water compounds) in this sample.

Water quality characteristics of the Avon Park Permeable Zone (APPZ) in the vicinity of HASR are similar to that the UFA, because brackish groundwater is in contact with a dolomitic limestone or dolostone (Reese and Richardson, 2008). At HASR, the open interval for the PBF-11 well is 1,500-ft to 1,677-ft bls, so a large portion of this permeable zone is sampled. The depth of the APPZ in the HASR area (southeast of Lake Okeechobee) typically extends from approximately -1400-ft to -1800-ft NGVD1929 (Reese and Richardson, 2008). The APPZ groundwater is brackish, although less so than the overlying UFA. Samples show moderate concentrations of major dissolved inorganic constituents (TDS, calcium, magnesium, sodium, potassium, sulfate, and chloride). Groundwater in the APPZ is in contact with dolomitic limestone, so carbonate alkalinity is moderate (122 mg/L) and pH is slightly alkaline (7.9). The redox condition is sulfate-reducing, with measureable dissolved sulfide and iron (1.5 mg/L and 160 µg/L, respectively). Dissolved inorganic trace constituent concentrations are also low, with measureable barium (22.8 µg/L), boron (110 µg/L), and strontium (10.5 mg/L) concentrations. All other metal concentrations except manganese are below the MDL (typically less than 11 µg/L). Nutrient nitrogen and phosphorus species concentrations are below the MDL. Gross alpha and radium radionuclide activities are below their regulatory criteria (less than 15 and 5 pCi/L, respectively). Organic compounds were not measured in any APPZ sample. Major and trace dissolved inorganic constituent and nutrient concentrations and radionuclide activities from the native APPZ are summarized in **Table 9-19**.

Table 9-18 -- Major and Trace Dissolved Inorganic Constituents, Nutrients, and Radionuclides in the Native Upper Floridan Aquifer at HASR (PBF-10R, PBF-13), 2000-2010

Constituent or Parameter	Unit	Criteria	PBF-10R and PBF-13					
			Mean	Std Dev	Median	Maximum	Minimum	N
Temperature	º C		24.1	0.7	24.0	25.0	21.4	24
Specific Conductance	in µS/cm		8,646	577	8,620	9,881	6,587	23
pH	std unit	6.5 - 8.5	7.4	0.2	7.4	7.9	7.1	24
ORP	mV		-190					1
Dissolved Oxygen	mg/L		0.6	0.7	0.4	2.7	0.1	18
Turbidity	NTU		0.36					1
Total Dissolved Solids	mg/L	500	5,314	490	5,300	6,500	4,064	23
Total Suspended Solids	mg/L		22					1
Color	PCU	15	< 5					1
Hardness	mg/L		1,176	130	1,204	1,300	936	6
Calcium	mg/L		156	9.3	157	170	135	25
Magnesium	mg/L		189	14.4	191	210	143	25
Sodium	mg/L	160	1,469	182	1,460	1,900	1,020	25
Potassium	mg/L		54.7	6.0	55.3	66.0	37.4	24
Sulfate	mg/L	250	833	106	836	1,100	561	23
Sulfide	mg/L		3.7	1.3	3.7	4.6	2.8	2
Bromide	µg/L		7.8					1
Chloride	mg/L	250	2,293	277	2,327	2,740	1,490	24
Fluoride	mg/L	4.0	1.6	0.8	1.3	3.5	1.2	7
Silica	mg/L		10.5	3.2	11.2	13.4	5.1	5
Total Alkalinity	mg/L as CaCO3		136	31.1	130	280	120	24
Total Cyanide	mg/L	200	< 0.005					3
Diss. Organic Carbon	mg/L		1.4	1.0	1.4	2.1	0.7	2
Total Organic Carbon	mg/L		2.2	0.6	2.1	3.0	1.6	4
Aluminum	µg/L	50				< 30	< 20	3
Antimony	µg/L	6				< 2.3	< 2.3	2
Arsenic	µg/L	10				< 2.6	< 1	3
Beryllium	µg/L	4				< 0.1	< 0.1	2
Barium	µg/L	2	13.7	4.7	11.7	22.0	10.0	7
Boron	µg/L					1,800	1,800	1
Cadmium	µg/L	5				< 1	< 0.7	3
Chromium	µg/L	100				< 1.8	< 0.83	3
Cobalt	µg/L					< 1	< 0.71	3
Copper	µg/L	1000				< 1.7	< 1.4	3
Iron	µg/L	300	47.1	23.6	57.8	63.5	20.0	3
Lead	µg/L	15				< 3	< 2.2	3
Manganese	µg/L	50	3.3	3.2	2.7	6.8	0.5	3
Mercury (Inorganic)	µg/L	2				< 0.06	< 0.06	2
Mercury (Ultrace),	ng/L	2000	0.005			< 0.01		2
Methyl Mercury	ng/L		0.0004			< 0.005		2
Molybdenum	µg/L							
Nickel	µg/L	100				< 2	< 1.8	3
Selenium	µg/L	50				< 6.2	< 2.1	3
Silver	µg/L	100				< 1	< 1	2
Strontium	µg/L		9,826	776	9,700	11,284	8,940	7
Thallium	µg/L	2				< 14	< 1	3
Uranium	µg/L	30	0.0737					1
Vanadium	µg/L					< 0.4	< 0.4	2
Zinc	µg/L	5000				< 14	< 10	3
Ammonia	mg/L							
Nitrate N	mg/L	10				< 0.10	< 0.10	1
Nitrite N	mg/L	1				< 0.5	< 0.5	1
Nitrogen, Tot Kjeldahl	mg/L		0.8					1
Phosphorus, Total as P	mg/L	0.01				< 0.026	< 0.010	2
ortho-Phosphorus	mg/L					< 0.5	< 0.5	1
Gross Alpha	pCi/L	15			< 4.67	< 30	< 3.53	3
Ra-226	pCi/L	5	2	0	2.32	2.38	1.84	3
Ra-228	pCi/L		1.1	0.7	1.1	1.6	0.64	2

Note: All samples collected from the wellheads prior to the onset of cycle testing. Concentrations reported as "<" are below the method detection limit. N, number of samples. ORP, oxidation-reduction potential. Units: mg/L, milligram per liter; µg/L, microgram per liter; ng/L, nanograms per liter; pCi/L, picocuries per liter; º C, degrees Celsius; µS/cm, microsiemens per cm; PCU, platinum cobalt units; NTU, nephelometric turbidity units; mV, millivolts Primary and secondary drinking water criteria are from Florida F.A.C. 62-520.400 and the Federal SDWA.

Table 9-19 -- Major and Trace Dissolved Inorganic Constituents, Nutrients, and Radionuclides in the Native Avon Park Producing Zone (PBF-11) Groundwater, 1999 - 2009

Constituent or Parameter	Unit	Criteria	Value					
			Mean	Std Dev	Median	Maximum	Minimum	N
Temperature	º C		23.6	0.7	23.4	24.9	22.8	17
Specific Conductance	in µS/cm		4,083	696	4,384	4,672	2,529	16
pH	std unit	6.5 - 8.5	7.93	0.38	7.80	9.00	7.58	17
ORP	mV							0
Dissolved Oxygen	mg/L		0.49	0.56	0.28	2.20	0.05	14
Turbidity	NTU							0
Total Dissolved Solids	mg/L	500	2,488	422	2,569	3,200	1,262	14
Total Suspended Solids	mg/L							0
Color	PCU	15						0
Hardness	mg/L as CaCO3		656	52	670	696	532	8
Calcium	mg/L		89.4	14.8	94.2	100	44.2	16
Magnesium	mg/L		107	5.1	108	120	97.0	16
Sodium	mg/L	160	660	32.1	651	723	611	16
Potassium	mg/L		24	3.0	24	34	20	15
Sulfate	mg/L	250	331	29.2	339	380	253	16
Sulfide	mg/L		1.5					1
Bromide	µg/L		< 8.0					1
Chloride	mg/L	250	1,162	100	1,200	1,320	1,000	17
Fluoride	mg/L	4	1.5					1
Silica	mg/L		10	3.8	13	13	6	3
Total Alkalinity	mg/L as CaCO3		122	24.2	130	140	45	17
Total Cyanide	mg/L	200	< 0.005					1
Diss. Organic Carbon	mg/L		1.27					1
Total Organic Carbon	mg/L		2.1	1.6	2.1	3.2	1.0	2
Aluminum	µg/L	50	< 30					1
Antimony	µg/L	6						0
Arsenic	µg/L	10	< 1					1
Beryllium	µg/L	4						0
Barium	µg/L	2	22.8	1.8	22.8	24.0	21.5	2
Boron	µg/L		110					1
Cadmium	µg/L	5	< 1					1
Chromium	µg/L	100	< 0.71					1
Cobalt	µg/L							0
Copper	µg/L	1000	< 1.7					1
Iron	µg/L	300	160	156	160	270	50	2
Lead	µg/L	15	< 2.2					1
Manganese	µg/L	50	17.2	3.1	17.2	19.4	15	2
Mercury (Ultrace),	ng/L	2000	5					1
Methyl Mercury	ng/L		0.18					1
Molybdenum	µg/L							0
Nickel	µg/L	100	< 1.8					1
Selenium	µg/L	50	< 6.2					1
Silver	µg/L	100						0
Strontium	µg/L		10,480	735	10,480	11,000	9,960	2
Thallium	µg/L	2	< 11					1
Uranium	µg/L	30						0
Zinc	µg/L	5000	< 3					1
Nitrate N	mg/L	10	0.004					1
Nitrite N	mg/L	1	< 0.004					1
Tot. Kjeldahl N	mg/L		0.511					1
Phosphorus, Total as P	mg/L		< 0.0026					1
Gross Alpha	pCi/L	15	< 0.5					1
Ra-226	pCi/L	5	2.59					1
Ra-228	pCi/L		< 0.26					1

Note: All samples collected from the PBF-11 wellhead prior to the onset of cycle testing. Concentrations reported as "<" are below the method detection limit. N, number of samples. ORP, oxidation-reduction potential. Units: mg/L, milligram per liter; µg/L, microgram per liter; ng/L, nanograms per liter; pCi/L, picocuries per liter; º C, degrees Celsius; µS/cm, microsiemens per cm; PCU, platinum cobalt units; NTU, nephelometric turbidity units; mV, millivolts. Primary and secondary drinking water criteria are from Florida F.A.C. 62-520.400 and the Federal SDWA.

9.3.1.3 Surficial Aquifer Water Quality

Water quality characteristics of the surficial aquifer are defined so that effects resulting from ASR cycle testing can be detected. Potential effects include leaching of inorganic constituents (such as metals) from the on-site backwash receiving pond, or (more unlikely) upward migration of groundwater from the storage zone. Sampling the surficial aquifer is a UIC permit requirement. At HASR, only constituents required by the UIC permit were analyzed. ASR cycle testing caused no effects on surficial aquifer water quality, which is discussed in **Section 9.9.2.** Therefore, water quality of the surficial aquifer is characterized using all sample data obtained during cycle tests 1 through 3, 2010 through 2012. Water quality characteristics of the surficial aquifer are summarized in **Table 9-20.**

Table 9-20 -- Water Quality Characteristics of Surficial Aquifer (PBS-11) Groundwater, 2010-2012

Constituent or Parameter	Unit	Criteria	Value					
			Mean	Std Dev	Median	Maximum	Minimum	N
Temperature	º C		24.7	0.80	24.8	26.1	22.2	52
Specific Conductance	in µS/cm		4,499	128	4,545	4,767	4,215	52
pH	std unit	6.5 - 8.5	7.0	0.13	7.0	7.5	6.6	52
ORP	mV		-232	52	-238	-98	-313	49
Dissolved Oxygen	mg/L		0.6	0.79	0.3	3.4	0.0	52
Turbidity	NTU		1.1	2.1	0.3	11	0.1	52
Total Dissolved Solids	mg/L	500	2,597	162	2,580	3,120	2,290	49
Color	PCU	15	15	5	15	35	5	50
Sulfate	mg/L	250	237	41.7	219	303	202	5
Chloride	mg/L	250	1,075	90	1,075	1,250	894	50
Arsenic	µg/L	10	1.4	0.53	1.4	2.2	0.7	10
Gross Alpha	pCi/L	15	6.4	3.7	6.6	16.6	1.1	13

Note: All samples collected from the PBS-11 well using a submersible pump, throughout the entire cycle testing program. N, number of samples. ORP, oxidation-reduction potential. Units: mg/L, milligram per liter; µg/L, microgram per liter; ng/L, nanograms per liter; pCi/L, picocuries per liter; º C, degrees Celsius; µS/cm, microsiemens per cm; PCU, platinum cobalt units; NTU, nephelometric turbidity units; mV, millivolts. Primary and secondary drinking water criteria are from Florida F.A.C. 62-520.400 and the Federal SDWA.

9.3.2 Cycle Testing Program

9.3.2.1 Overview

The overall cycle testing goal for HASR is to evaluate the feasibility of creating a large storage volume during a single wet season, for distribution in the dry season during an annual cycle. Excess flows from WCA-1 and -2 into Hillsboro Canal are captured and stored in the UFA, and then recovered back into Hillsboro Canal. Wet season storage would capture freshwater flows otherwise lost to tide. Dry season recovery would increase water supply and mitigate saltwater intrusion downstream.

Native UFA groundwater at HASR has poorer water quality that that at KRASR, due to higher TDS and major inorganic constituent concentrations. Mixing of fresh recharge water with brackish groundwater results in a lower percent volume recovery (21 percent) during cycle test 2 compared to KRASR. However, local freshening of the aquifer by recharging large volumes of fresh surface water results in improved percent recovery (41 percent) during cycle test 3.

Three cycle tests were completed at HASR. Cycle test 1 consisted of one month each: recharge, storage, and recovery. During cycle test 1 only, 85 percent of the water was recovered even though water quality exceeded the chloride and specific conductance maximum criteria (250 mg/L and 1275 µS/cm, respectively). A mixing zone exemption for chloride and specific conductance was in force for cycle test 1 only. Cycle test 2 was conducted with a longer recharge duration (3 months; 374 MG) followed immediately by recovery to surface water quality criteria. Cycle test 3 somewhat duplicated cycle test 2, but included a 2-month storage phase to evaluate water quality changes. Cycle test duration and volume characteristics are summarized in **Table 9-21.** A graphical display of the cycle test history at HASR is shown in **Figure 9-2.**

Table 9-21-- Recharge, Storage, and Recovery Pumping Rate, Durations, and Volumes During HASR Cycle Tests

Phase	Start Date	End Date	No. of Days	Avg. Pumping Rate (MGD)	Volume, in MG		Percent Volume Recovered
					Recharge	Recovery	
Cycle 1							
Recharge	4-Jan-10	4-Feb-10	31	4.8	153.96	__	__
Storage	5-Feb-10	7-Mar-10	30	__	__	__	__
Recovery	8-Mar-10	2-Apr-10	25	5.0	__	130.7	85 %
Cycle 2							
Recharge	26-Apr-10	26-Jul-10	92	3.8	374.91	__	__
Storage	27-Jul-10	27-Jul-10	1	__	__	__	__
Recovery	28-Jul-10	17-Aug-10	21	3.7	__	77.6	21 %
Cycle 3							
Recharge	10-Nov-11	7-Mar-12	118	4.8	356.86	__	__
Storage	8-Mar-12	28-May-12	78	__	__	__	__
Recovery	29-May-12	26-Jun-12	28	3.5	__	145	41 %

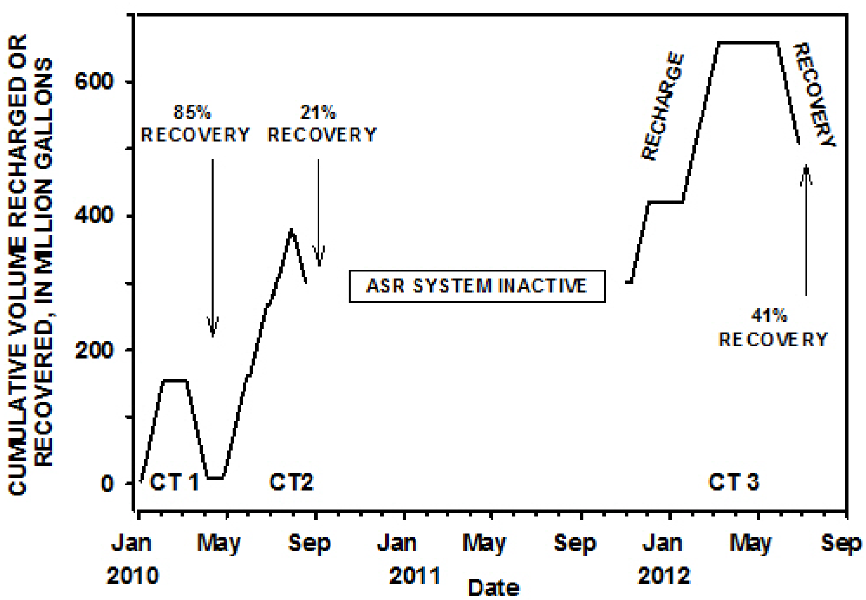

Figure 9-2 -- Cycle test (CT) history at the Hillsboro ASR system.

9.3.2.2 Cycle Test 1

The inaugural cycle test at HASR was initiated on 4 January 2010 and completed on 2 April 2010. Cycle test 1 consisted of recharge, storage, and recovery phases each having a duration of approximately 1 month. For this cycle only, a mixing zone exemption to CERPRA permit 01543872-003-GL (Appendix F) permitted the release of recovered water having chloride and specific concentrations that exceed the maximum regulatory criteria of 250 mg/L and 1,275 µS/cm respectively. Recharge and recovery pumping flow rates were similar, consistently at or near the 5 MGD rate. Wellhead pressures increased from 41 to 54 psi through recharge, but these values are below the UIC permit maximum value of 66 psi.

The suite of water quality analytes measured weekly through cycle test 1 was based primarily on NPDES and CERPRA permit requirements. Arsenic exceeded the SDWA maximum contaminant level (MCL; 10 µg/L) in recovered water samples from the ASR well, with concentrations ranging between 15 and 102 µg/L. Arsenic remained below the MCL in all monitor well samples throughout cycle test 1. Detailed discussions of water quality changes, including the “first flush” characterization of water and solids from the ASR well at the onset of recovery, are found in **Section 10**. Hydrogeologic and hydraulic analysis is presented in **Section 5.6.** During the recharge phase of cycle test 1, total coliforms were detected in all four weekly samples at the ASR wellhead **(Table 9-15)**.

The presence of total coliforms in recharge water at the ASR wellhead indicates that the UV disinfection system does not provide consistent and sufficient coliform inactivation. However, there were no detections of total or fecal coliforms in any monitor well sample during cycle test 1. During the recovery phase of cycle test 1, water discharged back to the Hillsboro Canal was monitored weekly for NPDES and CERPRA permit compliance. Turbidity measurements and mercury analyses were in compliance with permit criteria, and are discussed further in **Section 7.2**.

Toxicity tests were performed using source water and recovered water during cycle test 1 at HASR **(Table 9-22)**. Source water toxicity was evaluated in ecotoxicity tests that exceeded CERPRA or NPDES permit requirements. Recovered water toxicity was evaluated during specific conductance toxicity testing, as required by CERPRA permit 01543872-003-GL and NPDES permit FL0484890-001-IW7A (**Appendix F**). The specific conductance toxicity test is a bioassay to determine organism survival in mixtures of recovered water and surface water, when the discharge specific conductance value exceeds 1,275 µS/cm. Ecotoxicological studies of source and recovered water are consistent with objective 5 **(Table 3-1).** Results are discussed in **Section 10.**

Table 9-22 -- Toxicity Testing for Permit Compliance and Ecotoxicity Studies Conducted During Cycle Test 1 at HASR

Test or Study	Endpoint	Permit	Test Organism	
7-day chronic static renewal	Survival and reproduction	Ecotox	*Ceriodaphnia dubia*	water flea
7-day chronic static renewal	Survival and growth	Ecotox	*Pimephales promelas*	fathead minnow
LC50 96-hour acute static renewal	survival	NPDES and CERPRA	*Ceriodaphnia dubia*	water flea
LC50 96-hour acute static renewal	survival	NPDES and CERPRA	*Cyprinella leedsi*	bannerfin shiner
96-hour chronic non-renewal	growth	Ecotox	*Selanastrum capricornutum*	green algae

9.3.2.3 Cycle Test 2

Cycle test 2 consists of a longer recharge phase (3 months) followed by recovery, with no intervening storage phase. The purpose of this cycle test format is two-fold: 1) to quickly quantify the volume of water that could be recovered; and 2) to develop a buffer or mixed zone between the recharged water (fresh) and native groundwater (brackish) in the storage zone because most of the recharge volume will remain in the aquifer. Recharge and recovery proceeded with few system shut downs (16 out of 114 days), with average pumping rate of 3.7 to 3.8 MGD. The percent volume recovered that meets the specific conductance regulatory standard is 21 percent.

During cycle test 2, increasing ASR wellhead (PBF-13) pressures reduced recharge flow rates. ASR wellhead pressures increased from 50 to 78 psi, probably due to the accumulation of solids and biofilms clogging the open interval of the ASR well. To reduce wellhead pressure to permitted levels (less than 66 psi), two operational strategies were introduced: 1) weekly back-flushing of the ASR well for 2 hours to remove solids; and 2) conducting an ASR well rehabilitation (similar to that conducted at KRASR) at the end of cycle test 2 **(Section 9.2.2.3)**. Water from back-flushing operations was discharged into an adjacent storage pond that has no surface connection to the Hillsboro Canal. Turbidity monitoring of back-flushing water showed that turbidity declined from approximately 700 NTU to approximately 110 NTU during the first half-hour of the two-hour operation (Verrastro, 2011). The ASR well rehabilitation was performed in July 2011, after completion of cycle test 2 (Cardno-ENTRIX, 2011b). This maintenance measure resulted in a 20 percent improvement of specific injectivity (40 gpm/ft to 50 gpm/ft at a 5.0 MGD flow rate) in the ASR well.

The suite of water quality analytes measured weekly through cycle test 2 is identical to that of cycle test 1. These data were collected primarily to evaluate UIC, NPDES, and CERPRA permit compliance. Arsenic concentrations remained below the SDWA maximum contaminant level (MCL; 10 µg/L) in all samples during obtained cycle test 2. A more detailed discussion of water quality changes during HASR cycle tests is found in **Sections 9.4** through **9.8**. Total coliform exceedances (>4 CFU/100 mL) were detected in 12 of 14 samples at the ASR wellhead during cycle test 2 recharge phase, ranging between 8 and 190

CFU/100 mL. Fecal coliform exceedances (>2 CFU/100 mL) were detected in 6 of 14 weekly recharge samples at the ASR wellhead. Total and fecal coliforms also were detected (4 of 14 samples, and 2 of 14 samples, respectively) during recharge in SZMW PBF-10R, located 330-ft west of the ASR well. These results suggest that coliforms are transported at least 330-ft from the ASR well during recharge pumping. There were no detections of total, fecal, or any other microbe in any other well sampled during cycle test 2. The consistent occurrence of total coliforms, plus occasional detections of fecal coliforms and other microorganisms, indicates that the UV disinfection system does not provide consistent and sufficient coliform inactivation during recharge.

Turbidity was monitored at all wellheads and the Point of Discharge (POD) throughout cycle test 2. The turbidity of recharge water ranged between approximately 1 to 6 NTU. Extremely high turbidity values ranging between 70 and 1000 NTU were observed in the 330-ft SZMW (PBF-10R) during the latter half of the recharge phase. In comparison, turbidity values in the 1,010-ft SZMW (PBF-14) ranged between approximately 5 and 20 NTU throughout cycle test 2. Elevated turbidity values in the 330-ft SZMW are interpreted to result from borehole collapse, which was subsequently confirmed by depth sounding. The maximum depth of the borehole was only slightly below the casing seat depth. Unfortunately, collapse of this borehole compromises the water quality data from the 330-ft SZMW from cycle test 2 forward. Despite elevated turbidity values in the 330-ft SZMW, turbid water was not recovered at the ASR wellhead. The turbidity of recovered water ranged between 0.3 and 3.2 NTU, well below the Floridan Class III surface water criterion of 29 NTU above background, so that recovered water was discharged directly to Hillsboro Canal.

Only permit-required toxicity tests were performed during cycle test 2 **(Table 9-22)**. Recovered water toxicity was evaluated using toxicity test results, as required by CERPRA permit 01543872-003-GL and NPDES permit FL0484890-001-IW7A (Appendix F). Toxicity testing consisted of 7-day chronic static renewal tests using *C. Dubia* and *C. leedsi*, identical to those tests conducted during HASR cycle test 1. The specific conductance toxicity test is a bioassay to determine organism survival in mixtures of recovered water and surface water, when the specific conductance value exceeds 1,275 µS/cm. The results of both tests showed LC50 values greater than 100 percent for both test organisms. There was no acute toxicity quantified in mixtures of recovered and control water obtained throughout cycle test 2 recovery.

9.3.2.4 Cycle Test 3

The cycle test 3 objective was to expand the duration of recharge, storage, and recovery to almost one year, to demonstrate wet season recharge followed by dry season recovery. Theoretically, larger recharge volumes should more effectively "freshen" the aquifer, resulting in improved percent recovery. Operational issues delayed the start, so the duration of recharge was reduced to 1.5 months instead of 3 months, followed by 2.5 months storage. The pumping rate during recharge was 4.8 MGD, consistent with system design criteria. Pumping during recovery occurred more slowly than in earlier cycles, to evaluate the effect of different rates on recovery. Slower pumping may improve recovery from the HASR storage zone by minimizing mixing between fresh and native brackish groundwater. A complete suite of inorganic water quality analytes was measured weekly in samples from both storage zone monitor wells during all phases of cycle test 3. All inorganic water quality analytes were measured weekly during recharge and recovery from the ASR well. All other wells were sampled for permit compliance criteria only. Water quality changes including arsenic mobilization will be interpreted using the cycle test 3 geochemical data set **(Section 9.5.2).** Total coliform exceedances were detected in every sample at the ASR wellhead during cycle test 3 recharge phase, ranging between 17 and >200 CFU/100 mL. Fecal coliform and *E. coli* exceedances were detected in 6 of 10 weekly recharge samples at the ASR wellhead. An expanded suite of pathogens was analyzed in 3 weekly samples during the recharge phase **(Table 9-15)**, resulting in detections of *Enterococci*, *Clostridium perfringens,* and cyanobacteria. The consistent occurrence of total coliforms, plus frequent detections of fecal coliforms, indicates that the UV disinfection system does not provide consistent and sufficient coliform inactivation during recharge.

Microbes were rarely detected in samples away from the ASR well during cycle 3. In the surficial aquifer well (PBS-11), total coliforms were detected (>4 CFU/100 mL) in 3 of 29 samples. The surficial aquifer is in contact with surface water, so the appearance of coliforms is not unusual. There were no detections of total and fecal coliforms or other microbes in any SZMW sample throughout cycle test 3. There were a few detections (4 of 58 samples) of total coliforms in PBF-11 (APPZ) and PBF-12 (LFA) but these detections (ranging between 6 and 11 CFU/100 mL) were likely from wellhead contamination. Most microbes and pathogen detections during cycle test 3 occurred at the ASR wellhead during recharge, and the POD during recovery. Additional discussion of microbes in aquifers is found in **Section 9.4.2.**

Turbidity was monitored at all wellheads and the Point of Discharge (POD) throughout cycle test 2. The turbidity of recharge water ranged between approximately 1 to 6 NTU. Occasional high turbidity values (41 to > 1000 NTU) were observed in the 330-ft SZMW (PBF-10R) during the recharge phase, probably resulting from the borehole collapse. In comparison, turbidity values in all other wells are below 4 NTU throughout cycle test 3. The turbidity of recovered water discharged into Hillsboro Canal was less than 1 NTU, well below the CWA regulatory criterion of 29 NTU.

Only permit-required toxicity tests were performed during cycle test 3. Recovered water toxicity was evaluated with the 96-hour acute static renewal toxicity tests using *C. dubia* and *C. leedsi*. Recovered water mixtures obtained on the second and fourth weeks of recovery showed LC50 values greater than 100 percent for both organisms. No acute toxicity was quantified in recovered water during cycle test 3. Results are discussed further in **Section 10.**

9.4 Fate of Microbes and Pathogens in Storage Zone Groundwater

In most of south Florida, the surficial aquifer, the UFA, and the APPZ are considered to be “underground sources of drinking water” (USDWs) in the context of the UIC rules and the SDWA. USDWs in Florida typically are aquifers having TDS concentrations less than 10,000 mg/L, although other water quality criteria characteristics may apply. The “endangerment clause” of the SDWA precludes any degradation of groundwater quality at any time in a USDW. Many ASR systems, including KRASR and HASR, violate the endangerment clause of the SDWA as currently interpreted by the USEPA. Violations occur from exceedances of microbes and arsenic during cycle testing. Cycle testing at HASR and KRASR demonstrates that these exceedances are temporary, and occur only in the storage zone (UFA) during a portion of each cycle test. With the exception of cycle test 1 at HASR and KRASR, all recovered water entering the Kissimmee River or the Hillsboro Canal are in compliance with all relevant water quality criteria.

Microbes are inactivated at both ASR systems using a series of flow-through UV disinfection chambers located just upstream of the ASR well. The UV systems as currently constructed and operated do not provide sufficient and consistent microbe inactivation given the range of recharge water compositions. Therefore, microbes have been introduced to the UFA through the ASR well. Typically these are total coliforms and cyanobacteria, but infrequent detections of other bacteria and pathogens also have occurred. Conditions in the aquifer are not favorable for surface water microorganism survival, owing to darkness, pressure, anaerobic redox conditions, and the presence of native microorganisms. However, the storage duration that results in a 3-log (99.9 percent) or 4-log (99.99 percent) removal of pathogens has not been quantified in the UFA. Intensive sampling at the KRASR and HASR wellfields during cycle testing provides some indication of microbe and pathogen survival duration.

Microbe transport, fate, and attenuation times in the UFA are not well known. Australian in-situ studies of microbe survival in a brackish carbonate aquifer where reclaimed water is stored provide some basis for comparison. Pavelic et al. (1998) found that 1-log (90 percent) removal of *Enterococcus* occurred over approximately 17 days, when determined using cultures in diffusion chambers deployed to a depth of 345 ft bls at the Bolivar reclaimed water ASR system near Adelaide, Australia. Laboratory studies provide a more quantitative characterization of factors (e.g. temperature, water quality, presence of native microbes) that affect pathogen survival; however, they probably do not completely simulate aquifer conditions. Gordon and Toze (2004) concluded that *E. coli* and viral pathogens showed fastest 1-log removal times of 1 to 30 days under these conditions: aerobic, at 28°C, without nutrients, and in the presence of native microorganisms. In the same dataset but under anoxic (aquifer-like) conditions, *E. coli* and viral pathogen removal times were longer, ranging between 8 and 144 days. John and Rose (2004) conducted a bench-top study that evaluated coliform survival time and removal in mixtures of surface water, Floridan Aquifer groundwater, and synthetic water. A 2-log (99 percent) removal of fecal coliforms occurred over periods of 1 to 6 weeks in groundwater at temperatures between 22 and 30°C. Similarly, 2-log removal of *Enterococcus* occurred over periods of 1 to 5 weeks. Pathogens *Cryptosporidium parvum* and *Giardia lamblia* survived longer in groundwater mixtures, showing a 2-log removal over periods ranging between 3 weeks (30°C) to 7 weeks (at 22°C).

9.4.1 Microbes and Pathogens in Groundwater at KRASR

Insufficient and inconsistent microbe activation is documented through weekly analyses of recharge water at the ASR wellhead during each cycle at KRASR **(Table 9-4)**. Microbes, primarily total coliforms and cyanobacteria, are transported through permeable zones of the UFA during recharge. Total coliforms and cyanobacteria are detected at both the 350-ft SZMW and the 1,100-ft SZMW at KRASR, primarily during the recharge phase **(Figure 9-3; Table 9-23).** Those detections at SZMWs during storage and recovery typically show low concentrations (9 to 17 CFU/100 mL) but exceed the regulatory criterion of 4 CFU/100 mL. Total coliforms are the most frequently detected microbe constituent, so these data can define patterns of microbe occurrence through ASR cycle tests **(Figure 9-3 A).**

The greatest number of positive total coliform detections occurs during the recharge phase throughout each ASR wellfield. At KRASR, total coliforms were detected (4 CFU/100 mL) in 35 percent (60 of 171 samples) of all storage zone groundwater samples during recharge. Total coliform detections declined to 2 percent in storage phase samples, and to 3 percent in recovery phase samples. Recharged water was stored between 1 month and 1 year duration at KRASR, so it is likely that many total coliform detections during storage and recovery result from wellhead contamination.

Fecal coliforms were detected (>2 MPN/100 mL) in approximately 1 percent (2 of 171 samples) from the ASR well and SZMWs during the recharge phase of cycle tests 1 through 4 **(Table 9-23).** No fecal coliforms were detected in any sample during the storage and recovery phases of cycle tests 1 through 4 **(Figure 9-3 A and B).** All other bacteria and pathogens are rare or absent throughout all cycles in the 350-ft and 1,100-ft SZMW samples **(Table 9-23)**. No microorganisms were detected at the distal (2,350-ft and 4,200-ft) SZMWs. A statistical summary of microbe occurrence throughout all cycles at KRASR is shown in **Table 9-23**.

9.4.2 Microbes and Pathogens in Groundwater at HASR

A similar pattern of microbe occurrence was observed in storage zone groundwater at HASR **(Figure 9-3 C, D).** Total coliforms were detected (4 CFU/100 mL) in 34 percent (33 of 96 samples) of all storage zone groundwater samples during recharge. Total coliform occurrence declined to 0 percent in storage phase samples, and 4 percent in recovery phase samples **(Figure 9-3C).**

Recharged water was stored between 1 and 5 month duration at HASR, at pressures and environmental conditions in the aquifer that are not favorable for surface water microbe survival. It is likely that some total coliform detections during storage and recovery result from wellhead contamination, rather than survival of surface microorganisms. This is particularly true for the lower Floridan Aquifer well PBF-12, which exists near a buzzard roost. There were infrequent detections of total coliforms in other deeper wells that may be the result of wellhead contamination since there is no evidence for recharge water to infiltrate into the APPZ or the lower Floridan Aquifer **(Table 9-24).** Recharge water was sampled (n=3) for an expanded list of microorganisms and pathogens at the ASR wellhead during the recharge phase of cycle test 3. *E. coli,* enterococci, *C. perfringens* and coliphages are common in recharge water samples. *C. parvum and G. lamblia* were not detected.

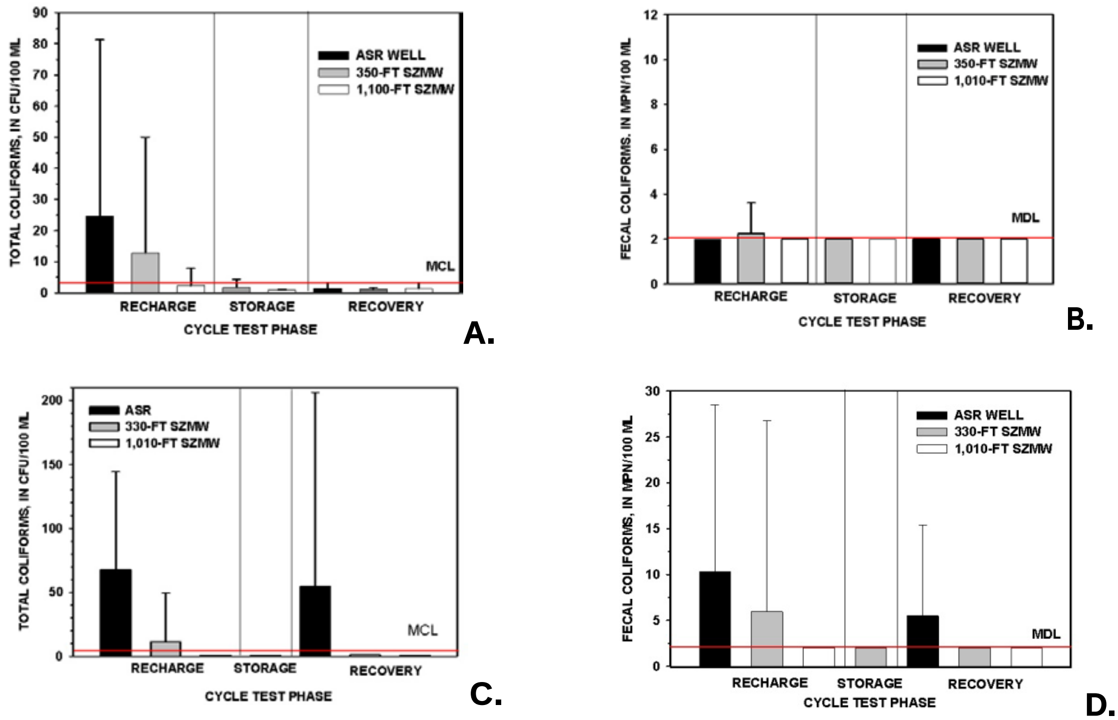

Figure 9-3 (A through D) -- Total Coliform and Fecal Coliform concentrations by phase in groundwater samples at KRASR (A. and B.) and HASR (C. and D.)

MCL, maximum contaminant level for Total Coliforms (4 CFU/100 mL). MDL, minimum detection limit for Fecal Coliforms (1 MPN/100 mL). Data from all cycle tests are combined for each well and phase. Error bars are standard deviation about the mean of the sample population. Data from **Table 9-23** and **9-24**.

Fecal coliforms were detected (>2 MPN/100 mL) in 17 percent (16 of 95 samples) from the ASR well and SZMWs during the recharge phase of cycle tests 1 through 3 **(Table 9-24)**. Fecal coliforms were detected (>2 MPN/100 mL) in 2 percent (1 of 45 samples) in the storage zone during storage and recovery phases. A statistical summary of microbe occurrence throughout all cycles at HASR are shown in **Table 9-24.**

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Table 9-23 -- Microbes and Pathogens in Groundwater at the KRASR, Cycle Tests 1 through 4 (2010-2013)

Microbe or Pathogen	Unit	No. Samples with Positive Detection	Total No. of Samples	Percent Detect	Minimum Value	Maximum Value	Geometric Mean	Std Dev	Median	Criterion for Detection
RECHARGE PHASE										
EXKR-1 ASR Well										
Total Coliform	CFU/100 mL	42	61	69	1	330	7	57	7	4
Fecal Coliform	MPN/100 mL	0	61	0	2	2				>2
E. coli	CFU/100 mL	1	18	6	1	2	1	0	1	>1
Enterococci	MPN/100 mL	3	12	25	1	40	2	11	1	>1
Clostridium perfringens	CFU/100 mL	6	14	43	1	53	4	17	1	>1
Coliphage	PFU/100 mL	0	12	0	1	1				>1
Giardia lamblia	oocysts/100mL	1	14	0	1.3	8.5				> U-flag value (8.5)
Cryptosporidium parvum	oocysts/100mL	1	14	7	1.3	21	4	5	3.1	> U-flag value (8.5)
Cyanobacteria	cells/mL	7	7	100	3	8253	95	3992	17	1
MW-10 350-FT SZMW										
Total Coliform	CFU/100 mL	13	56	23	1	182	2	37	1	4
Fecal Coliform	MPN/100 mL	2	56	4	2	11	2	1	2	>2
E. coli	CFU/100 mL	0	15	0	1	1				>1
Enterococci	MPN/100 mL	0	10	0	1	1				>1
Clostridium perfringens	CFU/100 mL	2	6	33	1	16	2	6	1	>1
Coliphage	PFU/100 mL	0	5	0	1	1				>1
Giardia lamblia	oocysts/100mL	0	6	0	0.3	5.3	1.7	1.9	2.8	> U-flag value (5.3)
Cryptosporidium parvum	oocysts/100mL	0	6	0	0.3	5.3	1.7	1.9	2.8	> U-flag value (5.3)
Cyanobacteria	cells/mL	4	4	100	2	3057	57	1471	213	1
OKF-100U 1,100-ft SZMW										
Total Coliform	CFU/100 mL	5	54	9.3	1	39	1.4	5.5	1	4
Fecal Coliform	MPN/100 mL	0	54	0	2	2				>2
E. coli	CFU/100 mL	0	11	0	1	2				>1
Enterococci	MPN/100 mL	0	2	0	1	1				>1
Clostridium perfringens	CFU/100 mL	1	2	50	1	2	1.4	0.7	1.5	>1
Coliphage	PFU/100 mL	0	2	0	1	1				>1
Giardia lamblia	oocysts/100mL	0	2	0	2.6	5.3				> U-flag value (5.3)
Cryptosporidium parvum	oocysts/100mL	0	6	0	2.6	5.3				> U-flag value (5.3)
OKF-100L APPZ										
Total Coliform	CFU/100 mL	0	53	0	1	1				4
Fecal Coliform	MPN/100 mL	0	129	0	2	2				>2
E. coli	CFU/100 mL	0	11	0	1	1				>1
MW-17 Surficial Aquifer										
Total Coliform	CFU/100 mL	8	50	16	1	41	1.9	8.0	1	4
Fecal Coliform	MPN/100 mL	0	50	0	2	2				>2
E. coli	CFU/100 mL	0	1	0	1	1				>1
STORAGE PHASE										
MW-10 350-FT SZMW										
Total Coliform	CFU/100 mL	3	56	5	1	17	1	3	1	4
Fecal Coliform	MPN/100 mL	0	56	0	2	2				>2
E. coli	CFU/100 mL	0	15	0	1	1				>1
Enterococci	MPN/100 mL	0	3	0	1	1				>1
Clostridium perfringens	CFU/100 mL	0	3	0	1	1				>1
Coliphage	PFU/100 mL	0	3	0	1	1				>1
Giardia lamblia	oocysts/100mL	0	3	0	2.6	4.2				> U-flag value (4.2)
Cryptosporidium parvum	oocysts/100mL	0	6	0	2.6	4.2				> U-flag value (4.2)
Cyanobacteria	cells/mL	3	2	66.7	1	53	7	29	6	>1
OKF-100U 1,100-FT SZMW										
Total Coliform	CFU/100 mL	0	57	0	1	1				4
Fecal Coliform	MPN/100 mL	0	57	0	2	2				>2
E. coli	CFU/100 mL	0	17	0	1	1				>1
Enterococci	MPN/100 mL	0	1	0	1	1				>1
Clostridium perfringens	CFU/100 mL	0	1	0	1	1				>1
Coliphage	PFU/100 mL	0	1	0	1	1				>1
Giardia lamblia	oocysts/100mL	0	1	0	2.6	2.6				> U-flag value (2.6)
Cryptosporidium parvum	oocysts/100mL	0	1	0	2.6	2.6				> U-flag value (2.6)
MW-19 and MW-19 2,350-FT and 4,200-FT SZMWs - COMBINED										
Total Coliform	CFU/100 mL	0	12	0	1	1				4
Fecal Coliform	MPN/100 mL	0	12	0	2	2				>2
OKF-100L APPZ										
Total Coliform	CFU/100 mL	0	46	0	1	2				4
Fecal Coliform	MPN/100 mL	0	46	0	2	2				>2
E. coli	CFU/100 mL	0	10	0	1	1				>1
MW-17 Surficial Aquifer										
Total Coliform	CFU/100 mL	5	41	12	1	50	1.5	9.0	1	4
Fecal Coliform	MPN/100 mL	0	41	0	2	2				>2
E. coli	CFU/100 mL	0	3	0	1	1				>1

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Table 9-23, *continued* -- Microbes and Pathogens in Groundwater at the KRASR, Cycle Tests 1 through 4 (2010-2013)

Microbe or Pathogen	Unit	No. Samples with Positive Detection	Total No. of Samples	Percent Detect	Minimum Value	Maximum Value	Geometric Mean	Std Dev	Median	Criterion for Detection
RECOVERY PHASE										
EXKR-1 ASR Well										
Total Coliform	CFU/100 mL	2	41	5	1	12	1	2	1	4
Fecal Coliform	MPN/100 mL	0	41	0	2	2				>2
E. coli	CFU/100 mL	0	1	0	1	1				>1
Enterococci	MPN/100 mL	0	1	0	1	1				>1
Clostridium perfringens	CFU/100 mL	0	1	0	1	1				>1
Coliphage	PFU/100 mL	0	1	0	1	1				>1
Giardia lamblia	oocysts/100mL	0	1	0	5.3	5.3				> U-flag value (5.3)
Cryptosporidium parvum	oocysts/100mL	0	1	0	5.3	5.3				> U-flag value (5.3)
Cyanobacteria	cells/mL	1	1	100	34	34				1
MW-10 350-FT SZMW										
Total Coliform	CFU/100 mL	1	47	2	1	4	1	1	1	4
Fecal Coliform	MPN/100 mL	0	47	0	2	2				>2
E. coli	CFU/100 mL	0	10	0	1	1				>1
Enterococci	MPN/100 mL	0	3	0	1	1				>1
Clostridium perfringens	CFU/100 mL	0	3	0	1	1				>1
Coliphage	PFU/100 mL	0	3	0	1	1				>1
Giardia lamblia	oocysts/100mL	0	3	0	5.3	5.3				> U-flag value (5.3)
Cryptosporidium parvum	oocysts/100mL	0	3	0	5.3	5.3				> U-flag value (5.3)
OKF-100U 1,100-FT SZMW										
Total Coliform	CFU/100 mL	1	48	2	1	15	1.1	2	1	4
Fecal Coliform	MPN/100 mL	0	48	0	2	2				>2
E. coli	CFU/100 mL	0	11	0	1	1				>1
Enterococci	MPN/100 mL	0	3	0	1	1				>1
Clostridium perfringens	CFU/100 mL	0	3	0	1	1				>1
Coliphage	PFU/100 mL	0	3	0	1	1				>1
Giardia lamblia	oocysts/100mL	0	3	0	0.4	5.3	2.2	2.8	5.3	> U-flag value (5.3)
Cryptosporidium parvum	oocysts/100mL	0	3	0	0.4	5.3	2.2	2.8	5.3	> U-flag value (5.3)
Cyanobacteria	cells/mL	1	3	33	1	36	3	20	1	1
OKF-100L APPZ										
Total Coliform	CFU/100 mL	1	44	2	1	16	1.1	2.3	1	4
Fecal Coliform	MPN/100 mL	0	44	0	2	2				>2
E. coli	CFU/100 mL	0	7	0	1	1				>1
MW-17 Surficial Aquifer										
Total Coliform	CFU/100 mL	12	44	27	1	48	2.1	8.9	1	4
Fecal Coliform	MPN/100 mL	0	44	0	2	2				>2
E. coli	CFU/100 mL	0	5	0	1	1				>1
POD										
Total Coliform	CFU/100 mL	8	52	15	1	82	2	15.4	1	4
Fecal Coliform	MPN/100 mL	1	52	1.9	2	4	2	0.3	2	>2
E. coli	CFU/100 mL	1	15	6.7	1	2	1	0.3	1	>1
Enterococci	MPN/100 mL	0	6	0	1	1				>1
Clostridium perfringens	CFU/100 mL	0	6	0	1	1				>1
Coliphage	PFU/100 mL	0	3	0	1	1.7				>1.7
Giardia lamblia	oocysts/100mL	0	4	0	5.3	5.3				> U-flag value (5.3)
Cryptosporidium parvum	oocysts/100mL	0	4	0	0.4	5.3				> U-flag value (5.3)
Cyanobacteria	cells/mL	5	6	83	1	27	8	11	13	1

Note: All samples from Storage Zone Monitor Wells (SZMW; MW-10, OKF-100U, MW-18, MW-19), wells open to the surficial aquifer (MW-17), and Avon Park Permeable Zone (OKF-100L), and the Point of Discharge (POD) at the base of the cascade aerator. Samples from the ASR wellhead (EXKR-1) are from the recharge and recovery phases only. Criteria for detection are in units for each microbe.

Table 9-24-- Microbes and Pathogens in Groundwater at the HASR, Cycle Tests 1 through 3 (2010-2012)

Microbe or Pathogen	Unit	No. Samples w/ Positive Detection	Total No. of Samples	Percent Detect	Minimum Value	Maximum Value	Geometric Mean	Std Dev	Median	Criterion for Detection
RECHARGE PHASE										
PBF-13 ASR Well										
Total Coliform	CFU/100 mL	28	32	88	1	> 200	28	76	20.5	4
Fecal Coliform	MPN/100 mL	14	31	45	1	79	3.7	18	2	>2
E. coli	CFU/100 mL	6	13	46	1	65	3.3	19	1	>1
Enterococci	MPN/100 mL	3	3	100	1	35	3.0	20	1	>1
Clostridium perfringens	CFU/100 mL	3	3	100	1	27	17	9	22	>1
Coliphage	PFU/100 mL	1	3	33	1	1				>1
Giardia lamblia	oocysts/100mL	0	3	0	4.4	5.3				> U-flag value (5.3)
Cryptospor. parvum	oocysts/100mL	0	3	0	4.4	5.3				> U-flag value (5.3)
Cyanobacteria	cells/mL	13	3	100	1	39	9	19	23	1
PBF-10R 330-FT SZMW										
Total Coliform	CFU/100 mL	5	32	16	1	190	1.7	38	1	4
Fecal Coliform	MPN/100 mL	2	32	6.3	2	120	2.4	21	2	>2
E. coli	CFU/100 mL	0	13	0	1	1				>1
PBF-14 1,010-ft SZMW										
Total Coliform	CFU/100 mL	0	32	0	1	2				4
Fecal Coliform	MPN/100 mL	0	32	0	2	2				>2
E. coli	CFU/100 mL	0	18	0	1	2				>1
PBF-11 APPZ										
Total Coliform	CFU/100 mL	0	32	0	1	1				4
Fecal Coliform	MPN/100 mL	0	32	0	2	2				>2
E. coli	CFU/100 mL	0	13	0	1	1				>1
PBF-12 LFA										
Total Coliform	CFU/100 mL	3	32	9	1	11	1.4	2.5	1	4
Fecal Coliform	MPN/100 mL	0	32	0	2	2				>2
E. coli	CFU/100 mL	0	13	0	1	1				>1
Enterococci	MPN/100 mL	0	2	0	1	1				>1
Clostridium perfringens	CFU/100 mL	0	2	0	1	1				>1
Coliphage	PFU/100 mL	0	2	0	1	1				>1
Giardia lamblia	oocysts/100mL	0	2	0	1	5.3				> U-flag value (5.3)
Cryptospor. parvum	oocysts/100mL	0	2	0	1	5.3				> U-flag value (5.3)
Cyanobacteria	cells/mL	1	2	50	1	4				1
PBS-11 Surficial Aquifer										
Total Coliform	CFU/100 mL	3	36	8	1	83	1.3	13.8	1	4
Fecal Coliform	MPN/100 mL	0	36	0	2	2				>2
E. coli	CFU/100 mL	3	16	19	1	12	1.3	2.7	1	>1
STORAGE PHASE										
PBF-10R 330-FT SZMW										
Total Coliform	CFU/100 mL	0	11	0	1	1				4
Fecal Coliform	MPN/100 mL	0	11	0	2	2				>2
E. coli	CFU/100 mL	0	15	0	1	1				>1
PBF-14 1,010-FT SZMW										
Total Coliform	CFU/100 mL	0	14	0	1	1				4
Fecal Coliform	MPN/100 mL	0	14	0	2	2				>2
E. coli	CFU/100 mL	0	14	0	1	2				>1
PBF-11 APPZ										
Total Coliform	CFU/100 mL	1	11	9	1	10	1.2	2.7	1	4
Fecal Coliform	MPN/100 mL	0	11	0	2	2				>2
E. coli	CFU/100 mL	0	11	0	1	1				>1
PBF-12 LFA										
Total Coliform	CFU/100 mL	0	9	0	1	3				4
Fecal Coliform	MPN/100 mL	0	9	0	2	2				>2
E. coli	CFU/100 mL	0	9	0	1	1				>1
PBS-11 Surficial Aquifer										
Total Coliform	CFU/100 mL	0	11	0	1	2				4
Fecal Coliform	MPN/100 mL	0	11	0	2	2				>2
E. coli	CFU/100 mL	0	11	0	1	1				>1
RECOVERY PHASE										
PBF-13 ASR Well										
Total Coliform	CFU/100 mL	1	8	13	1	430	2	151	1	4
Fecal Coliform	MPN/100 mL	1	8	13	1	30	2.8	10	2	>2
PBF-10R 330-FT SZMW										
Total Coliform	CFU/100 mL	0	12	0	1	2				4
Fecal Coliform	MPN/100 mL	0	12	0	2	2				>2
E. coli	CFU/100 mL	0	5	0	1	2				>2
PBF-14 1,010-FT SZMW										
Total Coliform	CFU/100 mL	0	5	0	1	2				4
Fecal Coliform	MPN/100 mL	0	5	0	2	2				>2
E. coli	CFU/100 mL	0	5	0	1	2				>2
PBF-11 APPZ										
Total Coliform	CFU/100 mL	0	12	0	1	2				4
Fecal Coliform	MPN/100 mL	0	12	0	2	2				>2
E. coli	CFU/100 mL	0	5	0	1	2				>2
PBF-12 LFA										
Total Coliform	CFU/100 mL	0	12	0	1	2				4
Fecal Coliform	MPN/100 mL	0	12	0	2	2				>2
E. coli	CFU/100 mL	0	5	0	1	2				>1
PBS-11 Surficial Aquifer										
Total Coliform	CFU/100 mL	0	11	0	1	2				4
Fecal Coliform	MPN/100 mL	0	11	0	2	2				>2
E. coli	CFU/100 mL	0	5	0	1	2				>1
POD										
Total Coliform	CFU/100 mL	5	5	100	5	> 200	37.1	98.5	71	4
Fecal Coliform	MPN/100 mL	2	5	40	2	70	8	32	2	>2
E. coli	CFU/100 mL	2	5	40	1	46	5	25	1	>1

Note: All samples from Storage Zone Monitor Wells (SZMW; PBF-10R and PBF-14) , wells open to the surficial aquifer (PBS-11), APPZ (PBF-11), Lower Floridan Aquifer (PBF-12), and Point of Discharge (POD). Samples from the ASR wellhead (PBF-13) are from the recharge and recovery phases only.

9.5 Arsenic Transport and Fate During ASR Cycle Tests

Arsenic mobilization during ASR cycle testing presents a significant challenge to expanded use of potable and reclaimed water ASR in Florida. Arsenic is released during oxidation of pyrite by dissolved oxygen as recharge water flows through permeable zones in the carbonate aquifer (Jones and Pichler, 2007; Fischler and Arthur, in review). Resultant arsenic concentrations measured in groundwater during ASR cycle testing can exceed the Federal and State maximum contaminant level (10 µg/L). Once released into the aquifer, arsenic can: 1) be sequestered by sorption to iron oxyhydroxide phases that are stable under oxic or sub-oxic aquifer redox conditions (Vanderzalm et al. 2011); or, 2) be transported as the dissolved complex arsenate (AsV) or arsenite (AsIII) under oxic to sub-oxic, iron-poor conditions (e.g. Höhn et al., 2006); or, 3) co-precipitate as an iron sulfide phase under sulfate-reducing, iron-rich conditions. The third condition has not been documented at any ASR system, and has important implications for arsenic attenuation and also regulatory compliance during ASR cycle tests in the Floridan Aquifer. Additional discussion of the mechanisms of arsenic mobilization and sequestration is found in Mirecki et al. (2013).

Characterization and controls on arsenic transport and fate during ASR cycle testing has been impeded in the United States by the lack of extensive sampling. Most ASR system investigations are performed by water utilities at potable water ASR systems (FDEP, 2007). Water quality datasets at utility ASR systems usually are limited to analytes required for permit compliance rather than geochemical characterization. Consequently, little is known of the magnitude and duration of arsenic mobilization, and factors that control arsenic transport and fate in the Floridan Aquifer. The cycle testing data set at KRASR is the result of extensive (weekly) groundwater sampling during the first three cycle tests, plus the addition of two distal SZMWs (MW-18, the 2,350 SZMW and MW-19, the 4,200-ft SZMW) to better characterize the extent of recharged water volume in the Floridan Aquifer particularly during later cycle tests that stored large volumes.

9.5.1 Arsenic Trends During KRASR Cycle Tests

Arsenic concentrations increased in the storage zone during the recharge phase, then subsequently declined during storage and recovery **(**Figure **9-4 A-F).** Based on the discussion in section 9.5, these reproducible trends are interpreted as arsenic mobilization during recharge, and arsenic attenuation during late storage and recovery. Arsenic mobilization was most clearly shown by the following features: 1) cycle test 1 data from the ASR well, the 350-ft SZMW, and the 1,100-ft SZMW; 2) cycle test 2 and 3 recharge and early storage data from the 350-ft SZMW, and the 1,100-ft SZMW. Arsenic exceedances (that is, groundwater concentrations greater than 10 µg/L) are observed only during oxic and sub-oxic conditions of a cycle test.

Movement of arsenic by pumping beyond the capture zone in the ASR wellfield is a major regulatory concern. In the absence of any geochemical sequestration mechanism, transport of an arsenic front beyond the monitoring wellfield could occur during successive cycles. Use of the "target storage volume" (TSV; Pyne, 1995) method of cycle testing is susceptible to offsite movement of an arsenic front. In the TSV method, successive cycles are characterized by increasingly larger recharge volumes followed by partial recovery. In the absence of a geochemical sequestration mechanism, groundwater arsenic will move laterally in response to recharge or recovery pumping. Given larger recharge volumes with successive cycles, a zone of mobilized arsenic can be transported off-site.

Weekly sampling throughout each entire cycle (particularly cycle tests 2 and 3) at KRASR provides sufficient data to evaluate the trend and lateral distance of arsenic transport in the UFA. Some remobilization of arsenic between cycle test 2 recovery and cycle test 3 recharge is suggested by early recharge “arsenic humps” at the 350-ft SZMW, and particularly at the 1,100-ft SZMW **(Figure 9-4 B,C)**. It appears that the maximum distance that arsenic is transported away from the ASR well is between 1,100-ft and 2,350-ft, because arsenic was never detected at the 2,350-ft or 4,200 ft SZMWs (**Figure 9-4 D, E)**. There likely is anisotropic groundwater flow direction and rate away from the ASR well. KRASR cycle tests always recover 100 percent by volume at the completion of each cycle. In the absence of a geochemical sequestration mechanism, a fraction of the arsenic released would be captured during recovery. However, there appears to be an arsenic sequestration mechanism occurring in the UFA at KRASR. Evidence for this mechanism is shown by the following features: 1) nearly every recovered water sample from the ASR well during cycle tests 2 through 4 shows arsenic concentration below the 10 µg/L regulatory criterion **(**Figure 9-4 **A)** despite exceedances in the UFA during recharge and storage; and 2) arsenic concentrations decline to levels below the 10 µg/L criterion during static conditions of storage in the 350-ft SZMW and the 1,100-ft SZMW. This sequestration mechanism involves precipitation of arsenic as a solid iron sulfide mineral under sulfate-reducing conditions of the UFA (Mirecki et al., 2013). Cycle testing data sets at KRASR demonstrate the first in-situ sequestration mechanism for arsenic under sulfate reducing conditions. More detail on UFA hydraulics is shown in the KRASR groundwater flow and solute transport model **(Section 5.5.4).**

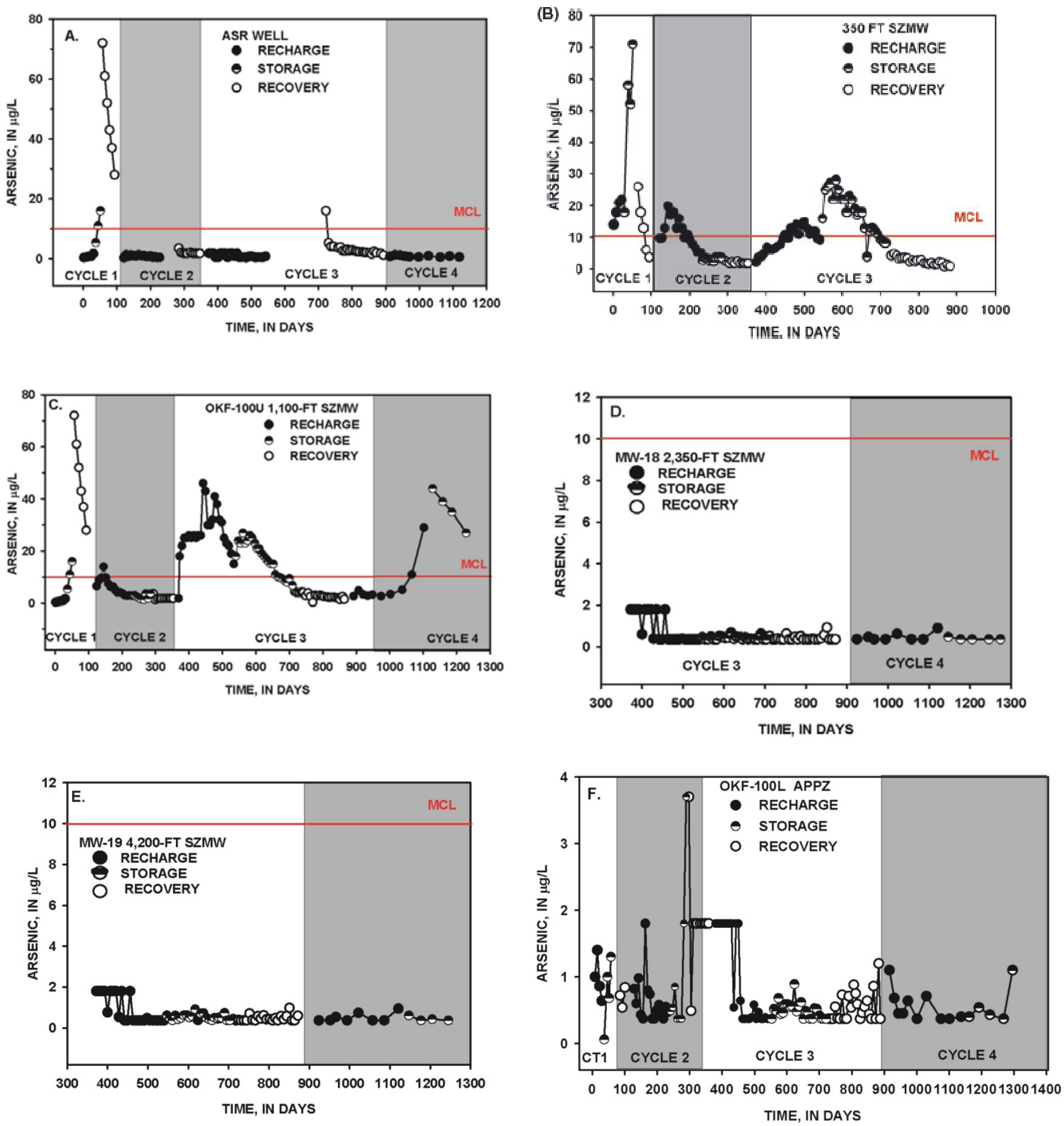

Figure 9-4 (A through F) -- Arsenic trends through time (cycle tests 1 through 4) at individual wells at KRASR.

A, ASR well (EXKR-1); B, 350-ft SZMW (MW-10); C, 1,100-ft SZMW (OKF-100U); D, 2,350-ft SZMW (MW-18); E, 4,200-ft SZMW (MW-19); F, 1,1000-ft SZMW (OKF-100, APPZ); All wells except OKF-100L are open to the UFA.

9.5.2 Arsenic Trends During HASR Cycle Tests

The water quality data sets obtained during three cycle tests at HASR were developed primarily to evaluate the ASR system for regulatory compliance. Therefore, there are limited data for geochemical evaluation of arsenic mobilization and sequestration mechanisms. In addition, collapse of the open interval at the 330-ft SZMW restricted storage zone sampling, so some samples from this well are compromised by high turbidity during cycle tests 2 and 3.

The highest arsenic concentrations occur during cycle test 1 at HASR, a pattern that is similar to that at KRASR and other Florida ASR systems. Cycle test 1 marks the initial contact between oxygenated recharge water and storage zone lithologies, and arsenic is released by pyrite oxidation. Unless a controlling geochemical mechanism sequesters arsenic, exceedances will occur in SZMWs during recharge and early storage as the mobilized “front” of arsenic is transported away from the ASR well. At HASR, there is some evidence that arsenic mobilized during cycle test 1 has been transported by a larger subsequent recharge volume during cycle test 2 to the 330-ft SZMW **(Figure 9-5 A and B).** A similar pattern was observed during cycle tests 2 and 3 at KRASR **(Figure 9-4C).** Arsenic was never detected at the 1,010-ft SZMW (PBF-14; **Figure 9-5 A, B, C**). Occasional exceedances of the arsenic MCL were detected at PBF-12, open to the Lower Floridan Aquifer **(Figure 9-5 D).** The wellhead pressure record and other water quality data from this well were examined for evidence of leaking down the annulus of PBF-12. The pressure record was fairly consistent through the period of HASR cycle testing (January 2010 through June 2012). Cyclic, week-long pressure variations occur that may reflect injection wells in the region but have no relation to leakage. Water quality of the LFA has specific conductance, chloride and TDS concentrations that are similar to seawater. Turbidity values are low (< 0.3 NTU) suggesting that the borehole is intact. It is possible that variable arsenic concentrations in PBF-12 result from metals contamination leaching from the casing, or relict arsenic that was released by oxygenated drilling fluids during well construction. There were no exceedances of the arsenic MCL in PBF-11, open to the APPZ.

9.6 Molybdenum Transport and Fate During ASR Cycle Tests

Increases in molybdenum concentration were observed during laboratory bench tests that simulated ASR cycle tests (Fischler and Arthur, in review). The aqueous geochemistry of molybdenum differs from that of arsenic, in that it remains in solution as a complex MoVI anion, molybdate (MoO_4^{2-}). Under increasing dissolved hydrogen sulfide concentrations (similar to those observed in the UFA at KRASR, about 3 mg/L), molybdate can react to form a dissolved thiomolybdate (MoS_4^{2-}; Erickson and Helz, 2000). The important aspect about molybdenum speciation is that over the time frame of a cycle test, molybdenum remains as a dissolved complex in groundwater, rather than re-precipitated as a sulfide solid phase as was observed with arsenic.

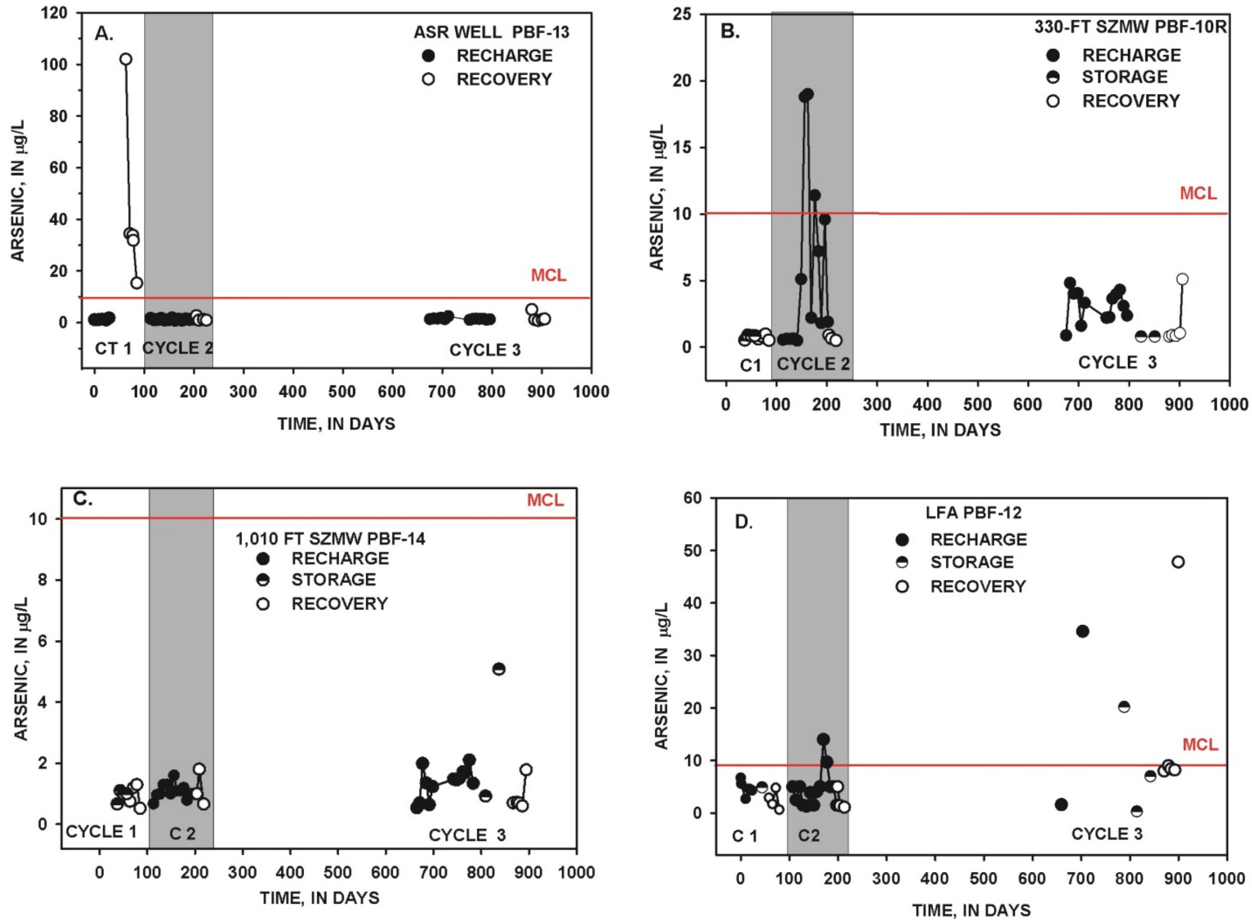

Figure 9-5 (A through D) -- Arsenic trends through time (cycle tests 1 through 3) at individual wells at HASR.

A, ASR well (PBF-13); B, 330-ft SZMW (PBF-10R); 1,010-ft SZMW (PBF-14); D, Lower Floridan Aquifer well PBF-12.

9.6.1 Molybdenum Trends During KRASR Cycle Tests

Molybdenum mobilization appears to mobilization during KRASR cycle tests, most likely by release during pyrite oxidation. The mean molybdenum concentration in native UFA samples from KRASR is 28 +/- 31 µg/L (n=4; **Table 9-8**). This mean concentration seems too high and variable for the native UFA; the analyses of 40 and 66 µg/L may reflect molybdenum contamination from drill bit lubricant. It is likely that the true background molybdenum concentration is 2 to 3 µg/L, which is similar to the concentration in recharge water (4.0 µg/L; **Table 9-2**). This background concentration is below the range of concentrations observed in recovered water samples from all SZMWs and the ASR well during cycle tests 1 through 4. In distal SZMWs, molybdenum concentrations were greatest during cycle test 1, with concentrations ranging between 50 and 500 µg/L **(Figure 9-6)**. In proximal SZMWs, maximum molybdenum concentrations occur during late recharge and early storage phases (350-ft SZMW, 47 µg/L**;** 1,100-ft SZMW, 180 µg/L) during cycle test 4, and concentrations sometimes exceed the World

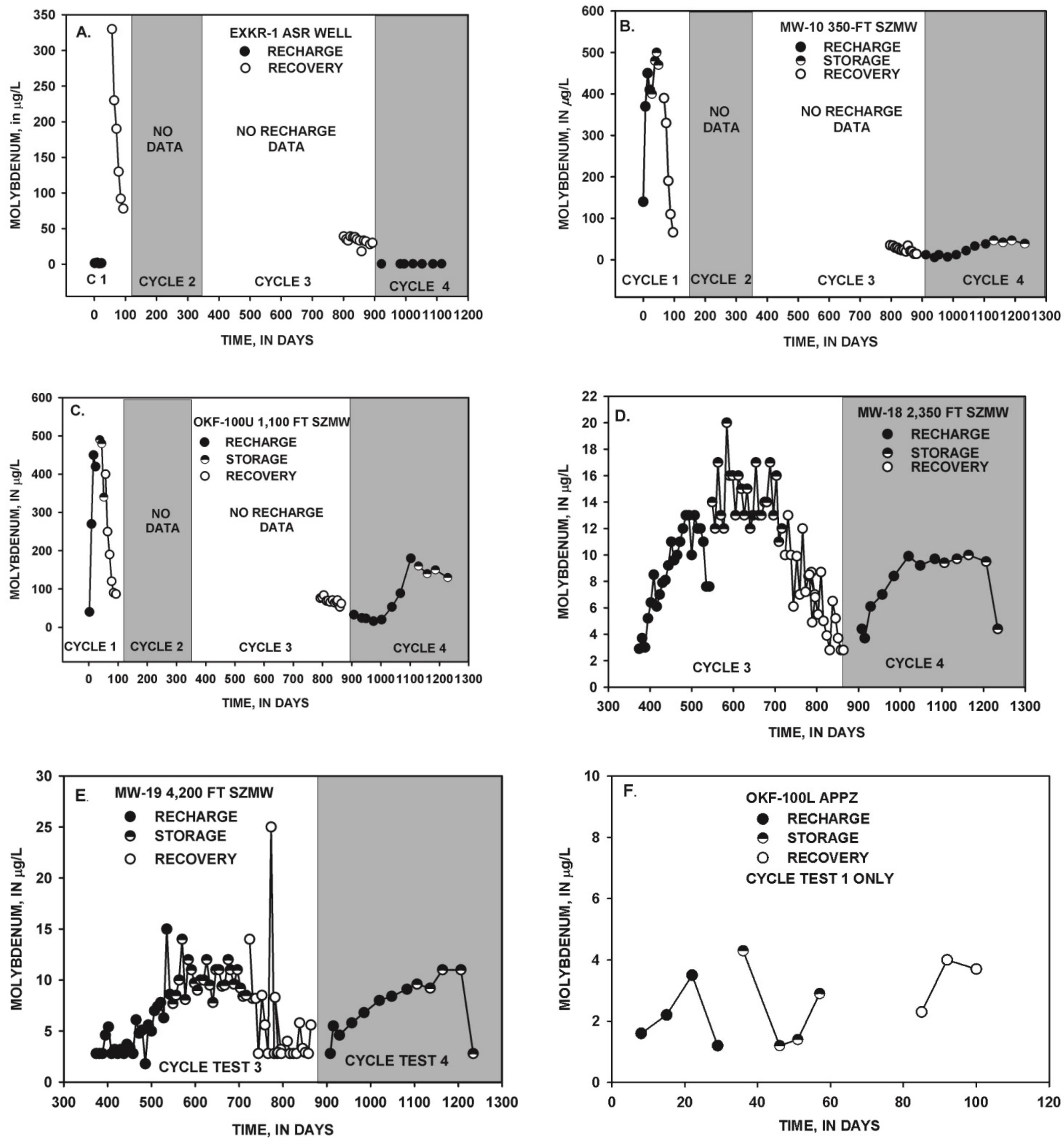

Figure 9-6 (A through F) – Molybdenum trends through time (cycle tests 1 through 4) at individual wells at KRASR.

A, ASR well (EXKR-1); B, 350-ft SZMW (MW-10); C, 1,100-ft SZMW (OKF-100U); D, 2,350-ft SZMW (MW-18); E, 4,200-ft SZMW (MW-19); F, 1,100-ft SZMW (OKF-100L, APPZ). All wells except OKF-100L are open to the UFA.

Health Organization guideline maximum concentration of 70 µg/L (World Health Organization, 2011). There was no statistically significant change in molybdenum concentration during cycle test 1 in OKF-100L, open to the APPZ.

9.6.2 Molybdenum Trends During HASR Cycle Tests

Limited molybdenum data exist from HASR cycle tests. Molybdenum was analyzed routinely only in SZMW samples during cycle test 3 at HASR. Molybdenum was measured during two "annual" analyses at the ASR well during cycle test 1, once during recharge (< 0.85 µg/L) and once during recovery (163 µg/L). The latter concentration suggests that molybdenum mobilization has occurred. In comparison, all groundwater concentrations in the ASR well and SZMWs during cycle test 3 are less than 12 µg/L **(Figure 9-7)**. The pattern of molybdenum occurrence during cycle tests is similar to that of arsenic, in that concentrations seem to decline with each successive cycle.

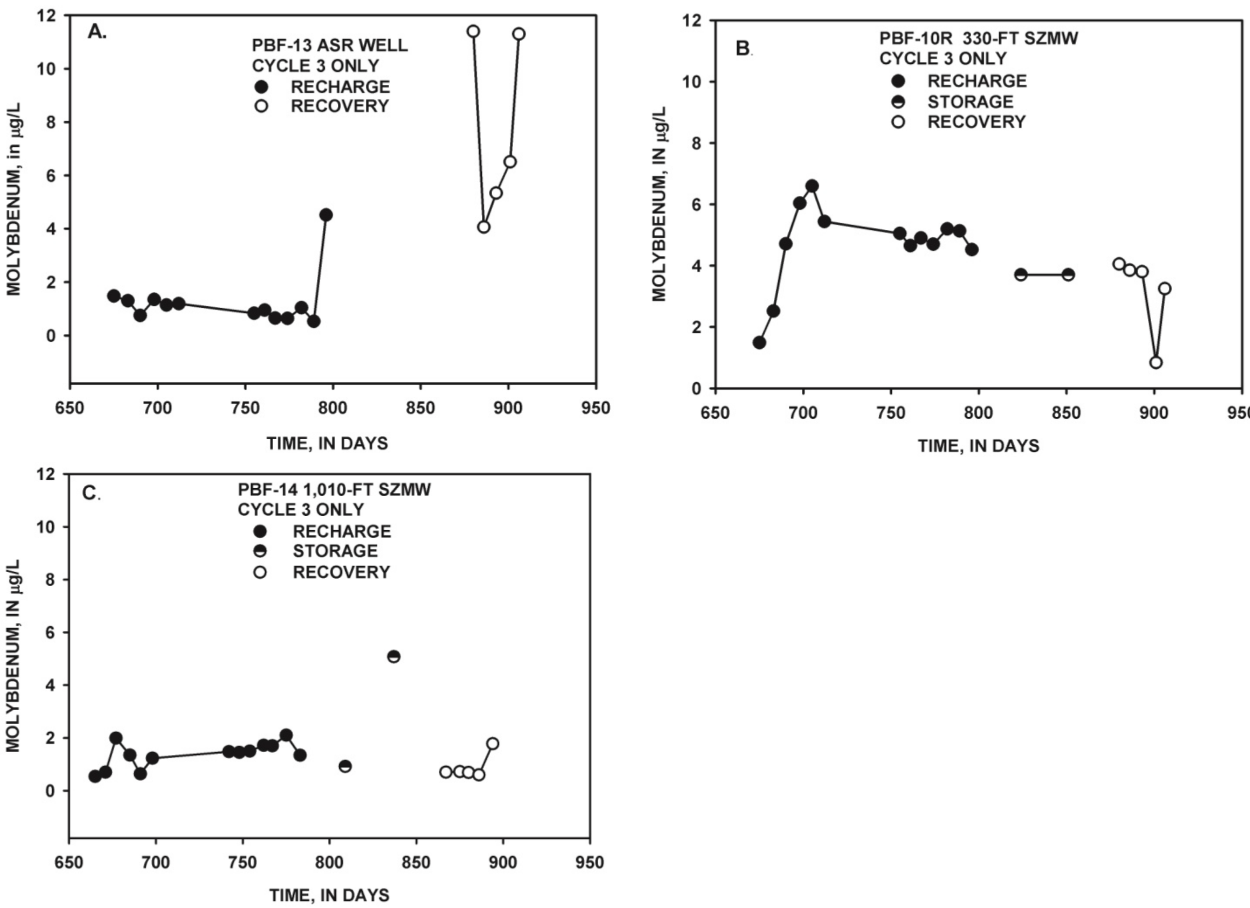

Figure 9-7 (A through C) -- Molybdenum trends through time (cycle test 3) at individual wells at HASR.

A, ASR well (PBF-13); B, 330-ft SZMW (PBF-10R); C, 1,010-ft SZMW (PBF-14). All wells are open to the UFA.

9.7 Phosphorus Transport and Fate During ASR Cycle Tests

Managing elevated phosphorus concentrations in surface waters that flow into Lake Okeechobee and the water conservation areas is one of the greatest challenges to successful ecosystem restoration. Phosphorus loading and subsequent eutrophication of Lake Okeechobee during the last few decades has degraded water quality, reduced the extent of submerged aquatic vegetation, and has caused fisheries to decline in abundance. Reduction of phosphorus concentration usually is achieved using stormwater treatment areas and use of best management practices. However, results of cycle testing, particularly at KRASR, show statistically significant reduction of phosphorus concentrations during each cycle.

9.7.1 Phosphorus Trends During KRASR Cycle Tests

Recovered water concentrations of phosphorus are consistently lower than recharge water concentrations at KRASR. The mean phosphorus concentration in recharge water measured at the ASR wellhead during all cycle tests is 66 +/- 42 μg/L (n=51), and concentrations range between < 4.4 μg/L (the MDL) and 250 μg/L. Phosphorus concentrations in recharge water are variable, but tend to be the highest at the beginning of the wet season (late spring and summer) when frequent rainfall scours the agricultural landscape.

The mean phosphorus concentration in recovered water measured at the ASR wellhead during all cycle tests is 10.8 +/- 11.6 μg/L (n= 44) and concentrations range between 1.4 μg/L and 67 μg/L. The T-test statistic indicates that the difference in median phosphorus concentration between recharge and recovered water is statistically significant (P <0.001). When recharge and recovery phosphorus data are subdivided into individual cycle tests, the reduction of median phosphorus concentration between recharge and recovered water is observed consistently **(Figure 9-8).**

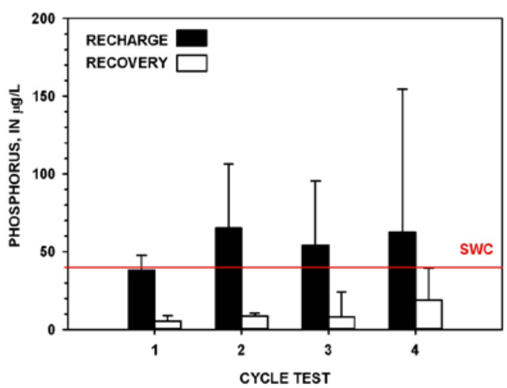

Figure 9-8 -- Median phosphorus concentrations in recharge (ASR well) and recovered water (ASR well and POD) during cycle tests 1 through 4.

SWC, surface water criterion. Error bars are standard deviation.

Phosphorus concentration data can also be viewed in time-series, analogous to previous plots for arsenic and molybdenum **(Figure 9-9)**. Declining phosphorus concentrations occurs as a result of advective transport (dilution), microbiological uptake, and apatite ($Ca_5(PO_4)_3(OH)$) precipitation. However, the main control of declining phosphorus concentrations has not yet been confirmed. The time series plot showing data from the 350-ft SZMW **(Figure 9-9 B)** suggests that much of the decline occurs during the static conditions of storage. Declining concentrations during storage suggest either biological uptake or apatite precipitation as the primary controls of phosphorus.

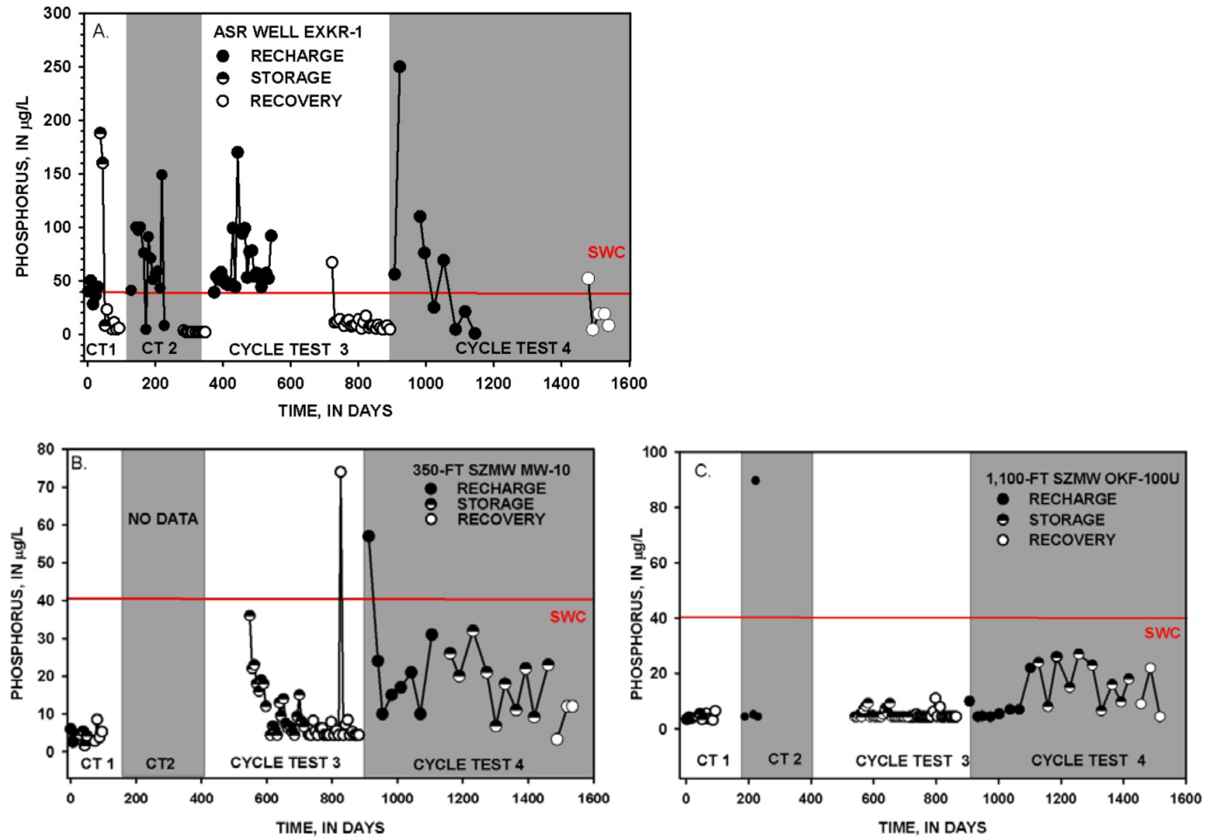

Figure 9-9 (A through C) -- Phosphorus trends through time (cycle tests 1-4) at individual wells at KRASR.

A, ASR well (EXKR-1); B, 350-ft SZMW (MW-10); C, 1,100-ft SZMW (OKF-100). All wells are open to the UFA. SWC, surface water criterion.

9.7.2 Phosphorus Trends During HASR Cycle Tests

Phosphorus concentrations in recovered water generally are lower than recharge water concentrations, but short recovery phases with limited sampling limit this conclusion. The median phosphorus concentration in recharge water measured at the ASR wellhead during cycle tests 2 and 3 is 21 +/- 42 µg/L (n=28), and concentrations range between < 3.0 µg/L (the MDL for this dataset) and 350 µg/L. Phosphorus concentrations in recharge water at HASR are lower compared to KRASR because HASR recharge flows directly from WCA-2 rather than agricultural lands. The median phosphorus concentration in recovered water measured at the ASR wellhead during cycle tests 2 and 3 is 7.9 +/- 62 µg/L (n= 9), and concentrations range between < 3.0 µg/L and 190 µg/L. The T-test statistic indicates that the difference in median phosphorus concentration from recharge versus recovered water is not statistically significant (P=0.491). This analysis does not clearly show declining phosphorus concentrations over time. During cycle test 2, there was no storage phase so microbial metabolism or apatite precipitation may not have sufficient time to occur.

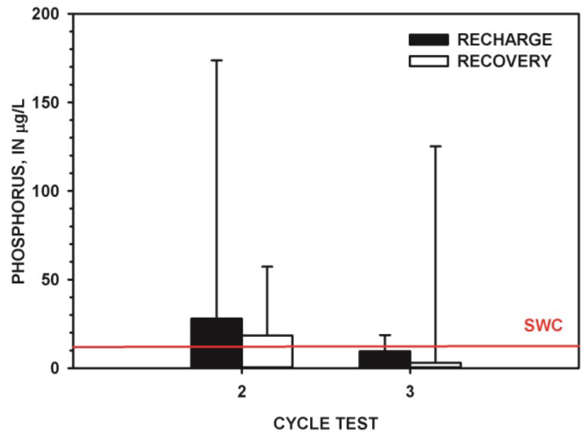

Figure 9-10 -- Median phosphorus concentrations in recharge (ASR well) and recovered water (POD) during cycle tests 2 and 3 at HASR. SWC, surface water criterion. Error bars are standard deviations.

During cycle test 3, all recovered water samples were collected at the point of discharge into Hillsboro Canal, not the ASR wellhead. It is possible that these samples could have been contaminated accidentally by phosphorus in splashed surface water. When recharge versus recovery phosphorus data are subdivided into individual cycle tests, the difference in median phosphorus concentration between recharge versus recovered water is not statistically significant (**Figure 9-10).**

9.8 Mercury, Methyl Mercury, and Mercury Methylation Potential During ASR Cycle Tests

The presence of mercury and methyl mercury in surface waters of south Florida, and resultant ecotoxicological effects, is well known (Perry, 2008). The source of inorganic mercury in the Everglades is atmospheric deposition (Marsik et al., 2006). Inorganic mercury is converted to mono-methyl mercury, a potent neurotoxin that is bioaccumulated and biomagnified at the top of food webs. Mercury methylation is mediated by sulfate-reducing microbes in wetlands, and the rate of methylation depends on concentrations of sulfate, sulfide, and organic carbon (Shao et al., 2012).

Inorganic mercury and methyl mercury occur in surface waters used for recharging the UFA, which is a sulfate-reducing aquifer. Therefore, the potential exists for increased mercury methylation in the storage zone, resulting in increased methyl mercury loads when recovered water is distributed back to the basin. Mercury methylation potential during ASR cycle tests was evaluated two ways: 1) by comparing recharge and recovered water concentrations of mercury and methyl mercury in ASR wellhead samples through all cycle tests; and 2) laboratory experiments using closed-system incubation of representative surface water and rock mixtures, spiked with a methyl mercury isotope tracer ($Me^{199}Hg$) to track microbe-mediated production of methyl mercury (Krabbenhoft et al., 2007).

Laboratory experiments represent a more regional approach to quantifying mercury methylation potential, so will be discussed in the ASR Regional Study technical data report.

9.8.1 Mercury and Methyl Mercury Trends During KRASR Cycle Tests

Recovered water concentrations of mercury and methyl mercury are consistently lower than recharge water concentrations. The median concentrations of mercury and methyl mercury in recharge water measured during all cycle tests at the ASR wellhead are: 1.83 +/- 0.94 ng/L (n=54), with concentrations ranging between 0.99 ng/L and 5.65 ng/L (for mercury); and 0.24 ng/L -/+ 0.53 ng/L (n=54), with concentrations ranging between <0.020 ng/L (the MDL) and 3.02 ng/L (for methyl mercury). All mercury analyses are less than the 12 ng/L surface water quality criterion; there is no surface water quality criterion for methyl mercury.

Mercury and methyl mercury concentrations in recovered water during all cycle tests at the ASR wellhead or POD were nearly at their respective minimum detection limits (0.15 ng/L and 0.020 ng/L, respectively). The median concentrations are: 0.15 +/- 0.08 ng/L (n= 42), with concentrations ranging between < 0.15 ng/L and 0.68 ng/L (for mercury); and 0.020 +/- 0.005 ng/L (n=42), with concentrations ranging between 0.054 ng/L and <0.019 ng/L (for methyl mercury). The t-test statistic (Mann-Whitney rank sum test) indicates that the difference in median mercury and methyl mercury concentrations between recharge and recovered water is statistically significant (P <0.001). When recharge and recovery data are subdivided into individual cycle tests, the reduction of median mercury and methyl mercury concentration between recharge and recovered water is consistent **(Figure 9-11).**

Mercury and methyl mercury concentration data can also be viewed in time-series, analogous to previous plots for arsenic and molybdenum **(Figure 9-12)**. Declining mercury and methyl mercury concentrations occur as a result of advective transport (dilution), sorption, or co-precipitation with solid sulfides. However, the main control of declining mercury and methyl mercury concentrations has not yet been confirmed. A time series plot showing data from ASR wellhead samples (recharge) and the POD (recovery) shows consistent reductions in mercury and methyl mercury concentrations during each cycle test, with recovered water concentrations frequently below the MDL for both compounds **(Figure 9-12)**. Declining mercury and methyl mercury concentrations, even during prolonged cycles, indicate that additional mercury methylation does not occur in the KRASR, and ASR will not increase the load of methyl mercury to the Kissimmee River.

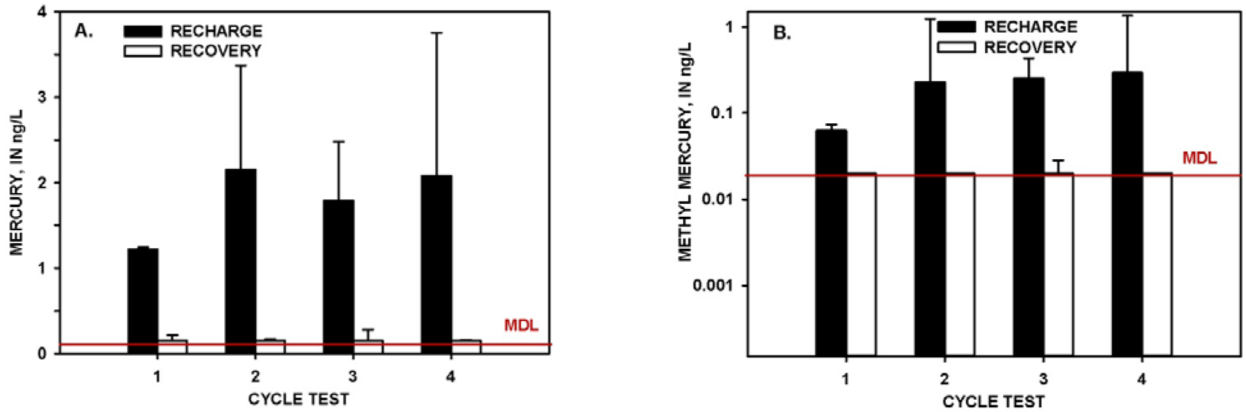

Figure 9-11 -- Median mercury (A.) and methyl mercury (B.) concentrations in recharge and recovered water from each cycle test at KRASR. Recovered water samples were measured at the ASR well and the POD. MDL, Minimum Detection Level. Error bars are standard deviations.

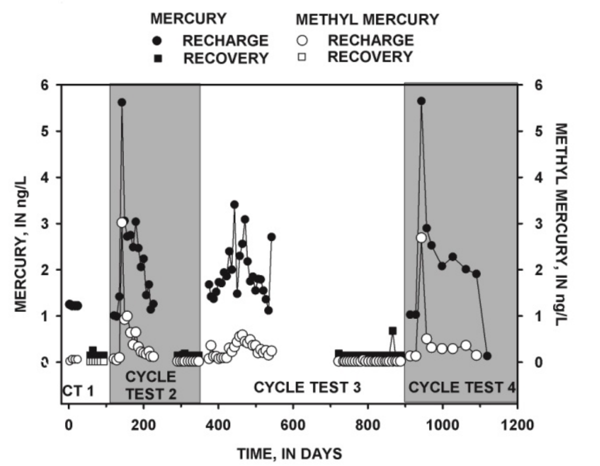

Figure 9-12 -- Time-series plot showing mercury and methyl mercury concentrations in recharge and recovered water from each cycle test at KRASR. Water samples were measured at the ASR well (recharge) and the POD (recovery).

9.8.2 Mercury and Methyl Mercury Trends During HASR Cycle Tests

There was no statistically significant difference in mercury and methyl mercury concentrations when HASR recharge water and recovered water samples are compared. The median concentrations of mercury and methyl mercury in recharge water measured during all cycle tests at the ASR wellhead are: 0.810 +/- 0.433 ng/L (n=33), with concentrations ranging between 0.513 ng/L and 2.49 ng/L (for mercury); and 0.153 ng/L -/+ 0.113 ng/L (n=33), with concentrations ranging between 0.049 ng/L and 0.536 ng/L (for methyl mercury). Mercury and methyl mercury concentrations in surface water at HASR generally are lower than those at KRASR. All mercury analyses are less than the 12 ng/L surface water quality criterion; there is no surface water quality criterion for methyl mercury.

Mercury and methyl mercury concentrations in recovered water during all cycle tests at the ASR wellhead or POD were statistically similar to their respective median concentrations in recharge water. The median concentrations of mercury and methyl mercury in recovered water are: 0.804 +/- 0.504 ng/L (n= 15), with concentrations ranging between 0.246 ng/L and 1.86 ng/L (for mercury); and 0.091 +/- 0.0971 ng/L (n=15), with concentrations ranging between 0.032 ng/L and 0.345 ng/L (for methyl mercury). The t-test statistic (Mann-Whitney rank sum test) indicates that the difference in median mercury and methyl mercury concentrations between recharge and recovered water is not statistically significant (P=0.517 for mercury, P=0.086 for methyl mercury). When recharge and recovery data are subdivided into individual cycle tests, the similarity of median mercury and methyl mercury concentrations between recharge and recovered water is consistent **(Figure 9-13).**

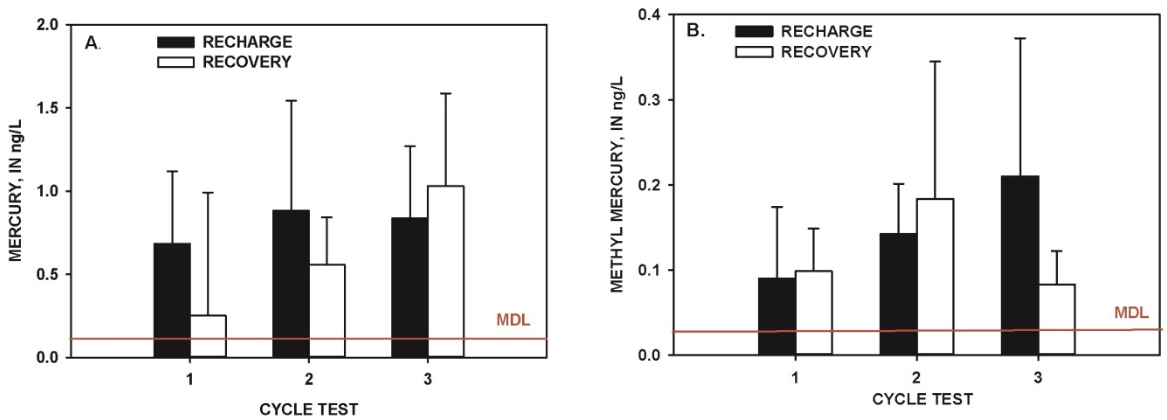

Figure 9-13 -- Median mercury (A.) and methyl mercury (B.) concentrations in recharge and recovered water from each cycle test at HASR. Recovered water samples were measured at the ASR well and the POD. MDL, Minimum Detection Level. Error bars are standard deviations.

It is likely that the similarity of mercury and methyl mercury concentrations between recharge and recovery is related to the cycle testing characteristics at HASR. During cycle test 1, 85 percent of the water was recovered after a month-long storage. These recovered water samples resemble recharge water. During cycle test 2, there was no storage interval and only 21 percent recovery, so recharge and recovered water are similar in composition. During cycle test 3, a larger volume was recharged, with 44 percent recovery. Although mercury concentrations are similar between recharge and recovery, the methyl mercury data suggests some reduction during storage and recovery. Similar to the conclusions at KRASR, there is no evidence for mercury methylation during cycle testing at HASR.

9.9 Water Quality Changes in the Surficial Aquifer During Cycle Testing

Hawthorn Group sediments (also known as the ICU) form a thick confining unit that separates the UFA and SAS at KRASR (500 ft) and HASR (780 ft). Therefore, it is unlikely that upward leakage will migrate from the UFA storage zone to the SAS. Water quality changes in the SAS can result from the following processes: 1) natural variations in recharge between wet and dry seasons; 2) at KRASR, percolation of water stored in the solids backwash pond; 3) at HASR, naturally occurring seepage from the quarry pond, beneath the ASR system, to Hillsboro Canal; and 4) leakage and migration of fluids in the annular space of the ASR and monitor wells.

9.9.1 Water Quality Changes in the Surficial Aquifer at KRASR

Variations in SAS water quality that result from any process can be estimated in time-series plots of chloride and total dissolved solids concentrations through the entire period of cycle testing at KRASR. The mean chloride concentration in the SAS at KRASR is 675 +/- 97 mg/L (n = 124); the mean TDS concentration in the SAS is 1,815 +/- 285 mg/L (n = 126). Time-series plots are shown in **Figure 9-14.**

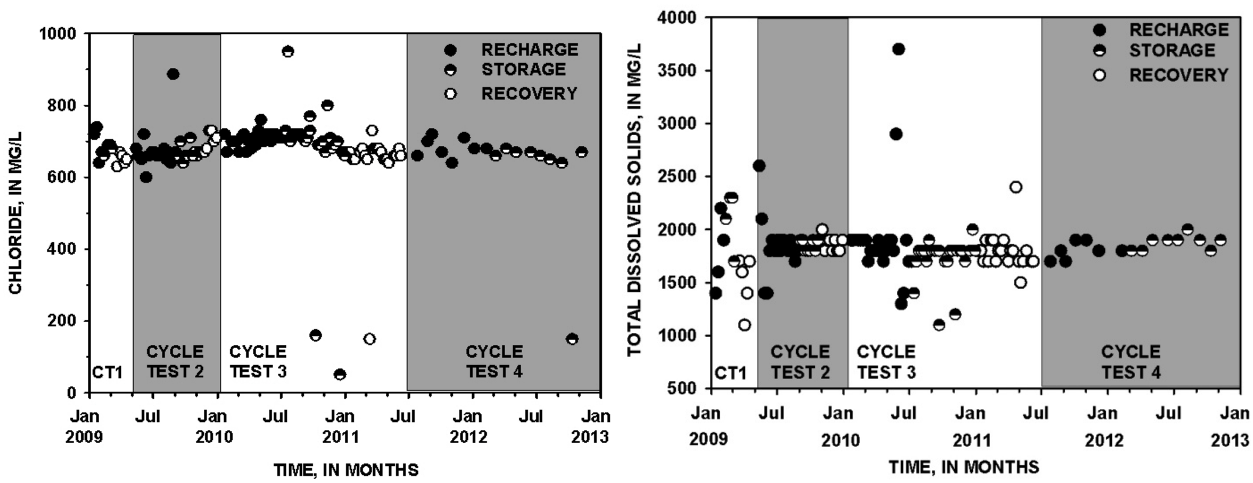

Figure 9-14 -- Time-series plots of chloride and total dissolved solids concentrations in the SAS during cycle testing at KRASR.

There is no systematic variation in either chloride or TDS concentrations in the SAS over time at KRASR. The coefficients of variation for chloride and TDS concentration are 16 percent and 14 percent, respectively. Outlier concentrations appear in each phase (recharge, storage, recovery), and probably result from field sampling or analytical errors.

9.9.2 Water Quality Changes in the Surficial Aquifer at HASR

Variations in SAS water quality that result from any process can be estimated in time-series plots of chloride and total dissolved solids concentrations through the entire period of cycle testing at HASR. The mean chloride concentration in the SAS at HASR is 1,075 +/- 90 mg/L (n = 50); the mean TDS concentration in the SAS is 2,597 +/- 162 mg/L (n = 49). Time-series plots are shown in **Figure 9-15**. There is no systematic variation in either chloride or TDS concentrations over time at HASR. The coefficients of variation for chloride and TDS concentration are 6.2 percent and 8.4 percent, respectively. Outlier concentrations appear in each phase (recharge, storage, recovery), and probably result from field sampling or analytical errors, or natural variability due to seepage in the SAS.

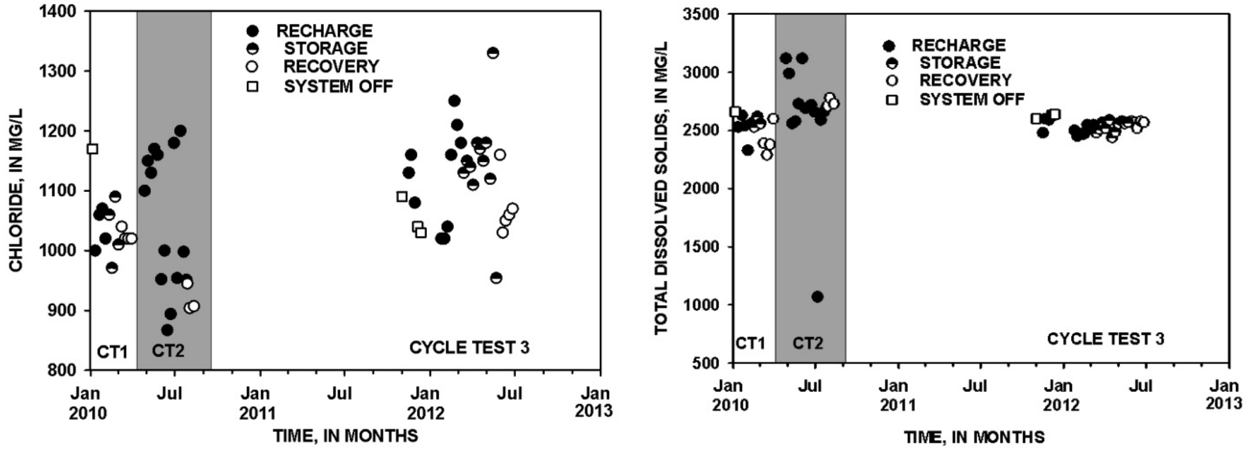

Figure 9-15 -- Time-series plots of chloride and total dissolved solids concentrations in the SAS during cycle testing at HASR.

9.10 FAS Water Quality After Cycle Test Completion

Storage zone water quality may differ from the native condition after completion of the cycle testing program if that ASR system has low percent recovery. At KRASR, the percent recovery is approximately 100 percent, so final groundwater quality characteristics are similar to the native condition. At HASR, the percent recovery was 41 percent during cycle test 3. Therefore, the final groundwater quality should be somewhat fresher in the vicinity of the ASR well. Native and final water quality constituent concentrations are compared to characterize post-cycle testing conditions in the storage zone.

9.10.1 FAS Water Quality After Cycle Test 4 at KRASR

The percent recoveries for cycle tests 1 through 4 range between 90 and 143 percent (Figure 9-1). High percent recoveries are typical for ASR systems that recharge an aquifer with fresh water quality. Figure 9-16 shows a comparison of selected water quality constituents in native and final storage zone samples from the ASR and SZMWs. At completion of cycle test 4, most constituent concentrations were less than or within one standard deviation of the native concentration. Final iron concentrations were higher in the ASR well and 1,100-ft SZMW compared to the native condition, but all concentrations were below the 0.80 mg/L criterion for the WQCE.

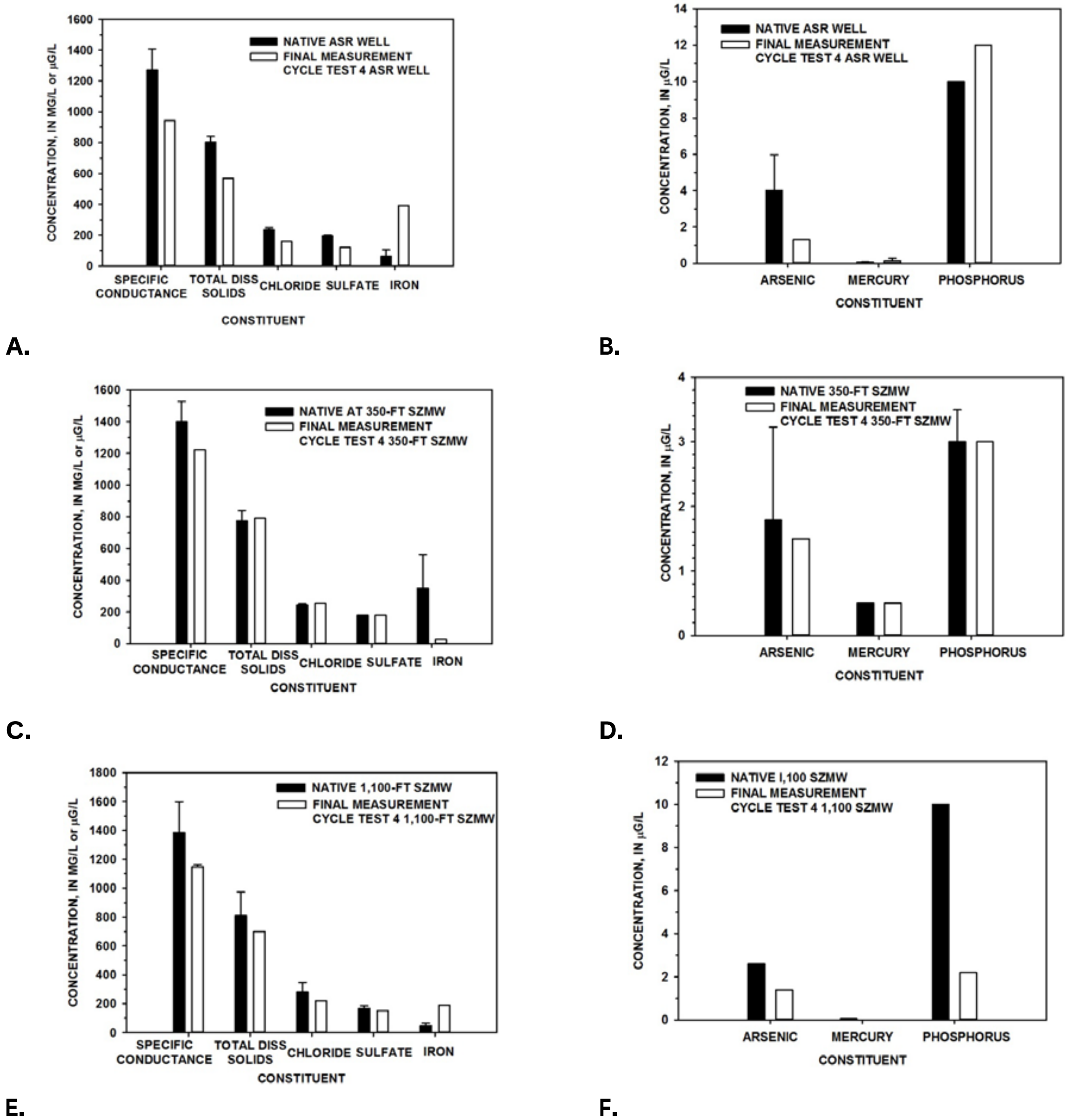

Figure 9-16 – Bar graphs comparing native and final UFA concentrations at KRASR.

Shown are selected major constituents (left) or trace constituents (right) in the native UFA and at the end of cycle test 4, measured at the ASR well (A,B), the 350-ft SZMW (C,D), and the 1,100-ft SZWM (E,F). Error bars are standard deviations of each sample population.

9.10.2 FAS Water Quality After Cycle Test 3 at HASR

Native storage zone water quality at HASR is brackish, and this limits the percent recovery during cycle tests 2 (21 percent) and 3 (41 percent; **Figure 9-2).** Consequently, after completion of cycle test 3, the storage zone remains fresher than native conditions due to dilution and displacement of native groundwater with recharge water. Cycle test 3 recovery phase data from the 1,010 SZMW (PBF-14) is compiled to characterize the final condition of the storage zone. The mean chloride concentration is 421 +/- 135 mg/L, and the mean arsenic concentration is 0.90 +/- 0.05 µg/L. Closer to the ASR well, water most likely is fresher. All other constituent concentrations are lower than that measured in the native aquifer prior to the onset of cycle testing **(Figure 9-17).**

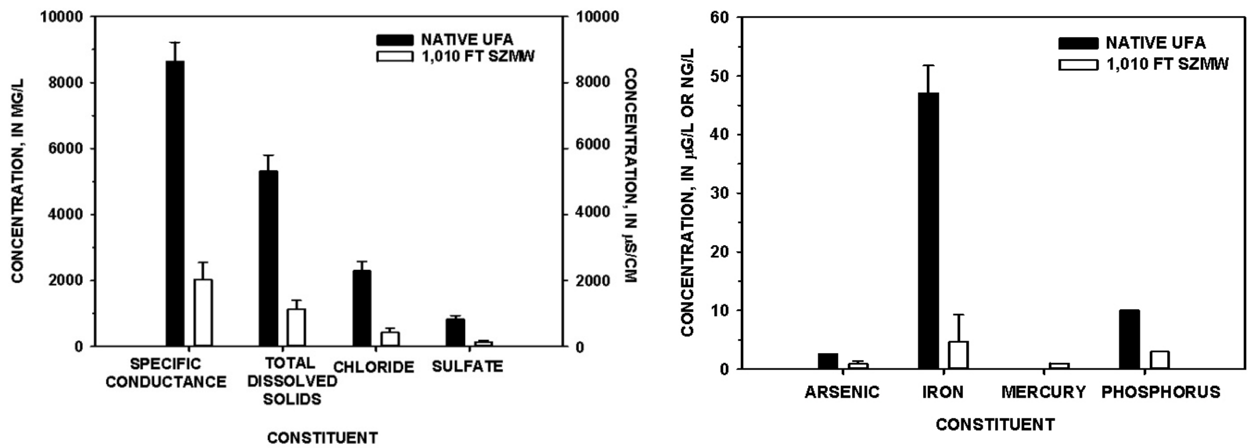

Figure 9-17 -- Bar graphs comparing native and final UFA concentrations at HASR.

Shown are selected major constituents (left) or trace constituents (right) in the native UFA and the UFA at completion of cycle test 3, measured at the 1,010-FT SZMW (PBF-14). Error bars are standard deviations of each sample population.

9.11 Summary and Conclusions

Evaluating water quality changes during the cycle testing is a major focus area for the cycle testing programs at both ASR systems. Major conclusions from interpretation of the KRASR and HASR datasets are summarized in the following sub-sections.

9.11.1 Cycle Testing at KRASR

- Four cycle tests were completed at the KRASR system. Cycle testing commenced on January 12, 2009, and was completed on July 1, 2013. The primary testing objective at KRASR was to evaluate ASR for long (multi-year), large volume cycles. Each cycle test increased in duration of each phase (recharge, storage, and recovery), and also the volume of Kissimmee River surface water recharged. Cycle test 4 was the longest (18 months), and resulted in the greatest volume recharged into the UFA (approximately 1 billion gallons or 3,070 acre-ft). This was one of the largest single-well cycle tests ever conducted in Florida. Percent recovery ranged between 90 and 143 percent for all four cycle tests.

- An extensive water quality data set was developed during the KRASR cycle testing program. Samples were collected weekly from the ASR well, 2 SZMWs, APPZ and SAS wells during cycle tests 1 and 2. The wellfield was expanded prior to cycle test 3 with the addition of 2 new SZMWs, again with weekly sample collection. Water quality trends that were defined during cycle tests 1 through 3 enabled a FDEP-approved reduction in sampling frequency to semi-monthly then monthly during cycle test 4. The KRASR water quality data set is among the most robust ever developed for an ASR system.

- The existing UV disinfection system provides inadequate attenuation of total and fecal coliforms in treated Kissimmee River recharge water, particularly at the onset of the wet season when surface water quality has high color values, and thus low UV transmittance. Total coliforms and cyanobacteria are detected at both the 350-ft SZMW and the 1,100-ft SZMW at KRASR, primarily during the recharge phase. No microorganisms were detected at the distal (2,350-ft and 4,200-ft) SZMWs. The percentage of FAS samples having detectable total coliforms that exceed the SDWA criterion declined during each phase of each cycle test: recharge (35 percent of all samples), storage (2 percent), and recovery (3 percent). Total coliform detections during storage and recovery probably include wellhead sample contamination, as coliforms are expected to die off during long storage durations.

- Arsenic is mobilized during recharge of each cycle test phase by pyrite oxidation, resulting in concentrations that exceed the 10 µg/L regulatory standard during the recharge and early storage phases. The maximum arsenic concentration (140 µg/L) was measured in the storage zone during recharge phase of cycle test 1. Subsequent arsenic maxima (approximately 40 µg/L) occurred during recharge or early storage phases of cycle tests 2 through 4. There is some evidence of arsenic remobilization in the data set from the 1,100-ft SZMW. However, arsenic mobilization is a temporary condition at KRASR, due to the interactions of organic- and iron-rich surface water with sulfate-reducing conditions of the UFA. A published geochemical modeling study indicates that arsenic is re-precipitated as a sulfide solid during storage and recovery in the storage zone. Arsenic concentrations measured in recovered water show concentrations below 10 µg/L in cycle tests 2, 3 and 4.

- Molybdenum is mobilized during recharge of each phase most likely by pyrite oxidation, resulting in significant concentration increases in the storage zone. The maximum molybdenum concentration (approximately 500 µg/L) was measured during the recharge and storage phases of cycle test 1. Maximum concentrations declined in SZMW samples during cycle test 4 recharge and storage phases, to 47 µg/L (350-ft SZMW) and 180 µg/L (1,100-ft SZMW). Storage zone concentrations sometimes exceed the 70 µg/L World Health Organization criterion for drinking water.

- Phosphorus is attenuated during KRASR cycle tests 1 through 4. The mean phosphorus concentration in recharge water is 66 +/- 42 µg/L; the mean phosphorus concentration in recovered water is 10.8 +/- 11.6 µg/L. The mechanism for phosphorus attenuation is probably microbiological metabolism and/or calcium phosphate (apatite) precipitation.

- Mercury and methyl mercury are attenuated during KRASR cycle tests 1 though 3 (cycle test 4 recovery data not yet available). Recovered water concentrations of mercury and methyl mercury are consistently lower than recharge water concentrations. The median concentrations of mercury and methyl mercury in recharge water measured at the ASR wellhead are: 1.83 +/- 0.94 ng/L, and

0.24 -/+ 0.53 ng/L, respectively. All mercury analyses are less than the 12 ng/L surface water quality criterion; there is no surface water quality criterion for methyl mercury. Mercury and methyl mercury concentrations in recovered water during all cycle tests at the ASR wellhead or POD were nearly at their respective minimum detection limits (0.15 ng/L and 0.020 ng/L, respectively). The median concentrations of mercury and methyl mercury are: 0.15 +/- 0.08 ng/L, and 0.020 +/- 0.005 ng/L, respectively. The t-test statistic (Mann-Whitney rank sum test) indicates that the difference in median mercury and methyl mercury concentrations between recharge and recovered water is statistically significant (P <0.001). The mechanism for mercury attenuation has not been identified.

- There is no change in surficial aquifer water quality that can be clearly related to upward migration of recharge water during cycle tests 1 through 4. Changes in total dissolved solids and chloride concentrations probably result from variations in recharge to the unconfined aquifer.

- At completion of cycle test 4, representative major inorganic constituent concentrations (total dissolved solids, chloride, sulfate) were less than or within one standard deviation of the native UFA concentration. Similarly, some representative trace inorganic constituent concentrations (arsenic and mercury) were lower in final samples compared to the native UFA. Final iron concentrations were higher in the ASR well and 1,100-ft SZMW compared to the native condition, but all concentrations were below the 0.80 mg/L criterion for the WQCE.

9.11.2 Cycle Testing at HASR

- Three cycle tests were completed at HASR system. Cycle testing commenced in January 2010, and was completed in June 2013. The ASR system was shut down for approximately 15 months between cycle tests 2 and 3. The primary objective was to show the feasibility of an annual cycle test, with recharge during the wet season and recovery during the dry season. Percent recoveries were 21 percent (cycle test 2) and 41 percent (cycle test 3) owing to mixing between fresh recharge and brackish native groundwater quality at this site. Percent recoveries are expected to improve with longer duration, larger volume recharge phases to displace native brackish groundwater.

- The water quality sampling program was designed primarily to evaluate permit compliance. Water quality samples were collected weekly throughout each cycle test, from the ASR well, two SZMWs, an APPZ well and an SAS well.

- Total and fecal coliforms were detected at a similar frequency at HASR compared to KRASR. The percentage of FAS samples having detectable total coliforms (> 4CFU/100 mL) declined during each phase: recharge (34 percent), storage (0 percent), and recovery (5 percent). Total coliform detections during storage and recovery probably include wellhead sample contamination, as coliforms are expected to die off during long storage durations.

- Arsenic is mobilized during recharge of each cycle test phase by pyrite oxidation, resulting in concentrations that exceed the 10 µg/L regulatory standard during the recharge and early storage phases. The maximum arsenic concentration (102 µg/L) was measured at the ASR wellhead during recovery phase of cycle test 1. Subsequent arsenic maxima (approximately 19 µg/L) occurred during recharge phase of cycle test 2 at the 330-ft SZMW. An arsenic exceedance in the LFA well (PBF-12; 35 and 47 µg/L) is unlikely to be related to ASR cycle testing. Instead, elevated arsenic concentrations may have resulted from well construction activities. Additional data are needed to quantify arsenic trends during cycle testing at HASR. However, generally speaking, arsenic concentrations are mostly below the 10 µg/L regulatory criterion.

- Molybdenum mobilization occurs, as shown in the cycle test 3 dataset, but concentrations remain below 12 µg/L in SZMWs throughout the cycle. A molybdenum concentration of 163 µg/L was measured in a single analysis during cycle test 1 recovery at the ASR well.

- There is no statistically significant difference in median phosphorus concentrations between recharge and recovered water samples. Recovered water samples were collected at the POD and may have been contaminated by phosphorus-rich surface water during sampling. Additional phosphorus analyses during future cycle tests would contribute to a better understanding of phosphorus transport and fate at this facility.

- There was no statistically significant difference in mercury and methyl mercury concentrations when HASR recharge water and recovered water samples are compared. The median concentrations in recharge water measured during all cycle tests at the ASR wellhead for mercury and methyl mercury are: 0.810 +/- 0.433 ng/L, and 0.153 ng/L -/+ 0.113 ng/L, respectively. All mercury analyses are less than the 12 ng/L surface water quality criterion; there is no surface water quality criterion for methyl mercury. The median concentrations in recovered water for mercury and methyl mercury are: 0.804 +/- 0.504 ng/L , and 0.091 +/- 0.0971 ng/L respectively. The t-test statistic (Mann-Whitney rank sum test) indicates that the difference in median mercury and methyl mercury concentrations between recharge and recovered water is not statistically significant (P=0.517 for mercury, P=0.086 for methyl mercury). Mercury and methyl mercury concentrations in surface water at HASR generally are lower than those at KRASR. Additional mercury and methyl mercury analyses during future cycle tests would contribute to a better understanding of phosphorus transport and fate at this facility.

- There is no change in surficial aquifer water quality that can be clearly related to upward migration of recharge water during cycle tests 1 through 3. Changes in total dissolved solids and chloride concentrations probably result from variations in recharge to the unconfined aquifer.

- Final water quality condition of the storage zone is fresher than the native UFA, with regard to total dissolved solids and chloride concentrations based on mean concentrations measured during cycle test 3 recovery at the 1,010-ft SZMW.

10. Ecotoxicological and Ecological Studies at CERP ASR Systems

10.1 Introduction

The Committee on Restoration of the Greater Everglades Ecosystem (CROGEE) recommended that "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 (NRC, 2001; 2002). To investigate the potential ecological impact and/or benefits of regional ASR implementation, the ASR Regional Study planners (composed of biologists, chemists, geologists, engineers and environmental toxicologists) developed a phased approach involving the progressive development, integration, and synthesis of toxicity testing and field research.

The primary objective of the initial phases of this ecotoxicological research was to identify a set of tests to evaluate the ecotoxicity and bioconcentration potential of CERP ASR recovered waters discharged to aquatic ecosystems (Johnson, 2005; Johnson et al., 2007; **Appendix L**). The studies recommended by the ASR Regional Study Biological Sub-Team were fully implemented during cycle tests 1 and 2 of the KRASR pilot project. This section introduces these ecological and ecotoxicological studies. Evaluation of these results for an ecological risk assessment will be discussed in the ASR Regional Study technical data report, currently in preparation. Permit-driven toxicity studies were conducted at KRASR and HASR, and these results were presented in **Section 7**.

10.2 Ecotoxicological and Ecological Studies at KRASR

Ecotoxicological and bioconcentration studies were conducted using source water (Kissimmee River) during the KRASR recharge phase of cycle test 1 to evaluate the aquatic toxicity and bioconcentration potential of the source water prior to storage. These tests, with some modifications, were again conducted during KRASR cycle tests 1 and 2 recovery periods.

The following ecotoxicity tests were conducted:

- 96-hour chronic growth test with the green algae *Selenastrum capricornutum*;
- 7-day chronic static-renewal survival and reproduction tests with the water flea *Ceriodaphnia dubia*;
- 7-day chronic static-renewal embryo-larval survival and teratogenicity test with the fathead minnow *Pimephales promelas*;
- 21-day chronic static-renewal survival and reproduction test with the water flea *Daphnia magna*;
- 96-hour Frog Embryo Teratogenesis Assay with *Xenopus* (FETAX); and
- 28-day flow-through bioconcentration studies using bluegill (*Lepomis macrochirus*) and a freshwater mussel (*Elliptio buckleyi*).

The acute and chronic study methods listed above were selected based on the CROGEE recommendations. Initial ASRRS ecotoxicological research studies were conducted prior to cycle testing at CERP ASR systems using source waters, laboratory-generated recovered waters, and Palm Beach County Water Utilities Department (PBCWUD) ASR recovered waters (Johnson, 2005; Johnson et al., 2007; Appendix L). NPDES and CERPRA permits for operational testing at KRASR also included acute and chronic toxicity testing requirements. Toxicity test results for cycle tests 1 and 2 are included here for completeness in the evaluation of the potential toxicity of recovered waters and their overlap with this study.

Periphyton studies were also conducted in the Kissimmee River during KRASR cycle tests 1 and 2 as recommended by the ASRRS Biology sub-team, and results were incorporated in the baseline characterization. The results for the KRASR studies are summarized below and full reports are included in **Appendix L**.

10.3 KRASR Cycle Test 1 Recharge Period

The toxicity tests were conducted using Kissimmee River water (recharge source water) and laboratory control (control) waters to evaluate the potential baseline toxic effect (if any) of the recharge water on aquatic organisms prior to treatment and storage. The following subsections present a brief summary of the tests conducted and results. All toxicity studies were conducted at Hydrosphere Research (Alachua, FL). The bioconcentration studies were conducted onsite by Golder Associates, Inc. (Gainesville FL). The periphyton taxonomy was conducted by Water and Air Research (Gainesville FL).

10.3.1 96-Hour Chronic Growth Test with the Green Algae *Selenastrum capricornutum*

The 96-hour algal test was conducted twice during the recharge period. The first test was initiated on January 15, 2009, and results did not show a quantifiable toxic effect of the recharge water on the growth of this sensitive algal species. There was no statistical difference between tests using recharge water versus the controls. The no observed effect concentration (NOEC) was 100 percent recharge water.

The second test was initiated on February 5, 2009, and results did show a reduction in cell reproduction at 50 percent and 100 percent recharge water. Therefore the NOEC was 25 percent recharge water. In other words, the Kissimmee River water had a negative effect on algal cell reproduction when compared to the laboratory controls during the second test. Results are summarized in **Table 10-1**.

Table 10-1 -- Results of the *Selenastrum capricornutum*, Green Algae Chronic Toxicity Test

	96-Hour Test (1)	
	Test Concentration (% recharge water)	**Cells/mL (x10^6)**
Test Initiated 1/15/09	Control	1.017
	6.25	1.115
	12.5	1.131
	25	1.058
	50	1.023
	100	0.990
	NOEC	**100 % recharge water**
Test Initiated 2/5/09	Control	**0.994**
	6.25	0.946
	12.5	0.914
	25	0.884
	50	0.728 (2)
	100	0.810 (2)
	NOEC	**25 % recharge water**

1. EPA 2002a. Test method 1003.0
2. Indicates significant difference between the samples and the control (p=0.05).

NOEC = no observed effect concentration

10.3.2 7-Day *Ceriodaphnia dubia* Static Renewal Chronic Toxicity Test

The 7-day static renewal *C. dubia* (water flea) tests were conducted twice during the KRASR cycle test 1 recharge period. These tests did not show a quantifiable toxic effect of the recharge water on the survival and reproduction of this sensitive invertebrate. There was no statistically significant difference between tests using recharge water versus the controls. The NOEC for survival was 100 percent. The IC_{25} is defined as the toxicant concentration that causes a 25 percent reduction in a biological response (mortality, fecundity for example). The IC_{25} for this test was estimated to be greater than 100 percent recharge water, meaning that solutions consisting of 100 percent recharge water obtained at the beginning and ending of cycle test showed no effect on reproduction in the test population of water fleas. Results are summarized in **Table 10-2**.

Table 10-2 -- Results of the *Ceriodaphnia dubia* Water Flea Survival and Reproduction Toxicity Test

	7-day Chronic with *Ceriodaphnia dubia*[1]		
	Test Concentration (Percent recharge water)	**Final Survival (Percent)**	**Three Brood Totals (Average number of neonates/female)**
Test Initiated 1/13/09	Control	100	24.8
	6.25	100	24.8
	12.5	100	24.8
	25	100	28.7
	50	100	31.9
	100	90	28.4
	NOEC	**100 % recharge water**	**100 % recharge water**
	IC_{25}	**--**	**>100 % recharge water**
Test Initiated 2/3/09	Control	80	24.0
	6.25	100	25.4
	12.5	100	24.1
	25	90	23.2
	50	100	23.5
	100	90	25.6
	NOEC	**100 % recharge water**	**100 % recharge water**
	IC_{25}	**--**	**>100 % recharge water**

Notes: 1. EPA, 2002a. Test Method 1002.0 2. No significant difference between the recharge water samples and the control. 3. IC_{25} = inhibitory concentration resulting in 25 percent reduction of survival and reproduction in the population of water fleas.

10.3.3 7-Day *Pimephales promelas* Static Renewal Chronic Toxicity Test

The 7-day static renewal *P. promelas* (fathead minnow) embryo-larval survival and teratogenicity tests were conducted twice during the KRASR cycle test 1 recharge period. The NPDES and CERPRA permits for this facility later required a 7-day static renewal *P. promelas* larval survival and growth test. Data generated from the ASRRS ecotoxicological program were used to meet this chronic permit requirement during cycle tests 1 and 2 of the recovery period, even though it was a different early life stage chronic test using the same fish species cited in the same USEPA method (USEPA, 2002a).

These embryo-larval tests did not show a quantifiable toxic effect of the recharge water on the survival and embryological development. There was no statistically significant difference between tests using recharge water versus the controls. The NOEC for survival and embryological malformations (terata) was 100 percent recovered water. Results are summarized in **Table 10-3**.

Table 10-3 -- Results of the *Pimephales promelas* Embryo-Larval Survival and Teratogenicity Toxicity Test

	7-day Chronic with *P. promelas*[1]			
	Test Concentration (Percent recharge water)	**Final Survival (Percent)**	**Final Terata Counts (Percent)**	**Total Mortality (Percent)**
Test Initiated 1/13/09	Control	90	0	10
	6.25	62.5	0	37.5
	12.5	82.5	0	17.5
	25	87.5	0	12.5
	50	85	0	15
	100	80	0	20
	NOEC	**100 % recharge water**	--	--
Test Initiated 2/3/09	Control	85	0	15
	6.25	65	0	35
	12.5	75	0	25
	25	75	0	25
	50	80	0	20
	100	85	0	15
	NOEC	**100 % recharge water**	--	--

1. EPA, 2002a. Method 1001.0

10.3.4 21-Day *Daphnia magna* Life Cycle Toxicity Test

One 21-day *D. magna* life cycle toxicity test was conducted during the KRASR cycle test 1 recharge period. This water flea is similar to *C. dubia*, but it has a longer life cycle, therefore the test is conducted for 21 days. This test was used in addition to the *C. dubia* because *D. magna* is more tolerant to water hardness than *C. dubia*, and it was expected to potentially help assess toxicity (if observed) caused by higher water conductivity from other sources of toxicity.

No effect was observed on survival or reproduction of *D. magna*. The NOEC was 100 percent and the IC_{25} is expected to be greater than 100 percent recharge water. Results are summarized in **Table 10-4**.

Table 10-4 -- Results of the 21-Day *Daphnia magna* Life Cycle Toxicity Test

	21-day Chronic Toxicity Test with *D. magna* [1]		
	Test Concentration (% recharge water)	**Final Survival (%)**	**Brood Totals (Average number of neonates per female)**
Test Initiated 1/13/09	Control	90	58.7
	6.25	80	64.0
	12.5	70	54.4
	25	60	55.1
	50	70	64.1
	100	90	66.5
	NOEC	**100 %**	**100 % recharge water**
	IC_{25}	--	**> 100 % recharge water**

(1) ASTM Method E1193-97

10.3.5 Frog Embryo Teratogenesis - *Xenopus* Test

Two Frog Embryo Teratogenesis Assay–*Xenopus* (FETAX) tests were conducted using recharge water. These tests did not show a quantifiable effect of the recharge water on the survival, malformations, or growth. There was no statistically significant difference between the tests using recharge water versus the controls. The NOEC for survival, malformations, and growth was 100 percent and the IC_{25} was estimated to be greater than 100 percent recharge water. **Table 10-5** and **Table 10-6** summarize these results.

Table 10-5 -- Results of the Frog Embryo Toxicity Assay – *Xenopus* Test (January 15, 2009 Sample)

Frog Embryo Teratogenesis Assay – Xenopus (FETAX)[(1)]						
Lab No. / Sample ID (% Recharge Water)	Mean Mortality (Percent)	Mean Malformation (Percent)	Mean Growth[2] (Percent)	Mortality Significantly Different From Control[3]	Malformation Significantly Different From Control[3]	Growth Significantly Different From Control[3]
FETAX Solution Control (100%)	5.0	0.0				
6-AN Reference (2,500 mg/L)	100.0	-	-	-	-	-
6-AN Reference (5.5 mg/L)	5.0	55.3	-	-	-	-
002 / ASR (6.25%)	2.5	0.0	102.4	No	No	No
002 / ASR (12.5%)	2.5	2.5	101.1	No	No	No
002 / ASR (25%)	20.0	4.2	102.2	No	No	No
002 / ASR (50%)	7.5	0.0	101.6	No	No	No
002 / ASR (100%)	15.0	8.8	103.8	No	No	No

Notes: 1. ASTM method E 1439-98. 2, Mean sample length (cm) divided by mean FETAX solution control length, expressed as % growth. 3. Mortality, malformation and growth results are based on statistical analysis using Kruskal-Wallis ANOVA ($p < 0.05$).

Table 10-6 -- Results of the Frog Embryo Toxicity Assay – *Xenopus* Test (February 2, 2009 Sample)

Frog Embryo Teratogenesis Assay – Xenopus (FETAX)[(1)]						
Lab No. / Sample ID (% recharge water)	Mortality Mean (%)	Mean Malformation (%)	Mean Growth[2] (%)	Mortality Significantly Different From Control[3]	Malformation Significantly Different From Control[3]	Growth Significantly Different From Control[3]
FETAX Solution Control (100%)	0.0	0.0				
6-AN Reference (2,500 mg/L)	100.0	-	-	-	-	-
6-AN Reference (5.5 mg/L)	0.0	57.5	-	-	-	-
003 / ASR (6.25%)	0.0	0.0	98.3	No	No	No
003 / ASR (12.5%)	0.0	0.0	99.9	No	No	No
003 / ASR (25%)	0.0	2.5	98.4	No	No	No
003 / ASR (50%)	2.5	2.6	99.7	No	No	No
003 / ASR (100%)	0.0	0.0	99.8	No	No	No

Notes: 1. ASTM method E 1439-98. 2. Mean sample length (cm) divided by mean FETAX solution control length, expressed as % growth. 3. Mortality, malformation and growth results are based on statistical analysis using Kruskal-Wallis ANOVA ($p < 0.05$).

10.3.6 Permit-Required Toxicity Tests

During the recharge period, the acute tests are required for permit compliance at the KRASR system. These tests were the acute 96-hour *C. dubia,* and the acute 96-hour *Cyprinella leedsi*, bannerfin shiner (fish) tests. No acute toxicity was quantified during these tests. Both LC_{50} values were greater than 100 percent recharge water. Results are summarized in **Table 10-7**.

Table 10-7 -- Results of the 96-hour *Ceriodaphnia dubia* and *Cyprinella leedsi* Acute Tests

	96-Hour Acute tests *C. dubia* and *C. leedsi*[1]		
	Test Concentration (% recharge water)	***C. dubia* Survival (%)**	***C. leedsi* Survival (%)**
Test Initiated 2/3/09	Control	100	100
	6.25	90	100
	12.5	90	100
	25	85	95
	50	100	100
	100	95	100
	LC_{50}	**>100 % recharge water**	**>100 % recharge water**

1. EPA, 2002b. Method 2002.0 and 2000.0
LC_{50} = lethal concentration to half of the individuals exposed.

10.3.7 Bioconcentration Study at KRASR Using Recharge Water

A 28-day bioconcentration study was conducted using Kissimmee River water obtained during the recharge period of Cycle 1 (January 12 to February 9, 2009). These studies were conducted onsite using the SFWMD Mobile Bioconcentration Laboratory.

10.3.8 Mobile Bioconcentration Laboratory

A mobile bioconcentration laboratory was designed and built by Golder for the SFWMD **(Figure 10-1)**. The laboratory was designed to conduct bioconcentration studies onsite at the ASR sites using recovered and source waters. The 20-ft trailer has two air conditioners mounted on the roof to control temperature. The laboratory also has external side access for the water pumps.

The water distribution system in the laboratory is flow-through. The head tank water bath is connected to a chiller/heater and pump with a temperature control range of 60 to 80 degrees Fahrenheit (^{o}F). This head tank holds two 20-gallon aquaria that feed the source and/or recovered water to the test chambers. Each water type is pumped from the head tank into a 6-inch PVC channel that distributes water to up to 12 different test chambers. These 10-gallon test aquaria are located on either side of the trailer on two levels, six above and six below. Test water is gravity-fed to the aquaria from a 4-inch head of water to ensure equal flow rates. Each aquarium has a stand pipe that maintains the tank volume to approximately 8 gallons. The flow rate of the system allows for a minimum of five tank replacements per day.

Figure 10-1 -- Mobile bioconcentration laboratory at KRASR

Left, exterior back access door. Center, bioconcentration gallery. Right, exterior side view.

Located on the right side of the laboratory is a double door cabinet that is the pump house. Within this cabinet is located the chiller/heater and air and water pumps. One pump provides flow through the chiller while the other pumps feed test waters to the head tanks from external sources. This cabinet is accessible both from the outside as well as from the inside of the laboratory. The mobile laboratory was designed to be as flexible as possible in order to allow on-site testing of aquatic organisms of different sizes under variable conditions. The key advantage of using an on-site mobile laboratory (compared to offsite testing at a commercial laboratory) is that it allows flow-through access to source and recovered water in unlimited volumes. The mobile laboratory was positioned on the KRASR in a location that allowed for access to both the recovered water and the stored back water. The water flow in the laboratory is illustrated in **Figure 10-2**.

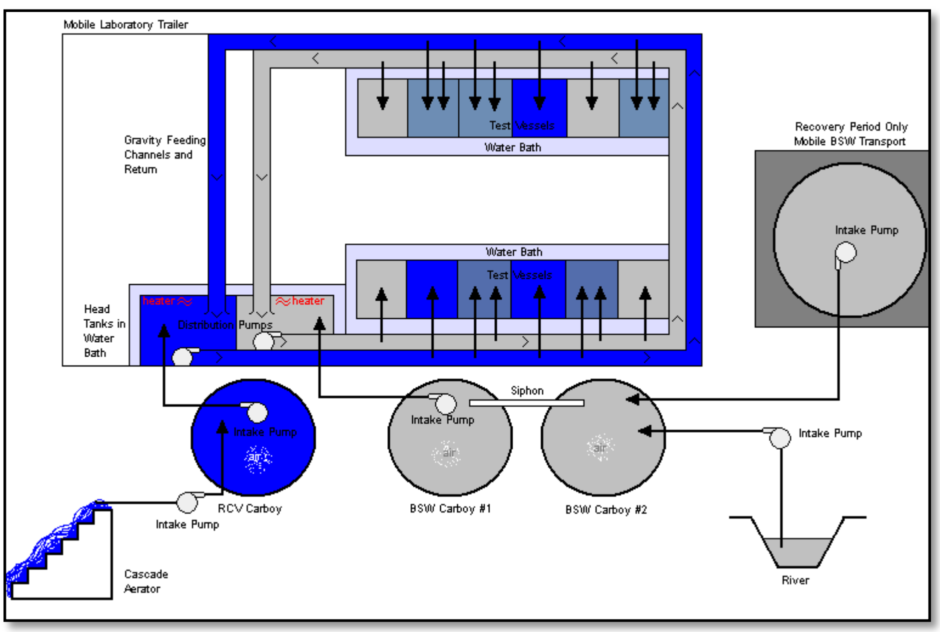

Figure 10-2 – Schematic showing the flow directions and mixing of background and test waters in the mobile concentration laboratory

10.3.9 Cycle 1 Recharge Bioconcentration Studies

Prior to the cycle test 1 KRASR recovery event, the mobile laboratory was transported to the site and set up to conduct the bioconcentration studies using Kissimmee River source water, following ASTM method E 1002-94. The study design was based on studies conducted during the initial stages of the ASR Regional Study ecotoxicology program (Johnson, 2005; **Appendix L**).

Fish and mussels were exposed under flow-through conditions to source water for 28 days in order to evaluate the potential for bioconcentration of selected trace metals and radium. The bioconcentration studies used the bluegill fish (*Lepomis macrochirus*) and a freshwater mussel (*Elliptio buckleyi*) **(Figure 10-3)**, also known as the Florida Shiny Spike. All test organisms were held in reverse osmosis water at Hydrosphere Research Laboratories for one month prior to the initiation of the bioconcentration studies. Mussels were collected from a private lake (Lake McMeekin) in Hawthorne, Florida. The *L. macrochirus*, were supplied by Osage Catfisheries Inc. (Osage Beach, MO). Fish were fed Finfish Starter #2 during the test and the mussels were not fed since they were exposed to unfiltered flowing river water. The chemical composition of the commercial feed was chemically analyzed to document its metal and radium concentrations.

Figure 10-3 -- *Lepomis macrochirus*, bluegill (left); *Elliptio buckleyi*, Florida shiny spike (right).

The metals analyzed in the recharge water and animal tissues were mercury (total and methyl mercury), arsenic, molybdenum, antimony, aluminum, cadmium, chromium, nickel, selenium, and zinc. Radium-226 and -228 radionuclides were also analyzed in freshwater mussels. Metals analyses were conducted by Frontier Geosciences Inc. (Seattle, WA) on fish and mussel tissues and water samples. Radium analyses were conducted on water and mussel tissues at Paragon Analytics (Fort Collins, CO).

Whole fish were homogenized for all fish analyses. Whole mussels were used for metals analysis and they were shucked at Frontier Geosciences Inc. and only soft tissues analyzed. For radium analysis, mussels were shucked onsite within the mobile laboratory providing only soft tissue for shipment to Paragon Analytics.

Table 10-8 summarizes the background levels of metals in fish (pre-exposure). Three separate composite samples were analyzed to define the background levels in test fish. Fish from this lot were then exposed in triplicate chambers to full strength recharge water under flow-through conditions for 28 days. At test conclusion, duplicate composite samples were collected from each test chamber and analyzed for metal concentrations. **Table 10-9** summarizes the fish tissue metal concentrations following the 28-day exposure period.

Five metals (aluminum, antimony, arsenic, cadmium and selenium) were not detected in fish tissues prior to exposure to recharge water. Post-exposure fish tissues showed non-detectable concentrations for all metals except arsenic and aluminum. Arsenic accumulated in all fish tissues with an average concentration of 0.46 mg/kg. One of the six tissue samples analyzed had a detectable concentration of aluminum (3.8 mg/kg). All other metals decreased in concentration (depurated) during the course of the exposure. Comparison of fish tissue concentrations before and after exposure to recharge water showed that chromium, mercury, molybdenum and nickel concentrations were statistically lower at the end of the exposure.

Table 10-8 – Results of Fish Tissue Metal Concentrations Pre-Exposure to Recharge Water. These are background fish tissue concentrations.

Analyte	Replicates			Average
	1	2	3	
Aluminum (mg/kg)	<2.5	<2.6	<2.5	<2.53
Antimony (mg/kg)	<0.025	<0.026	<0.025	<0.0253
Arsenic (mg/kg)	<0.32	<0.32	<0.31	<0.317
Cadmium (mg/kg)	<0.013	<0.013	<0.012	<0.013
Chromium (mg/kg)	0.63	0.53	0.95	0.70
Mercury (ng/g)	22.7	13.7	25.6	20.67
Methyl Mercury (ng/g)	18.8	14.3	32.2	21.77
Molybdenum (mg/kg)	0.12	0.07	0.14	0.11
Nickel (mg/kg)	0.44	0.40	0.47	0.44
Selenium (mg/kg)	<0.63	<0.64	<0.62	<0.63
Zinc (mg/kg)	20.8	23.8	34.5	26.4

Notes: ng/g = nanograms per gram. mg/kg = milligrams per kilogram.

Table 10-9 -- Results of Fish Tissue Metal Concentrations Post-Exposure to Recharge Water During 28-Day Bioconcentration Test

Analyte	Test Chamber Replicates						Average
	A		B		C		
	1	2	1	2	1	2	
Aluminum (mg/kg)	<2.5	<2.5	<2.5	<2.5	3.8	<2.4	1.67
Antimony (mg/kg)	<0.025	<0.025	<0.025	<0.025	<0.024	<0.024	<o.025
Arsenic (mg/kg)	0.53	0.42	0.46	0.50	0.42	0.42	0.46*
Cadmium (mg/kg)	<0.013	<0.013	<0.013	<0.013	<0.012	<0.012	<0.013
Chromium (mg/kg)	0.28	0.31	0.32	0.29	0.68	0.29	0.36*
Mercury (ng/g)	13.1	11.6	14.6	11.6	14.9	13.0	13.1*
Methyl Mercury (ng/g)	17.3	15.6	18.7	16.3	14.7	15.3	16.3
Molybdenum (mg/kg)	<0.06	0.06	0.09	0.08	0.06	<0.06	0.053*
Nickel (mg/kg)	0.21	0.21	0.37	0.20	0.29	0.21	0.248*
Selenium (mg/kg)	<0.63	<0.64	<0.63	<0.64	<0.61	<0.61	<0.623
Zinc (mg/kg)	16.9	20.4	25.9	21.8	22.0	19.2	21.03

Notes: * Indicates statistically significant difference between post exposure and background concentrations
ND= non-detectable as defined by each MRL. ng/g = nanograms per gram; mg/kg = milligrams per kilogram.

The freshwater mussels were exposed concurrently with the fish under identical conditions. Three separate composite mussel samples were analyzed prior to the test to define the background tissue concentrations. **Table 10-10** summarizes the mussel tissue background concentrations. Antimony and selenium were not detected. **Table 10-11** summarizes the mussel tissue metal concentrations following the 28-day exposure to recharge water.

Table 10-10 – Background Metals Concentrations in Mussel Tissue. Mussel tissues were analysed before exposure to recharge water

Analyte	Replicates			Average
	1	2	3	
Aluminum (mg/kg)	9.4	3.9	8.3	7.2
Antimony (mg/kg)	<0.024	<0.023	<0.026	<0.024
Arsenic (mg/kg)	0.81	0.49	0.69	0.66
Cadmium (mg/kg)	0.257	0.183	0.362	0.267
Chromium (mg/kg)	0.45	<0.23	0.27	0.24
Mercury (ng/g)	43.9	40.4	42.6	42.3
Methyl Mercury (ng/g)	12.6	6.5	6.3	8.5
Molybdenum (mg/kg)	0.06	<0.06	<0.06	0.04
Nickel (mg/kg)	0.20	0.09	0.21	0.17
Ra-226 (pCi/g)	4.4	2.44	4.4	3.75
Ra-228 (pCi/g)	1.26	0.96	1.53	1.25
Selenium (mg/kg)	<0.61	<0.59	<0.65	<0.62
Zinc (mg/kg)	27.7	10.0	25.6	21.1

mg/kg = milligrams per kilogram; ng/g = nanogram per gram.; pCi/g = picocuries per gram.

Table 10-11 – Metals Concentrations in Mussel Tissue After Exposure to Recharge Water. Samples were analyzed after 28-Day Bioconcentration Test

Analyte	Test Chamber Replicates						Average
	A		B		C		
	1	2	1	2	1	2	
Aluminum (mg/kg)	29.6	22.8	34.2	72.3	17.3	18.0	32.37
Antimony (mg/kg)	<0.023	<0.026	<0.025	<0.024	<0.023	<0.023	<0.024
Arsenic (mg/kg)	0.56	0.84	0.77	0.63	0.59	0.50	0.65
Cadmium (mg/kg)	0.240	0.297	0.299	0.190	0.229	0.173	0.238
Chromium (mg/kg)	<0.23	<0.27	<0.25	<0.24	<0.23	0.28	0.17
Mercury (ng/g)	41.8	40.2	40.8	34.2	38.4	25.7	36.85
Methyl Mercury (ng/g)	4.9	4.5	6.1	6.7	7.4	4.6	5.70
Molybdenum (mg/kg)	0.08	0.07	0.06	0.06	ND	ND	0.05
Nickel (mg/kg)	0.16	0.37	0.13	0.13	0.15	0.24	0.20
Ra-226 (pCi/g)	0.61	1.85	1.91	1.64	0.76	1.41	1.36*
Ra-228 (pCi/g)	0.92	0.91	0.71	0.83	1.23	0.92	0.92
Selenium (mg/kg)	<0.59	<0.66	<0.62	<0.59	<0.59	<0.59	0.607
Zinc (mg/kg)	15.5	40.9	16.4	23.6	27.4	43.5	27.88

* Indicates statistically significant difference between post exposure and background concentrations

Antimony and selenium in mussel tissues remained below the detection limits after exposure to recharge water. Aluminum and zinc increased in tissues from 7.2 to 32.37 mg/kg and 21.1 to 27.88 mg/kg, respectively. Chromium, total mercury, methyl mercury, and radium-228 tissue concentrations declined at the end of the exposure period. The mussels showed a statistically significant decrease in radium-226. The recharge water concentrations at test initiation and conclusion are summarized in **Table 10-12**. It is important to note that these concentrations are primarily in µg/L. The only metal not detected throughout the entire test was cadmium. The bioconcentration study protocol was successfully applied during the recharge period. Both species proved to be sensitive to metal concentration fluctuations responding through bioconcentration and depuration.

Table 10-12 -- Recharge Water Metal and Radium Concentrations During the 28-Day Bioconcentration Test

Analyte	Recharge Water				Average
	Day 0		Day 28		
	1	2	1	2	
Aluminum (µg/L)	115	101	61.3	58.9	84.05
Antimony (µg/L)	0.110	0.129	0.087	0.081	0.10
Arsenic (µg/L)	1.10	1.10	1.08	0.99	1.07
Cadmium (µg/L)	ND	ND	ND	ND	ND
Chromium (µg/L)	0.48	0.43	0.26	0.23	0.35
Mercury (ng/L)	1.75	1.61	2.00	2.34	1.92
Methyl Mercury (ng/L)	0.100	0.062	0.154	0.126	0.11
Molybdenum (µg/L)	1.31	1.29	1.16	1.13	1.22
Nickel (µg/L)	0.74	0.76	ND	ND	0.75
Ra-226 (pCi/L)	0.53	*	0.7	-0.2	0.34
Ra-228 (pCi/L)	-0.45	*	-0.10	0.50	-0.02
Selenium (µg/L)	0.68	0.84	ND	ND	0.76
Zinc (µg/L)	11.6	10.7	23.2	22.4	16.98

* Data points not collected µg/L = micrograms per liter.

As shown in **Table 10-13**, survival of exposed fish and mussels was excellent. Mortalities occurred on Day 19 due to a loss of power to the mobile laboratory, but this did not affect the test results.

Table 10-13 – Mortalities of Fish and Mussels During the 28-Day Exposure to Recharge Water

Station	Replicate	Study Day																													Total
		0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19*	20	21	22	23	24	25	26	27	28	
Fish	A		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	9	0	0	0	0	0	0	0	0	0	9
	B		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	23	0	0	0	0	0	0	0	0	0	23
	C		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	13	0	0	0	0	0	0	0	0	0	13
Mussels	A		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	B		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	C		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

*Day 19 loss of power

10.3.10 Periphyton Study

Periphyton baseline field studies were included in the ecotoxicology program in order to include plant communities in the assessment of potential risks and/or benefits of ASR implementation. Periphyton is attached algae that grow on submerged surfaces in aquatic ecosystems, and this community can be a valuable indicator of water quality. Periphyton communities were sampled using periphytometers (**Figure 10-4;** Wildlife Supply Company, Yulee FL, model 156-D30) according to FDEP standard operating procedure (SOP) FS7000. A periphytometer consists of a buoyant frame that holds eight glass slides that provide a clean surface for periphyton to colonize. Periphytometers were deployed for a 28-day period.

On January 13, 2009, 10 periphytometers were deployed in the Kissimmee River concurrent with the KRASR recharge period. **Figure 10-5** shows the stations which were located from the vicinity of the flow control structure, approximately 4,000-ft up-river from the KRASR system, to the mouth of the Kissimmee River approximately 1.5-miles down-river from the KRASR system.

Periphyton analysis used the Utermohl (1931, 1958) method for inverted microscope examination. Specimens were identified to genus, if possible, using standard taxonomic references. This analysis provides data as densities for each taxon (units per square centimeter) from which the Shannon-Wiener diversity index, Pielou's Evenness index, and Hulbert Evenness index were calculated. The Shannon-Wiener diversity index (H) takes into account both the number of unique species in a sample as well as the evenness of their abundance. High index values result from either more species or more even abundance. Pielou's Evenness index is a ratio of the Shannon-Wiener diversity index to the theoretical maximum value of the Shannon-Wiener diversity index if all species in the sample were equally abundant (H/Hmax). Hulbert's evenness index is an additional evenness index that incorporates the theoretical minimum value of the Shannon-Wiener diversity index for the sample. This theoretical minimum is subtracted from the terms in Pielou's index prior to calculating the ratio $[(H-H_{min})/(H_{max}-H_{min})]$.

Ash-free dry weight provides a measure of the mass of organic material that has grown on the slides. The samples are first dried to remove all water weight, then combusted to remove all organic material. The remainder is the inorganic material from the sample and the difference between that remainder and the initial dry weight of the sample is the ash-free dry weight.

Figure 10-4 -- Location of periphytometer stations in the Kissimmee River in the vicinity of the KRASR system.

Figure 10-5 – Examples of periphytometers during initial deployment (left), and after a 28-day deployment (right).

The following tables summarize the taxonomy and densities observed **(Table 10-14),** the diversity and evenness indices generated from these data **(Table 10-15),** and the ash-free dry-weights for each station on day 28 **(Table 10-16).** These data characterize the baseline for the Kissimmee River in the vicinity of the KRASR. These data and subsequent field exposures will serve as the baseline for the KRASR. **Appendix L** includes the complete taxonomy report.

Table 10-14 -- Baseline Periphyton Density

Densities reported as Units Per Square Centimeter of species collected on periphytometers in the Kissimmee River in the vicinity of the KRASR system (cycle test 1 recharge, January - February 2009)

	PERIPHYTOMETER STATION ID									
TAXA	1	2	3	4	5	6	7*	8	9	10
DIVISION CYANOBACTERIA										
Aphanocapsa	10,989	4,082	1,905	--	--	7,937	--	6,645	--	--
Chroococcus	--	--	--	10,390	--	--	3	1,3289	--	--
Gloeocapsa	--	--	--	3,896	--	--	--	--	--	--
Heteroleibleinia	--	--	--	--	--	--	--	13,289	--	--
Jaaginema	7,326	--	1,905	2,597	1,587	--	--	--	--	4,926
Leptolyngbya	29,304	16,327	--	--	--	7,937	--	16,611	21,978	19,704
Merismopedia	--	--	--	2,597	1,587	--	--	3,322	3,663	--
Microcystis	--	--	--	--	--	--	--	9,967	--	--
Planktolyngbya	7,326	--	--	1,299	--	--	--	--	--	--
Pseudanabaena	3,663	--	--	--	--	--	5	6,645	14,652	--
DIVISION CHLOROPHYTA										
Ankistrodesmus	--	--	--	--	--	--	--	--	--	4,926
Chlamydomonas	21,978	1,2245	--	7,792	4,762	23,810	63	3,322	10,989	24,631
Closterium	--	4,082	--	--	--	7,937	--	--	--	--
Euastrum	--	--	--	--	1,587	--	--	--	--	--
Kirchneriella	--	--	--	1,299	--	--	--	--	3,663	--
Lagerheimia	--	4,082	--	1,299	--	--	--	--	--	--
Protoderma	3,663	--	--	1,299	--	--	--	--	--	--
Scenedesmus	18,315	8,163	7,619	5,195	6,349	--	3	19,934	--	4,926
Spirogyra	--	12,245	1,905	1,299	--	7,937	--	--	--	--
Stigeoclonium	7,326	4,082	--	5,195	3,175	--	--	--	--	--
Tetraedron	3,663	--	1,905	--	--	--	--	--	--	--
Tetrastrum	--	--	1,905	--	--	--	--	--	--	--
Ulothrix	--	--	1,905	--	--	--	--	--	--	--
DIVISION CHRYSOPHYTA										
CLASS BACILLARIOPHYCEAE (diatoms)										
Achnanthes	29,304	20,408	64,762	12,987	23,810	7,937	13	93,023	7,326	--
Amphora	--	4,082	1,905	1,299	--	7,937	--	3,322	--	--
Aulacoseira	10,989	--	13,333	3,896	15,873	--	3	13,289	--	14,778
Bacillaria	--	--	--	5,195	--	--	--	9,967	--	--
Capartogramma	--	--	1,905	--	--	--	--	--	--	--
Cocconeis	10,989	53,061	24,762	7,792	63,492	23,810	3	36,545	32,967	9,852
Cyclotella	29,304	16,327	11,429	7,792	1,587	15,873	5	9,967	3,663	14,778
Encyonema	3,663	8,163	9,524	2,597	1,587	47,619	--	9,967	3,663	--
Eunotia	--	--	--	--	1,587	--	3	--	--	--
Fragilaria	--	--	3,810	10,390	--	--	--	26,578	--	19,704
Gomphonema	91,575	355,102	76,190	131,169	104,762	198,413	29	289,037	120,879	38,9163
Hippodonta	--	--	3,810	1,299	--	--	3	19,934	--	--
Melosira	153,846	69,388	11,429	16,883	3,175	325,397	3	19,934	175,824	137,931
Navicula	355,311	334,694	186,667	94,805	182,540	492,063	44	355,482	509,158	423,645
Nitzschia	245,421	244,898	160,000	49,351	88,889	1,071,429	23	112,957	190,476	334,975
Pseudostaurosira	--	--	--	--	--	--	--	6,645	40,293	--
Staurosira	--	--	--	--	--	--	--	--	--	4,926
Staurosirella	10,989	--	5,714	1,299	--	15,873	5	3,322	--	14,778
Surirella	29,304	24,490	3,810	6,494	3,175	15,873	3	9,967	--	4,926
Synedra	128,205	118,367	15,238	35,065	--	158,730	3	26,578	87,912	201,970
Thalassiosira	3,663	--	--	--	--	--	--	--	--	--
DIVISION CRYPTOPHYTA										
Cryptomonas	--	--	--	1,299	--	--	--	--	--	--

*The periphytometer at station 7 was tampered with during the course of the study and was found sitting on top of vegetation in the littoral zone.

Table 10-15 -- Baseline Periphyton Diversity and Evenness Indices

Indices calculated from samples collected in the Kissimmee River in the vicinity of the KRASR system (cycle test 1 recharge, January - February 2009)

Periphyton Station ID	Shannon-Wiener Diversity Index	Pielou's Evenness	Hulbert Evenness
1	3.204	0.708	0.660
2	2.892	0.681	0.634
3	2.977	0.658	0.599
4	3.357	0.691	0.628
5	2.611	0.639	0.590
6	2.472	0.605	0.549
7*	3.085*	0.755*	0.611*
8	3.212	0.683	0.626
9	2.635	0.674	0.636
10	2.744	0.671	0.628

*The periphytometer at station 7 was tampered with during the course of the study.

Table 10-16 -- Baseline Periphyton Ash-Free Dry Weights

Data obtained from samples collected in the Kissimmee River in the vicinity of the KRASR (cycle test 1 recharge, January - February 2009)

Periphyton Station ID	Ash-Free Dry Weight (g/m^2)
ASR 1	18.10
ASR 2	7.19
ASR 3	5.27
ASR 4	3.84
ASR 5	5.15
ASR 6	17.1
ASR 7	*
ASR 8	7.09
ASR 9	14.10
ASR 10	15.40

*The periphytometer at station 7 was tampered with during the course of the study.

10.4 KRASR Cycle 1 Recovery Period

The cycle test 1 recovery phase was initiated on March 9, 2009 and lasted for 39 days. Concurrent ecotoxicology program and permit-required testing was conducted during this period of time. These data are summarized below. To facilitate discussion, in many cases the summarized recharge and recovery data are presented side by side. The permit required toxicology data are also included to support the endpoints presented in **Section 7**.

10.4.1 96-Hour Chronic Growth Test with the Green Algae *Selenastrum capricornutum*

The 96-hour algal test was conducted four times during the recovery period to quantify the potential effects of recovered water throughout the first recovery phase. These data are summarized in **Table 10-17**. Recharge data are included for comparison.

Table 10-17 -- Comparative Results of the 96-hour *Selenastrum Capricornutum* Green Algae Chronic Toxicity Tests[(1)]

Tests were conducted during the KRASR cycle test 1 recharge and recovery periods. Data presented as cells/ml ($x10^6$)

Test Concentration (Percent)	Recharge		Recovery			
	15 JAN 2009	5 FEB 2009	12 MAR 2009	19 MAR 2009	26 MAR 2009	2 APR 2009
Control	1.017	0.995	1.574	1.758	1.470	1.219
6.25	1.146	0.946	1.644	1.712	1.532	1.284
12.5	1.131	0.915	1.920	1.700	1.579	1.383
25	1.058	0.885	1.961	1.818	1.718	1.574
50	1.023	0.728[(2)]	2.035	1.756	1.792	1.684
100	0.990	0.810[(2)]	2.036	1.862	1.790	1.974
NOEC	**100 % recharge water**	**25 % recharge water**	**100 % recovered water**	**100 % recovered water**	**100 % recovered water**	**100 % recovered water**

1. EPA 2002a. Test Method 1003.0
2. Indicates significant difference between the water samples tested and the control (p=0.05)

All four algal tests conducted using recovered water did not show a quantifiable toxic effect of the recovered water on the growth of this sensitive algal species; there was no statistically significant difference in results between the recovered water and the controls. The NOEC was 100 percent recovered water. The effect observed in the recharge water (reduction in algal reproduction) was no longer present after storage and recovery. Storage appeared to have removed surface water constituents that had affected algal growth.

10.4.2 7-Day *Ceriodaphnia dubia* Static Renewal Chronic Toxicity Tests

The 7-day static renewal *C. dubia* tests were conducted four times during the recovery period. These tests did not show a quantifiable effect of the recovered water on the survival this sensitive invertebrate. There was no statistically significant difference between results using the recovered water versus the controls. Similar results were observed during the recharge period. The NOEC for survival was 100 percent. The test results are summarized in **Table 10-18**.

Table 10-18 -- Results of the *Ceriodaphnia dubia* Water Flea Survival and Reproduction Toxicity Test

Test	Test Concentration (%)	Recharge		Recovery			
		13 JAN 2009	3 FEB 2009	10 MAR 2009	17 MAR 2009	24 MAR 2009	31 MAR 2009
Final Survival	Control	100	80	100	100	90	100
	6.25	100	100	90	100	80	100
	12.5	100	100	89	100	90	100
	25	100	90	90	100	100	100
	50	100	100	100	100	100	90
	100	90	90	100	100	90	100
	NOEC	**100 % recharge water**	**100 % recharge water**	**100 % recovered water**	**100 % recovered water**	**100 % recovered water**	**100 % recovered water**
Three Brood Totals (Average # of neonates/female)	Control	24.8	24.0	31.8	23.6	21.8	23.4
	6.25	24.8	25.4	27.4	22.8	18.7	24.3
	12.5	24.8	24.1	22.3(2)	25.9	23.1	26.0
	25	28.7	23.2	28.3	25.4	25.8	26.1
	50	31.9	23.5	29.2	26	26.4	24.0
	100	28.4	23.6	30.1	25.9	16.8	22.3
	NOEC	100 %	100 %	6.25 %	100 %	100 %	100 %
	IC_{25}	>100 %	>100 %	>100 %	>100 %	95.52 %	>100 %

1. EPA 2002a. Test Method 1002.0 2. Indicates significant difference between the samples and the control (p=0.05)

An effect on reproduction of *C. dubia* was observed in two of the tests using recovered water. The March 10, 2009 test showed a statistically significant difference between the 12.5 percent recovered water and the controls. This data point is considered a test anomaly since no effects on reproduction were observed at higher recovered water concentrations up to 100 percent. The March 24, 2009 sample of recovered water showed an IC_{25} of 95.52 percent, indicating a minor but measurable reduction in reproduction of the water flea in 95.52 percent recovered water. Due to the immediate mixing of the recovered water in the Kissimmee River, this does not represent a potential impact to the aquatic system.

10.4.3 7-Day *Pimephales promelas* Static Renewal Chronic Toxicity Tests

The 7-day static renewal *P. promelas* embryo-larval survival and teratogenicity tests were conducted three times during the recovery period. These tests did not show a quantifiable effect of the recovered water on the survival and embryological development of this sensitive fish. There was no statistically significant difference between the results using recovered water versus the controls. This result is similar to that using the recharge water. The NOEC for survival and embryological malformations (terata) was 100 percent recovered water. These data are summarized in **Table 10-19**.

Table 10-19 -- Results of the *Pimephales promelas* Embryo-Larval Survival and Teratogenicity Toxicity Tests(1) Tests were conducted during the KRASR cycle test 1 recharge and recovery phases

		RECHARGE		RECOVERY		
Test	**Concentration (%)**	**13 Jan 2009**	**3 Feb 2009**	**24 Mar 2009**	**31 Mar 2009**	**7 Apr 2009**
Final Survival (%)	Control	90	85	90	80	97.5
	6.25	62.5	65	87.5	85	80
	12.5	82.5	75	92.5	87.5	62.5
	25	87.5	75	92.5	81.6	75
	50	85	80	90	87.2	95
	100	80	85	95	77.5	70
	NOEC	100 % recharge water	100 % recharge water	100 % recovered water	100 % recovered water	100 % recovered water
Final Terata Counts	Control	0	0	0	0	0
	6.25	0	0	1	0	0
	12.5	0	0	1	0	0
	25	0	0	0	1	0
	50	0	0	3	0	0
	100	0	0	2	0	0
Total Mortality (%)	Control	10	15	10	20	2.5
	6.25	37.5	35	12.5	15	20
	12.5	17.5	25	7.5	12.5	37.5
	25	12.5	25	7.5	18.4	25
	50	15	20	10	12.5	5
	100	20	15	5	22.5	30

1. EPA 2002a. Method 1001.0

10.4.4 21-Day *Daphnia magna* Life Cycle Toxicity Tests

One 21-day *D. magna* life cycle toxicity test was conducted during cycle test 1 recovery. No effect was observed on survival or reproduction of *D. magna*, therefore the NOEC was 100 percent recovered water, and the IC_{25} is expected to be greater than 100 percent recovered water. These results are similar to those tests using recharge water. These data are summarized in **Table 10-20**.

Table 10-20 – Results of the 21-Day *Daphnia magna* Life Cycle Toxicity Tests(1)

Test Concentration (%)	Recharge		Recovery	
	Final Survival (Percent)	**Brood Totals (Avg. no. of neonates/female)**	**Final Survival (Percent)**	**Brood Totals(Avg. no. of neonates/female)**
Control	90	58.7	100	61.2
6.25	80	64.0	80	59.5
12.5	70	54.4	80	51.9
25	60	55.1	90	56.7
50	70	64.1	100	62.5
100	90	66.5	70	48.6
NOEC	**100%**	**100%**	**100%**	**100%**
IC_{25}	**--**	**>100%**	**--**	**>100%**

1. ASTM E1193-97

10.4.5 Frog Embryo Teratogenesis Assay – *Xenopus* Toxicity Test

Three Frog Embryo Teratogenesis Assay – *Xenopus* FETAX tests were conducted using recovered water. These tests did not show a quantifiable effect of the recovered water on the survival, malformations, or growth. There was no statistically significant difference between the results using recovered water versus the controls. The NOEC for survival, malformations, and growth was 100 percent, and the IC_{25} was estimated to be greater than 100 percent recovered water. **Tables 10-20** through **10-23** summarize these results. The recharge tests were similar and also did not show effects on this species.

Table 10-21 -- Results of the Frog Embryo Toxicity Test (March 11, 2009)

Frog Embryo Teratogenesis Assay – Xenopus (FETAX)(1)

Lab No. / Sample ID(% recovered water)	Mean Mortality (%)	Mean Malformation (%)	Mean Growth[2] (%)	Mortality Significantly Different From Control[3]	Malformation Significantly Different From Control[3]	Growth Significantly Different From Control[3]
FETAX Solution Control (100%)	0.0	3.8				
6-AN Reference (2,500 mg/L)	100.0	-	-	-	-	-
6-AN Reference (5.5 mg/L)	20.0	48.0	-	-	-	-
001 / RCV (6.25%)	2.5	2.5	100.1	No	No	No
001/ RCV (12.5%)	0.0	0.0	98.8	No	No	No
001 / RCV (25%)	2.5	0.0	100.0	No	No	No
001 / RCV (50%)	2.5	2.5	100.6	No	No	No
001 / RCV (100%)	0.0	10.0	98.8	No	No	No

NOTES: 1. ASTM method E 1439-98. 2. Mean sample length (cm) divided by mean FETAX solution control length, expressed as % growth. 3. Mortality, malformation and growth results are based on statistical analysis using Kruskal-Wallis ANOVA (P<0.05).

Table 10-22 -- Results of the Frog Embryo Toxicity Tests (March 16, 2009)

Frog Embryo Teratogenesis Assay – Xenopus (FETAX)(1)

Lab No. / Sample ID (% recovered water)	Mean Mortality (%)	Mean Malformation (%)	Mean Growth[1] (%)	Mortality Significantly Different From Control[2]	Malformation Significantly Different From Control[2]	Growth Significantly Different From Control[2]
FETAX Solution Control (100%)	0.0	2.5				
6-AN Reference (2,500 mg/L)	100.0	-	-	-	-	-
6-AN Reference (5.5 mg/L)	15.0	50.3	-	-	-	-
002 / RCV (6.25%)	5.0	0.0	101.0	No	No	No
002 / RCV (12.5%)	2.5	0.0	100.0	No	No	No
002 / RCV (25%)	2.5	0.0	100.8	No	No	No
002 / RCV (50%)	0.0	2.5	99.0	No	No	No
002 / RCV (100%)	2.5	7.8	101.1	No	No	No

Notes 1. ASTM method E 1439-98. 2. Mean sample length (cm) divided by mean FETAX solution control length, expressed as % growth. 3. Mortality, malformation and growth results are based on statistical analysis using Kruskal-Wallis ANOVA (P<0.05).

Table 10-23 -- Results of the Frog Embryo Toxicity Tests (March 23, 2009)

Frog Embryo Teratogenesis Assay – *Xenopus* (FETAX)[(1)]

Lab No. / Sample ID (% recovered water)	Mortality Mean (%)	Mean Malformation (%)	Mean Growth[1] (%)	Mortality Significantly Different From Control[2]	Malformation Significantly Different From Control[2]	Growth Significantly Different From Control[2]
FETAX Solution Control (100%)	1.3	1.3				
6-AN Reference (2,500 mg/L)	100.0	-	-	-	-	-
6-AN Reference (5.5 mg/L)	20.0	49.2	-	-	-	-
003 / RCV (6.25%)	5.0	0.0	100.3	No	No	No
003 / RCV (12.5%)	12.5	0.0	98.3	No	No	No
003 / RCV (25%)	12.5	3.1	99.4	No	No	No
003 / RCV (50%)	2.5	2.5	100.1	No	No	No
003 / RCV (100%)	0.0	2.5	98.6	No	No	No

NOTES: 1. ASTM method E 1439-98. 2. Mean sample length (cm) divided by mean FETAX solution control length, expressed as % growth. 3. Mortality, malformation and growth results are based on statistical analysis using Kruskal-Wallis ANOVA (P<0.05).

10.4.6 FDEP Permit-Required Toxicity Tests

One of the initial concerns regarding ASR recovered water discharges to surface waters in South Florida was related to the potential increase in specific conductance in the receiving water due to the discharge of recovered waters. In order to evaluate this concern, four recovered water samples were collected as the specific conductance of the cycle test 1 recovered water increased over time, as follows:

- Day 2 of recovery;
- When the daily specific conductance measurement of the recovered water increases by 1/3 of the difference between the Day 2 specific conductance and 1,275 µmhos/cm;
- When the daily specific conductance measurement of the recovered water increases by 2/3 of the difference between the Day 2 specific conductance and 1,275 µmhos/cm; and
- Final 2 days of recovery or when the specific conductance measurement reaches or exceeds 1,275 µmhos/cm, whichever occurs first.

Table 10-24 summarizes these acute toxicity data. As shown, the increased specific conductance did not have an acute effect on the test species, *C. dubia* and *C. leedsi*.

Table 10-24 -- CERPRA Toxicity Tests Conducted as Recovered Water Specific Conductance Values Increased Over the Cycle Test 1 Recovery Period

	96-Hour Acute with *C. dubia* and *C. leedsi*[1]			
	Test Concentration (%)	***C. dubia* Survival (%)**	***C. leedsi* Survival (%)**	**Recovered Water Specific Conductance (μmhos/cm)**
Test Initiated 03/12/09 and 3/11/09[2]	Control	100	100	**528 (Day 2 of recovery period)**
	6.25	100	100	
	12.5	100	100	
	25	100	100	
	50	100	100	
	100	100	100	
	LC_{50}	**>100%**	**>100%**	
Test Initiated 3/17/09 and 03/20/09[2]	Control	100	100	**722**
	6.25	100	100	
	12.5	100	100	
	25	100	100	
	50	95	100	
	100	100	100	
	LC_{50}	**>100%**	**>100%**	
Test Initiated 04/02/09	Control	100	100	**1,037**
	6.25	100	100	
	12.5	100	100	
	25	100	100	
	50	95	100	
	100	100	100	
	LC_{50}	**>100%**	**>100%**	
Test Initiated 04/17/09	**Control**	**100**	**100**	**1,219 (last day of recovery)**
	6.25	100	100	
	12.5	100	100	
	25	100	100	
	50	100	100	
	100	100	100	
	LC_{50}	**>100%**	**>100%**	

1. EPA 2002b. Method 2002.0 and 2000.0
2. *C. dubia* testing conducted on first listed date. *C. leedsi* tests conducted on second listed date.

10.4.7 Bioconcentration Study at KRASR Using Recovered Water

The design for the 28-day bioconcentration study during the cycle test 1 recovery was similar to the one used during the recharge period. The major difference was that during the recharge period only source water was tested (100 percent recharge water). Additional treatments were tested during recovery and they are discussed below. The recovery study was conducted from March 9 to April 6, 2009.

During recovery, since recovered water was being discharged to the Kissimmee River, background surface water had to be collected and transported from a site 1 mile upstream of KRASR (outside the influence of the ASR discharge). Recovered water was collected by pumping recovered water from the top of the ASR discharge cascade aerator. The bioconcentration study was conducted using a laboratory control and 3 treatments as follows:

- Laboratory control water prepared using reverse osmosis water
- Recovered ASR water, 100% unaltered
- Background surface water, 100% unaltered
- 50/50 mixture of background surface water and recovered ASR water

The laboratory water control was used to ensure that the testing conditions were adequate for the test species. The recovered water was tested in full strength, and diluted to 50 percent using Kissimmee River surface water. Full strength background was also tested to evaluate its quality.

In the mobile laboratory water was pumped to the flow-through diluting system and test solutions were delivered to the exposure chambers containing fish or mussels at a rate of 7.5 gallons per hour per hour or 11 turnovers a day. Fish and mussels were exposed to flow-through solutions in separate tanks. Each test exposure treatment was conducted in triplicate. The exposure chambers were placed in water baths to maintain a constant temperature of approximately 25 °C.

The same test species were used for the recovered water bioconcentration studies as in the recharge study, the bluegill, *L. macrochirus*, and the mussel, *E. buckleyi*. Since recovered water is void of planktonic species, mussels were fed algae during the test period. Fish were fed as outlined during the recharge period.

The objectives of these bioconcentration tests were to evaluate the potential accumulation of selected metals and radium in the tissues of the test organisms exposed to surface water and recovered water. To determine if there was a difference in metal concentrations in treatment types and tissue concentrations for bioconcentration studies, statistical comparisons were made using Analysis of Variance (ANOVA) using the NCSS-2007 software. The level of statistical significance was the standard alpha=0.05 level. The laboratory control water was treated by reverse osmosis prior to use. Water quality is summarized in **Table 10-25.** The survival of the test species was acceptable and is summarized in **Table 10-26**. These results document that the test conditions were acceptable for the bioconcentration exposure.

If some of the replicates had metal concentrations at or below the detection limit, one-half the detection limit was used when calculating the mean. If all the samples were non-detects, the detection limit was used as the mean. Water quality analytical data for background water, recovered ASR water, and the 50/50 mix of background and ASR recovered water are shown in **Table 10-27.** Note that arsenic concentrations in the recovered ASR water and the 50/50 mix water exceed the SDWA MCL.

Table 10-25 -- Trace Metals and Radium in Laboratory Control Water				
	Replicate samples			
Analyte	**1**	**2**	**3**	**Average**
Aluminum (mg/L)	2.6	2.2	2.5	2.43
Antimony (mg/L)	0.023	0.011	0.01	0.0147
Arsenic (mg/L)	<0.04	<0.04	<0.04	<0.04
Cadmium (mg/L)	<0.004	<0.004	<0.004	<0.004
Chromium (mg/L)	<0.03	<0.03	<0.03	<0.03
Mercury (ng/g)	<0.08	0.08	0.22	0.113
Methyl Mercury (ng/L)	<0.019	<0.019	<0.019	<0.019
Molybdenum (mg/L)	0.06	0.03	0.02	0.037
Nickel (mg/L)	0.26	0.27	0.28	0.27
Ra-226 (pCi/L)	0.06	-0.11	-0.06	-0.04
Ra-228 (pCi/L)	0.11	0.07	0.3	0.16
Selenium (mg/L)	0.2	<0.19	0.25	0.182
Zinc (mg/L)	0.17	0.17	0.17	0.17

Table 10-26 -- Mortalities of Fish and Mussels During the 28-day Exposure to Recovered Water (March 9 through April 6, 2009)

Table 10-26 -- Mortalities of Fish and Mussels During the 28-day Exposure to Recovered Water (March 9 through April 6, 2009)

Period	Treatment Type	Station	Replicate	Study Day																													
				0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	Total
Recovery	Background Surface Water	Fish	A	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
			B	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
			C	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		Mussels	A	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
			B	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
			C	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	50/50 Mixture of Background Surface Water and Recovered Water	Fish	A	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
			B	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
			C	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
		Mussels	A	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
			B	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
			C	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Recovered ASR Water	Fish	A	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
			B	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
			C	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		Mussels	A	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
			B	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
			C	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Table 10-25 -- Trace Metal Water Quality Data for Bioconcentration Study

Samples obtained at the start (day 0) and finish (day 28) of the study. Analyses in bold font exceed the SDWA MCL.

Test Treatment		Day 0							Day 28						
		Fish Vessels			Mussel Vessels				Fish Vessels			Mussel Vessels			
	Analyte	A	B	C	A	B	C	Average	A	B	C	A	B	C	Average
Background Surface Water	Aluminum (µg/L)	151	121	113	111	102	210	134.7	52	158	130	265	221	533	226.5
	Antimony (µg/L)	0.098	0.099	0.099	0.109	0.102	0.102	0.102	0.087	0.086	0.094	0.093	0.085	0.090	0.0892
	Arsenic (µg/L)	1.47	1.47	1.44	1.36	1.46	1.39	1.43	1.54	1.63	1.64	1.72	1.73	2.06	1.72
	Cadmium (µg/L)	0.008	0.007	0.01	0.008	0.008	0.009	<0.020	<0.004	0.004	0.006	0.008	0.008	0.017	0.0075
	Chromium (µg/L)	0.21	0.21	0.18	0.19	0.14	0.17	0.18	0.20	0.36	0.31	0.54	0.45	1.10	0.493
	Mercury (ng/L)	1.77	1.79	1.76	1.76	1.80	2.07	1.83	1.44	1.38	1.52	1.62	1.57	1.31	1.473
	Methyl Mercury (ng/L)	0.135	0.088	0.094	0.121	0.090	0.094	0.1037	0.121	0.140	0.121	0.137	0.095	0.105	0.1198
	Molybdenum (µg/L)	3.05	3.10	3.01	3.10	3.09	3.16	3.085	2.84	2.76	2.86	2.82	2.93	3.5	2.952
	Nickel (µg/L)	0.83	0.92	0.90	0.94	0.88	0.88	0.892	0.69	0.77	0.74	0.84	0.82	1.14	0.833
	Ra-226 (pCi/L)	-	-	-	0.41	-0.05	1.04	0.467	-	-	-	0.34	0.48	0.1	0.307
	Ra-228 (pCi/L)	-	-	-	0.46	0.4	0.83	0.5637	-	-	-	0.01	-0.09	0.48	0.133
	Selenium (µg/L)	1.04	1.11	1.16	1.11	1.19	1.06	1.112	0.73	0.69	0.68	0.75	0.70	0.79	0.723
	Zinc (µg/L)	2.85	1.66	1.91	1.99	1.30	1.67	1.897	0.66	1.49	1.23	2.46	2.55	4.68	2.178
50/50 Mixture of Background Surface Water and Recovered ASR Water	Aluminum (µg/L)	64.5	45.0	63.9	76.3	161	71.5	80.37	13.9	22.0	25.2	22.2	18.5	15.5	19.55
	Antimony (µg/L)	0.271	0.273	0.279	0.232	0.276	0.270	0.2668	0.089	0.083	0.086	0.091	0.091	0.092	0.08867
	Arsenic (µg/L)	**36.5**	**36.7**	**36.4**	**29.3**	**38.6**	**36.2**	**35.62**	**25.3**	**19.7**	**16.2**	**16.9**	**18.0**	**20.9**	**19.5**
	Cadmium (µg/L)	0.019	0.027	0.025	0.005	0.017	0.022	0.0192	<0.004	<0.004	<0.004	<0.004	<0.004	<0.004	<0.004
	Chromium (µg/L)	0.06	0.06	0.09	0.11	0.08	0.07	0.078	0.09	0.11	0.13	0.11	0.12	0.10	0.11
	Mercury (ng/L)	0.94	0.98	1.01	1.28	0.91	1.38	1.083	0.63	0.86	0.91	0.77	0.71	0.59	0.745
	Methyl Mercury (ng/L)	0.037	0.034	0.055	0.062	0.054	0.067	0.0515	0.077	0.067	0.079	0.106	0.090	0.066	0.0808
	Molybdenum (µg/L)	159	154	153	130	169	158	153.8	72.2	55.2	45.1	46.3	51.4	59.1	54.88
	Nickel (µg/L)	2.50	2.37	2.57	2.18	2.71	2.50	2.472	1.92	1.70	1.55	1.50	1.55	1.55	1.628
	Ra-226 (pCi/L)	-	-	-	0.5	0.43	0.44	0.457	-	-	-	1.17	0.91	0.94	1.007
	Ra-228 (pCi/L)	-	-	-	0.64	0.45	0.36	0.483	-	-	-	0.13	0.45	0.58	0.387
	Selenium (µg/L)	1.51	1.36	1.43	1.41	1.43	1.37	1.4183	1.93	1.68	1.47	1.32	1.56	1.63	1.598
	Zinc (µg/L)	1.53	1.46	1.12	2.03	1.71	1.26	1.518	0.75	0.90	0.87	0.70	0.59	0.72	0.755
Recovered ASR Water	Aluminum (µg/L)	3.8	3.1	4.2	8.9	6.8	7.5	5.7	4.2	2.7	3.1	2.6	2.4	2.4	2.9
	Antimony (µg/L)	0.442	0.444	0.440	0.447	0.460	0.454	0.4478	0.096	0.117	0.096	0.091	0.099	0.101	0.100
	Arsenic (µg/L)	**69.5**	**70.0**	**68.5**	**69.0**	**68.8**	**68.8**	**69.1**	**41.9**	**39.9**	**37.4**	**37.2**	**38.6**	**37.7**	**38.78**
	Cadmium (µg/L)	0.058	0.063	0.052	0.040	0.072	0.062	0.0578	0.174	0.177	0.178	0.182	0.186	0.194	0.1818
	Chromium (µg/L)	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	0.05	0.05	0.04	0.05	0.04	0.04	0.045
	Mercury (ng/L)	0.15	0.17	0.17	0.4	0.2	0.21	0.217	0.1	0.29	0.15	0.15	0.19	0.13	0.168
	Methyl Mercury (ng/L)	<0.019	<0.019	<0.019	0.021	<0.019	<0.019	0.0114	0.021	0.021	<0.019	<0.019	<0.019	0.023	0.0156
	Molybdenum (µg/L)	296	306	316	287	302	269	296	101	99.0	100	101	95.9	98.9	99.3
	Nickel (µg/L)	4.02	3.96	3.86	3.99	4.00	4.06	3.982	2.37	2.33	2.19	2.34	2.25	2.18	2.277
	Ra-226 (pCi/L)	-	-	-	0.36	1.57	2.26	1.397	-	-	-	2.4	2.12	2.01	2.18
	Ra-228 (pCi/L)	-	-	-	0.16	0.17	0.33	0.22	-	-	-	0.65	-0.2	0.45	0.30
	Selenium (µg/L)	1.80	1.87	1.75	1.92	1.78	1.76	1.813	2.34	2.28	2.29	2.59	2.36	2.21	2.345
	Zinc (µg/L)	0.69	1.13	1.29	1.03	1.05	1.06	1.042	0.63	0.67	0.60	0.54	0.66	0.56	0.61

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Table 10-28 and **10-29** summarize the background levels of metals, mercury, and radium in fish and mussel tissues measured before the cycle test 1 recovery phase. Concentrations of aluminum, antimony, cadmium, and chromium were below detection limits in the background fish tissues. Background mussel tissue concentrations of antimony, chromium and selenium were also below the detection limits.

Table 10-26 -- Background Metals in Fish Tissues

Analyte	Replicate						Average
	1	2	3	4	5	6	
Aluminum (mg/kg)	<2.4	<2.4	<2.3	<2.5	<2.4	<2.4	<2.4
Antimony (mg/kg)	<0.024	<0.024	<0.023	<0.025	<0.024	<0.024	<0.024
Arsenic (mg/kg)	<0.29	<0.30	0.32	<0.31	0.31	<0.30	0.205
Cadmium (mg/kg)	<0.012	<0.012	<0.012	<0.012	<0.012	<0.012	<0.012
Chromium (mg/kg)	<0.24	<0.24	<0.23	<0.25	<0.24	<0.24	<0.24
Mercury (ng/g)	20.7	19.4	21.6	14.5	18.8	17.9	18.82
Methyl Mercury (ng/g)	28.7	20.9	22.9	19.4	17.4	20.0	21.6
Molybdenum (mg/kg)	0.10	0.06	0.08	0.06	0.07	0.06	0.07
Nickel (mg/kg)	0.09	0.10	0.09	0.12	0.10	0.15	0.11
Selenium (mg/kg)	<0.59	<0.60	<0.58	0.66	0.60	<0.61	0.41
Zinc (mg/kg)	27.8	27.8	62.9	25.8	28.2	31.1	33.93

Table 10-27 -- Background Metal and Radium in Mussel Tissues

Analyte	Replicate						Average
	1	2	3	4	5	6	
Aluminum (mg/kg)	7.8	3.1	3.6	3.6	6.3	6.3	5.12
Antimony (mg/kg)	<0.023	<0.024	<0.023	<0.023	<0.024	<0.023	<0.023
Arsenic (mg/kg)	0.54	0.50	0.38	0.54	0.62	0.54	0.52
Cadmium (mg/kg)	0.242	0.199	0.158	0.229	0.302	0.226	0.226
Chromium (mg/kg)	<0.23	<0.24	<0.23	<0.23	<0.24	<0.23	<0.23
Mercury (ng/g)	34.8	35.1	38.1	35.5	40.6	45.6	38.3
Methyl Mercury (ng/g)	8.7	7.7	6.2	7.9	10.0	7.8	8.1
Molybdenum (mg/kg)	<0.06	<0.06	<0.06	0.06	<0.06	<0.06	0.04
Nickel (mg/kg)	0.09	0.04	0.04	0.05	0.06	0.05	0.055
Ra-226 (pCi/g)	1.01	1.83	2.20	1.42	1.20	1.18	1.47
Ra-228 (pCi/g)	0.71	0.47	1.61	0.78	0.98	1.30	0.98
Selenium (mg/kg)	<0.57	<0.60	<0.59	<0.59	<0.60	<0.58	<0.59
Zinc (mg/kg)	11.0	7.76	8.93	10.6	13.2	7.64	9.86

Tables 10-30 and **10-31** summarize the post exposure levels of metals, radium and mercury in fish and mussels, respectively.

Table 10-30 -- Post- Exposure Fish Tissue Metal Concentrations

Test Treatment	Analyte	Replicates						
		A		B		C		Average
		1	2	1	2	1	2	
Background Surface Water	Aluminum (mg/kg)	<2.5	<2.5	<2.5	<2.5	3.2	3.2	1.9
	Antimony (mg/kg)	<0.025	<0.025	<0.025	<0.025	<0.025	0.050	0.019
	Arsenic (mg/kg)	0.44	0.47	0.43	0.48	0.39	0.42	0.44
	Cadmium (mg/kg)	<0.012	<0.012	0.015	<0.012	<0.012	<0.012	0.008
	Chromium (mg/kg)	<0.25	<0.25	<0.25	<0.25	<0.25	1.39	0.34
	Mercury (ng/g)	16.6	15.1	18.4	16.7	19	14.6	16.7
	Methyl Mercury (ng/g)	9.1	4.9	14.5	11.0	16.4	8.4	10.77
	Molybdenum (mg/kg)	<0.06	<0.06	<0.06	0.07	<0.06	0.07	0.04
	Nickel (mg/kg)	0.13	0.09	0.14	0.13	0.14	0.72	0.23
	Selenium (mg/kg)	<0.62	<0.62	<0.62	<0.62	<0.61	<0.62	<0.62
	Zinc (mg/kg)	19.9	15.1	17.0	20.0	26.0	17.9	19.3
50/50 Mixture of Background Surface Water and Recovered ASR water	Aluminum (mg/kg)	<2.3	<2.5	2.8	<2.4	2.6	82.2	15.2
	Antimony (mg/kg)	<0.023	<0.025	<0.025	<0.024	<0.023	<0.025	<0.024
	Arsenic (mg/kg)	0.41	0.42	0.50	0.41	0.50	0.54	0.46
	Cadmium (mg/kg)	<0.012	<0.012	<0.012	<0.012	<0.012	<0.012	<0.012
	Chromium (mg/kg)	<0.23	<0.25	<0.25	<0.24	<0.23	0.41	0.17
	Mercury (ng/g)	16.7	12.8	12.7	18.0	13.1	23.1	16.1
	Methyl Mercury (ng/g)	16.8	10.3	10.0	11.5	8.9	6.3	10.63
	Molybdenum (mg/kg)	0.11	0.09	0.13	0.09	0.08	0.11	0.10
	Nickel (mg/kg)	0.29	0.11	0.22	0.15	0.13	0.22	0.19
	Selenium (mg/kg)	<0.59	<0.62	<0.62	<0.61	<0.58	<0.62	<0.61
	Zinc (mg/kg)	19.0	20.1	24.7	60.6	41.3	22.7	31.4
Recovered ASR Water	Aluminum (mg/kg)	<2.5	<2.4	<2.5	<2.5	<2.5	<2.5	<2.5
	Antimony (mg/kg)	<0.025	<0.024	<0.025	<0.025	<0.025	<0.025	<0.025
	Arsenic (mg/kg)	0.33	0.45	0.44	0.38	0.40	0.48	0.41
	Cadmium (mg/kg)	<0.012	<0.012	<0.012	<0.013	<0.012	<0.012	<0.012
	Chromium (mg/kg)	<0.25	<0.24	<0.25	<0.25	<0.25	0.47	0.182
	Mercury (ng/g)	18.8	13.4	15.4	20.3	21.5	15.9	17.6
	Methyl Mercury (ng/g)	21.3	17.3	17.9	26.9	29.6	18.6	21.93
	Molybdenum (mg/kg)	0.17	0.11	0.11	0.13	0.10	0.16	0.13
	Nickel (mg/kg)	0.10	0.06	0.09	0.15	0.05	0.14	0.10
	Selenium (mg/kg)	<0.62	0.60	<0.62	<0.63	0.62	<0.61	0.36
	Zinc (mg/kg)	30.7	15.1	22.5	30.5	27.7	33.1	26.6

Table 10-31 -- Post-Exposure Mussel Tissue Metal and Radium Concentrations

Test Treatment	Analyte	Replicates A 1	A 2	B 1	B 2	C 1	C 2	Average
Background Surface Water	Aluminum (mg/kg)	105	33.3	56.3	82.8	35.1	20.6	55.5
	Antimony (mg/kg)	<0.024	<0.025	<0.025	<0.023	<0.025	<0.024	<0.024
	Arsenic (mg/kg)	1.08	1.00	0.88	1.37	1.01	1.07	1.07
	Cadmium (mg/kg)	0.340	0.392	0.368	0.419	0.441	0.302	0.377
	Chromium (mg/kg)	0.35	0.30	0.38	0.62	0.35	0.33	0.39
	Mercury (ng/g)	39.3	72.7	73.7	78.9	51.0	46.2	60.3
	Methyl Mercury (ng/g)	8.4	9.8	12.5	8.3	7.5	7.7	9.03
	Molybdenum (mg/kg)	0.08	0.07	0.07	0.09	0.06	0.07	0.07
	Nickel (mg/kg)	0.26	0.28	0.15	0.19	0.10	0.14	0.19
	Ra-226 (pCi/g)	1.29	1.14	1.89	1.09	0.64	0.40	1.08
	Ra-228 (pCi/g)	0.73	1.22	0.98	0.73	1.52	1.10	1.05
	Selenium (mg/kg)	<0.61	<0.62	<0.61	<0.59	<0.62	0.61	0.36
	Zinc (mg/kg)	49.5	33.8	33.0	62.1	49.5	30.3	43.0
50/50 Mixture of background surface water and recovered ASR water	Aluminum (mg/kg)	43.5	41.0	68.0	42.9	62.6	48.6	51.1
	Antimony (mg/kg)	<0.023	<0.025	<0.025	<0.024	<0.025	<0.024	<0.024
	Arsenic (mg/kg)	0.89	1.56	1.59	1.53	1.73	1.08	1.40
	Cadmium (mg/kg)	0.230	0.402	0.366	0.381	0.424	0.204	0.335
	Chromium (mg/kg)	0.28	0.40	0.36	0.31	0.41	<0.24	0.31
	Mercury (ng/g)	37.2	62.4	83.6	66.6	60.6	33.4	57.3
	Methyl Mercury (ng/g)	4.2	9.5	10.1	9.3	14.3	8.7	9.35
	Molybdenum (mg/kg)	0.06	0.11	0.09	0.09	0.11	0.07	0.09
	Nickel (mg/kg)	0.15	0.31	0.32	0.22	0.21	0.26	0.25
	Ra-226 (pCi/g)	1.13	1.41	1.43	2.22	1.51	2.15	1.64
	Ra-228 (pCi/g)	0.04	0.60	0.64	0.82	0.93	1.16	0.70
	Selenium (mg/kg)	<0.58	<0.62	<0.62	<0.59	<0.62	<0.60	<0.61
	Zinc (mg/kg)	37.8	46.0	44.4	34.6	36.5	24.4	37.3
Recovered ASR Water	Aluminum (mg/kg)	14.9	14.2	20.1	8.8	21.4	11.0	15.1
	Antimony (mg/kg)	<0.025	<0.025	<0.025	<0.025	<0.025	<0.025	<0.025
	Arsenic (mg/kg)	2.09	2.80	2.52	0.98	2.96	1.71	2.18
	Cadmium (mg/kg)	0.339	0.271	0.316	0.211	0.401	0.228	0.294
	Chromium (mg/kg)	0.27	<0.25	0.28	<0.25	0.38	0.29	0.25
	Mercury (ng/g)	74.2	46.3	54.3	33.4	45.1	46.7	50.0
	Methyl Mercury (ng/g)	11.6	6.8	10.1	5.4	9.3	6.0	8.20
	Molybdenum (mg/kg)	0.11	0.14	0.12	0.07	0.15	0.10	0.12
	Nickel (mg/kg)	0.39	0.47	0.55	0.25	0.39	0.35	0.40
	Ra-226 (pCi/g)	-0.07	1.98	1.58	1.24	2.18	2.53	1.57
	Ra-228 (pCi/g)	0.77	1.22	1.34	0.98	0.52	1.18	1.00
	Selenium (mg/kg)	<0.61	0.61	<0.62	<0.62	<0.62	<0.63	0.36
	Zinc (mg/kg)	38.0	29.7	31.3	17.9	45.9	27.4	31.7

10.4.8 Periphyton Study

A field periphyton study was conducted during the recovery phase of cycle test 1 in a similar manner to that of the recharge phase. Several periphytometers were also disturbed during the recovery period. On day 14 of the recovery period, three periphytometers (from stations 4, 7, and 8) were missing and slides were also missing from periphytometers at stations 5, 6, and 10. On day 28, the periphytometer at station 9 was missing and the periphytometer from station 7 was floating free of its anchor approximately 75 m south of station 5. Only periphytometers from stations 1, 2, and 3 made it through the 28-day recovery study completely intact. Periphytometers from stations 4, 8, and 9 were completely lost and therefore no data is available for these stations. On day 28 only a single slide was intact at station 10 and it was used for taxonomy therefore there is no ash-free dry weight data for this location.

Periphytometers were deployed on March 9, 2009 for the recovery period. Half of the exposure slides were collected for analysis at the mid-point of the exposure and the other half were collected on day 28. Each sample consisted of four slides randomly selected from the periphytometer, of which three were stored dry and used to determine ash-free dry weight and one was preserved in a 4-percent formalin solution for taxonomic analysis.

Table 10-32 shows the taxonomy and densities observed on day 28 for the recovery period. **Table 10-33** shows the comparative diversity and evenness indices generated from the data for the recharge and recovery period. **Table 10-34** provides the ash free dry-weights for both study periods. The complete taxonomy report is included in **Appendix L**.

Table 10-28 -- Density (Units Per Square Centimeter) of Periphyton Species Collected in the Kissimmee River in the Vicinity of the KRASR Pilot Project (March - April 2009)

	Periphytometer Station ID						
Taxa	**1**	**2**	**3**	**5**	**6**	**7**	**10**
DIVISION CYANOBACTERIA							
Aphanothece	--	1253	--	--	--	--	--
Chroococcopsis	4082	1253	--	2088	12698	19841	--
Chroococcus	9184	--	2088	--	12698	11905	8658
Geitleribactron	--	14617	--	235908	301587	523810	411255
Heteroleibleinia	24490	2923	37578	31315	6349	23810	25974
Leptolyngbya	--	--	4175	--	--	--	--
Merismopedia	3061	418	12526	6263	--	7937	160173
Planktolyngbya	3061	3759	14614	4175	3175	--	30303
Planktothrix	--	418	52192	8351	--	--	12987
Pseudanabaena	3061	4594	2088	8351	6349	19841	34632
Snowella	--	418	--	--	--	--	--
DIVISION CHLOROPHYTA							
Ankistrodesmus	45918	5011	29228	--	--	--	--
Characium	11224	2506	14614	2088	3175	--	25974
Chlamydomonas	5102	5847	12526	6263	--	--	25974
Kirchneriella	--	--	2088	--	--	--	--
Scenedesmus	1020	--	8351	2088	--	--	4329
Spirogyra	--	--	--	4175	3175	--	--
Stigeoclonium	3061	835	--	--	--	--	--
Ulothrix	--	--	2088	--	--	--	--
Unid chlorophyceae filament basal cells	6122	2923	--	4175	12698	--	--
DIVISION CHRYSOPHYTA							
CLASS BACILLARIOPHYCEAE							
Achnanthes	18367	12111	22965	10438	101587	83333	4329
Amphipleura	--	--	--	6263	--	--	--
Amphora	--	418	10438	--	--	11905	4329
Aulacoseira	--	--	4175	--	--	--	--
Cocconeis	26531	35080	20877	66806	50794	107143	95238
Cyclotella	1020	835	6263	--	6349	3968	38961
Diploneis	--	--	--	--	--	--	4329
Encyonema	2041	418	6263	4175	6349	7937	--
Fragilaria	2041	--	2088	--	6349	--	17316
Gomphonema	29592	1253	12526	6263	15873	3968	90909
Navicula	33673	29234	123173	116910	206349	198413	77922
Nitzschia	98980	19211	260960	215031	257143	321429	316017
Staurosira	--	--	--	2088	--	--	--
Surirella	1020	--	--	--	--	--	--
Synedra	--	--	--	--	--	--	4329
Thalassiosira	1020	--	--	--	--	--	--

Table 10-33 -- Diversity and Evenness Indices for the Periphyton Species Collected in the Kissimmee River in the Vicinity of the KRASR

Station ID	Recharge			Recovery		
	Shannon-Wiener Diversity Index	Pielou's Evenness Index	Hulbert Evenness Index	Shannon-Wiener Diversity Index	Pielou's Evenness Index	Hulbert Evenness Index
1	3.204	0.708	0.660	3.379	0.758	0.718
2	2.892	0.681	0.634	3.339	0.749	0.710
3	2.977	0.658	0.599	3.117	0.689	0.635
4	3.357	0.691	0.628	--	--	--
5	2.611	0.639	0.590	2.696	0.624	0.571
6	2.472	0.605	0.549	2.679	0.655	0.609
7	--	--	--	2.511	0.659	0.622
8	3.212	0.683	0.626	--	--	--
9	2.635	0.674	0.636	--	--	--
10	2.744	0.671	0.628	3.153	0.729	0.688

Table 10-34 -- Ash-Free Dry Weights for the Periphyton Species Collected in the Kissimmee River in the Vicinity of the KRASR Pilot Project

Periphyton Station ID	Recharge	Recovery
	Ash-Free Dry Weight (g/m^2)	Ash-Free Dry Weight (g/m^2)
1	18.10	1.58
2	7.19	0.82
3	5.27	3.56
4	3.84	--
5	5.15	3.19
6	17.1	1.08
7	--	2.17
8	7.09	--
9	14.10	--
10	15.40	--

Interpretation of periphyton data is complicated by the loss of field sampling equipment that ultimately resulted in missing data. Sample stations were established on both sides of the river to fully represent the Kissimmee River system. All of the indices as well as the number of taxa collected, density of periphyton, and ash-free dry weight at each station were compared between the East and West sides of the river (T-test, α=0.05). There was no indication of a significant difference between the two sides of the river for any of the parameters tested. The two sampling periods (during recharge and recovery) were then compared (Paired T-test) and significant differences were found for several of the parameters. For the stations that were successfully sampled during both periods, the Shannon-Wiener diversity index (p=0.01), Pielous's evenness index (p=0.02), and Hulbert evenness index (p=0.02) were higher during the recovery period than the recharge period. The density of periphyton (p=0.048) and ash-free dry weight (p=0.03), however, were both significantly lower during recovery when compared to the recharge. Due to the missing data, conclusions can't be drawn at this time of the ecological significance of these values.

All of these parameters were evaluated for spatial patterns in relation to the location of the KRASR discharge point. Both absolute numbers as well as relative differences were correlated to their distance from the KRASR site and no significant patterns were found that would indicate that the KRASR discharge of recovered water affected the periphyton communities in the Kissimmee River. In fact, the difference at the sampling station located in front of the KRASR showed that the difference between baseline (recharge) conditions and the recovery period were generally smaller than at the other sampling stations. Although there were some differences found between the recharge and recovery periods, we do not have enough seasonal data to make conclusions at this time.

10.5 KRASR Cycle Test 2 Recovery

During the KRASR cycle test 2, toxicity tests and field studies were conducted only during the recovery period, and these are discussed below. Changes in the scope of work during this cycle test are discussed in the applicable sections.

- **Ecotoxicology program tests**
    - 96-hour green alga, *S. capricornutum*, growth; and
    - 96-hour Frog Embryo Teratogenesis Assay – *Xenopus* (FETAX).
- **Required regulatory ecotoxicological tests**
    - Routine acute toxicity tests
        - 96-hour water flea, *C. dubia,* and
        - 96-hour bannerfin shiner, *C.leedsi.*
    - Permit-required chronic toxicity tests
        - 7-day water flea, *C. dubia*, survival and reproduction, and
        - 7-day fathead minnow, *P. promelas*, embryo-larval survival and teratogenesis
- **Field biological studies**
    - *In situ* bioconcentration studies using caged freshwater mussels (*E. buckleyi*) exposed in the Kissimmee River in the vicinity of the ASR recovered water discharge
    - *In situ* specific conductance measurements
    - Periphyton field studies

KRASR Cycle 2 recovery started on October 28, 2009 and ended on January 2, 2010. The scope of work for Cycle 2 was modified by the Biology Sub-Team, part of the ASR Project Development Team and the changes are discussed in the applicable subsections, including rationale.

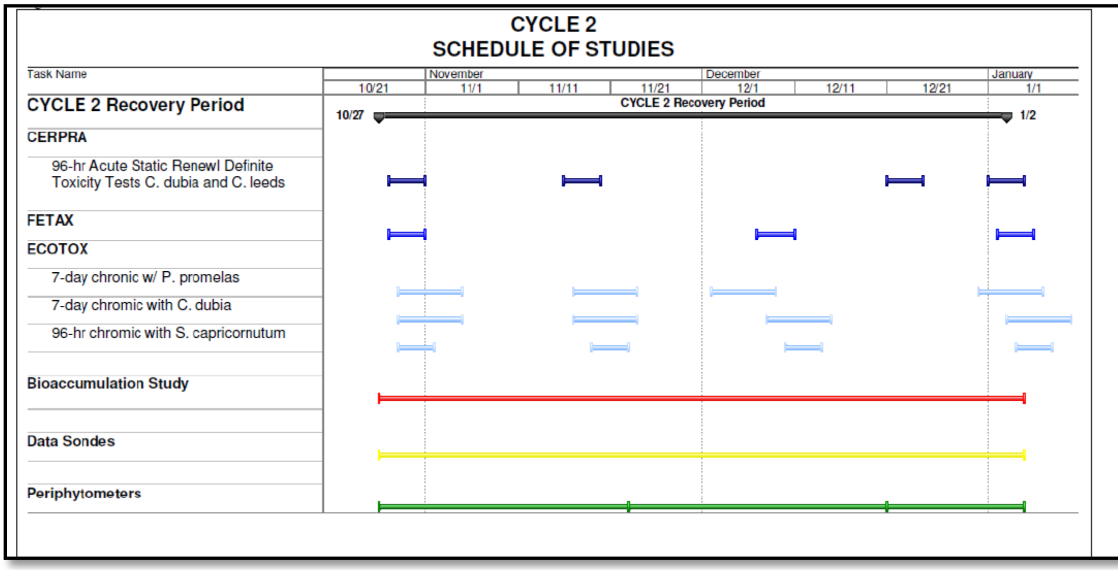

Figure 10-6 -- Ecotoxicological studies conducted during KRASR cycle test 2 recovery.

10.5.1 96-Hour Chronic Growth Test with the Green Algae *Selenastrum capricornutum*

The 96-hour algal test was conducted four times during the cycle test 2 recovery to quantify the potential changing effects of recovered water quality throughout the 2-month recovery duration. These data are summarized in **Table 10-35**. No statistically significant effect was measured in any of the tests conducted; therefore the NOEC was 100 percent recovered water.

Table 10-295 -- Comparative Results of the 96-hour *Selenastrum capricornutum* Green Algae Chronic Toxicity Tests. Tests conducted during the KRASR Cycle 2 Recovery. Unit is cells/mL (x10[6])

96-hour Chronic Growth Test [(1)]				
	Test Initiation Date			
Test Concentration (Percent)	**10/29/09**	**11/19/09**	**12/10/09**	**01/04/10**
Control	0.862	1.323	1.352	1.349
6.25	1.023	1.430	1.856	1.635
12.5	0.860	1.508	1.813	1.875
25	0.820	1.665	2.131	2.250
50	0.897	1.658	2.129	2.832
100	0.826	2.240	2.273	3.174
NOEC	100 % recovered water	100 % recovered water	100 % recovered water	100 % recovered water

1. EPA 2002 a. Test Method 1003.0.

10.5.2 Frog Embryo Teratogenesis Assay – *Xenopus* Toxicity Test

FETAX tests were conducted three times during cycle test 2 recovery. These tests did not show a quantifiable effect of the recovered water on the survival, malformations, and growth of the frog embryo. There was no statistically significant difference between the recovered water and controls. The NOEC for survival, malformations, and growth was 100 percent recovered ASR water. **Tables 10-36** through **10-38** summarize these results.

Table 10-36 -- Results of the Frog Embryo Toxicity Test (October 28, 2009)

Frog Embryo Teratogenesis Assay – Xenopus (FETAX)(1)						
Lab No. / Sample ID (% recovered water)	**Mean Mortality (%)**	**Mean Malformation (%)**	**Mean Growth[1] (%)**	**Mortality Significantly Different From Control[2]**	**Malformation Significantly Different From Control[2]**	**Growth Significantly Different From Control[2]**
FETAX Soln Control100%	0.0	2.5				-
6-AN Ref. (2,500 mg/L)	100.0	-	-	-	-	-
6-AN Ref.(5.5 mg/L)	0.0	56.4	-	-	-	-
001 / ASR (6.25%)	0.0	0.0	99.4	No	No	No
001 / ASR (12.5%)	2.5	5.0	99.4	No	No	No
001 / ASR (25%)	2.5	0.0	100.1	No	No	No
001 / ASR (50%)	2.5	0.0	99.7	No	No	No
001 / ASR (100%)	0.0	0.0	99.6	No	No	No

mg/L = milligram per liter. 1, ASTM method E 1439-98. 2. Mean sample length (cm) divided by mean FETAX solution control length, expressed as % growth. 3. Mortality, malformation and growth results are based on statistical analysis using Kruskal-Wallis ANOVA (P<0.05).

Table 10-37 -- Results of the Frog Embryo Toxicity Test (December 7, 2009)

Frog Embryo Teratogenesis Assay – Xenopus (FETAX)(1)						
Lab No. / Sample ID (% recovered water)	**Mean Mortality (%)**	**Mean Malformation (%)**	**Mean Growth[1] (%)**	**Mortality Significantly Different From Control[2]**	**Malformation Significantly Different From Control[2]**	**Growth Significantly Different From Control[2]**
FETAX Soln Control100%	0.0	1.3				
6-AN Ref. (2,500 mg/L)	100.0	-	-	-	-	-
6-AN Ref.(5.5 mg/L)	12.5	51.6	-	-	-	-
003 / ASR (6.25%)	0.0	0.0	99.1	No	No	No
003 / ASR (12.5%)	2.5	0.0	99.1	No	No	No
003 / ASR (25%)	5.0	0.0	99.8	No	No	No
003 / ASR (50%)	0.0	0.0	100.0	No	No	No
003 / ASR (100%)	2.5	0.0	100.3	No	No	No

mg/L = milligram per liter. 1. ASTM method E 1439-98. 2. Mean sample length (cm) divided by mean FETAX solution control length, expressed as % growth. 3. Mortality, malformation and growth results are based on statistical analysis using Kruskal-Wallis ANOVA (P<0.05).

Table 10-38 -- Results of the Frog Embryo Toxicity Test (January 2, 2010)

Frog Embryo Teratogenesis Assay – Xenopus (FETAX)[(1)]

Lab No. / Sample ID (Percent recovered water)	Mean Mortality (%)	Mean Malformation (%)	Mean Growth[1] (%)	Mortality Significantly Different From Control[2]	Malformation Significantly Different From Control[3]	Growth Significantly Different From Control[3]
FETAX Soln Control100%	0.0	1.3				
6-AN Ref. (2,500 mg/L)	100.0	-	-	-	-	-
6-AN Ref.(5.5 mg/L)	0.0	57.5	-	-	-	-
001 / RCV (6.25%)	0.0	0.0	98.6	No	No	No
001/ RCV (12.5%)	0.0	2.5	98.8	No	No	No
001 / RCV (25%)	0.0	2.5	99.0	No	No	No
001 / RCV (50%)	0.0	0.0	99.8	No	No	No
001 / RCV (100%)	0.0	7.5	98.9	No	No	No

Notes: 1. ASTM method E 1439-98.2. Mean sample length (cm) divided by mean FETAX solution control length, expressed as % growth. 3. Mortality, malformation and growth results are based on statistical analysis using Kruskal-Wallis ANOVA ($P<0.05$). 4. Growth and malformation results are based on statistical analysis using ANOVA ($P<0.5$).

10.5.3 Permit-Required Toxicity Tests

These acute and chronic toxicity test endpoints were summarized in **Section 7 (Table 1-2)**. Data supporting those endpoints are presented in **Table 10-39**. The *C. dubia* and *C. leedsi* acute tests did not show quantifiable toxicity in any of the four acute tests conducted over the cycle test 2 recovery duration. The NOEC was 100 percent recovered water.

The *C. dubia* chronic tests were conducted four times during the cycle test 2 recovery. Only three data sets are presented because the fourth test was considered invalid by the testing laboratory due to laboratory control issues. No effect on survival of this water flea was quantified in any of the tests. Therefore the NOEC for survival was 100 percent recovered water.

A chronic effect on reproduction was observed during the November and December 2009 tests **(Table 10-40)**. In both tests, the number of young produced by the females was reduced in 100 percent recovered water. In both cases the NOEC was 50 percent recovered water; in other words, once the recovered water is diluted by half in the environment, this effect is no longer quantifiable. The effect was more significant during the December 2009 test, in which the case the effect on reproduction was more pronounced, resulting in an IC_{25} of 76.41 percent recovered water. In other words, the reproduction of this sensitive water flea is reduced by 25 percent at 76.41 percent recovered water or higher. For comparison, the NOEC for survival was 100 percent for all the tests conducted during cycle test 1 recovery. The second from the last sample during cycle test 1 recovery also had a quantifiable IC_{25} of 95.52 percent for reproduction reduction, which was considered measurable, but negligible.

Table 10-39 -- *C. dubia* and *C. leedsi* 96-Hour Acute Toxicity Tests			
	96-Hour Acute Tests[1]		
	Test Concentration (Percent)	***C. dubia* Survival (Percent)**	***C. leedsi* Survival (Percent)**
Test Initiated 10/29/09	Control	100	100
	6.25	100	75
	12.5	100	80
	25	100	95
	50	100	90
	100	100	85
	LC_{50}	**>100%**	**>100 %**
Test Initiated 11/17/09	Control	100	100
	6.25	100	95
	12.5	95	100
	25	100	100
	50	100	100
	100	100	100
	LC_{50}	**>100%**	**>100 %**
Test Initiated 12/22/09	Control	100	100
	6.25	100	100
	12.5	100	100
	25	100	95
	50	100	95
	100	100	95
	LC_{50}	**>100%**	**>100 %**
Test Initiated 01/02/10	Control	100	100
	6.25	100	100
	12.5	100	100
	25	100	100
	50	100	100
	100	100	100
	LC_{50}	**>100%**	**>100 %**
1. EPA 2002b. Method 2002.0 and 2000.0			

Table 10-40 -- Results of the 7-Day Chronic *C. dubia* Survival and Reproduction Tests[1]				
		Test Initiation Date		
Endpoint	**Test Concentration (Percent)**	**10/29/09**	**11/17/09**	**12/08/09**
Percent Survival	Control	100	90	100
	6.25	100	100	100
	12.5	90	100	100
	25	90	100	100
	50	90	100	90
	100	100	100	90
	NOEC	**100%**	**100%**	**100%**
Three Brood Totals (Average # of neonates /female)	Control	16.0	30.1	30.1
	6.25	16.6	27.2	29.8
	12.5	16.9	28.5	29.4
	25	16.3	26.9	28.6
	50	16.7	26.8	28.7
	100	19.3	23.6[2]	17.2[2]
	NOEC	**100%**	**50%**	**50%**
	IC_{25}	**>100%**	**>100%**	**76.41%**
NOTES: 1. EPA 2002a. Method 1002.0. 2. Indicates significant difference between the recovered water samples and the control (p=0.05).				

10.5.4 7-Day *Pimephales promelas* Static Renewal Chronic Toxicity Test

Four 7-day *P. promelas* chronic toxicity tests were conducted using recovered water from cycle test 2. These tests did not show a quantifiable effect of the recovered water on the survival and embryological development of this sensitive fish embryo. There was no statistically significant difference between the results in recovered water versus the controls. Similar to the cycle test 1 recovered water tests, the NOEC for survival and embryological malformations (terata) was 100% percent recovered water. These data are summarized in **Table 10-41**.

Table 10-41 -- Results of the 7-Day Fathead Minnow *P. Promelas* Embryo-Larval Survival And Teratogenicity Test[(1)]

		Test Initiation Date			
Test	**Test Concentration (%)**	**10/29/09**	**11/17/09**	**12/8/09**	**12/31/09**
Percent Survival	Control	100	85	100	97.5
	6.25	100	87.5	97.5	97.5
	12.5	100	92.5	95	100
	25	95	97.5	100	100
	50	97.5	85	100	100
	100	100	87.5	97.5	100
	NOEC	**100 %**	**100 %**	**100 %**	**100 %**
Final Terata Counts	Control	0	1	0	0
	6.25	0	2	0	0
	12.5	0	1	1	0
	25	1	0	0	0
	50	1	4	0	0
	100	0	4	1	0
Total Mortality (%)	Control	0	15	0	2.5
	6.25	0	12.5	2.5	2.5
	12.5	0	7.5	5	0
	25	5	2.5	0	0
	50	2.5	15	0	0
	100	0	12.5	2.5	0

1. EPA 2002a. Method 1001.0

10.5.5 Bioconcentration Study – *In-situ* Exposures of Caged Freshwater Mussels

Based on the results of the KRASR cycle test 1 bioconcentration studies and recommendations from the ASR PDT and Biological Sub-Team, the mobile laboratory bioconcentration studies were replaced with in-situ exposures of freshwater mussels in the receiving water (Kissimmee River). **Figure 10-7** shows the locations of the exposure locations.

Figure 10-7 -- Location of *in-situ* exposure of caged mussels, periphytometers, and water quality sondes.

The objective of the bioconcentration *in situ* exposures of caged mussels was to evaluate the potential uptake of metals and radium from recovered water, and its dilutions in the receiving water body during the recovery period. The ASTM method E-1002-94 was used as a guide to conduct these field exposures. This study was conducted using the freshwater mussel *E. buckleyi*, similar to the bioconcentration study conducted during cycle test 1 ASR recovery.

All mussels were held in laboratory water for one month prior to the initiation of the field study. The study commenced on October 27, 2009 and was completed on January 4, 2010 for a total duration of 69 days during cycle test 2 recovery. Exposures were conducted *in situ* at the four locations shown in **Figure 10-7**. Two stations (ASR3A and ASR 3B) were directly in the mixing zone of the discharged recovered water and the Kissimmee River. The other 2 stations were upstream (ASR 1) and downstream (ASR5) of the KRASR POD.

Mussels were housed in custom designed cages made of a PVC frame and hardware mesh **(Figure 10-8)**. Individual compartments were constructed to maintain equal spacing and thus similar exposure for each mussel. The cages were a double stack design with 49 compartments in each layer. Three cages were deployed at each station location. They were anchored to the bottom via cinderblocks and maintained mid water column via Styrofoam buoys. Mussels used in these caged exposures were collected from a private lake, Lake McMeekin, in Hawthorne, Florida.

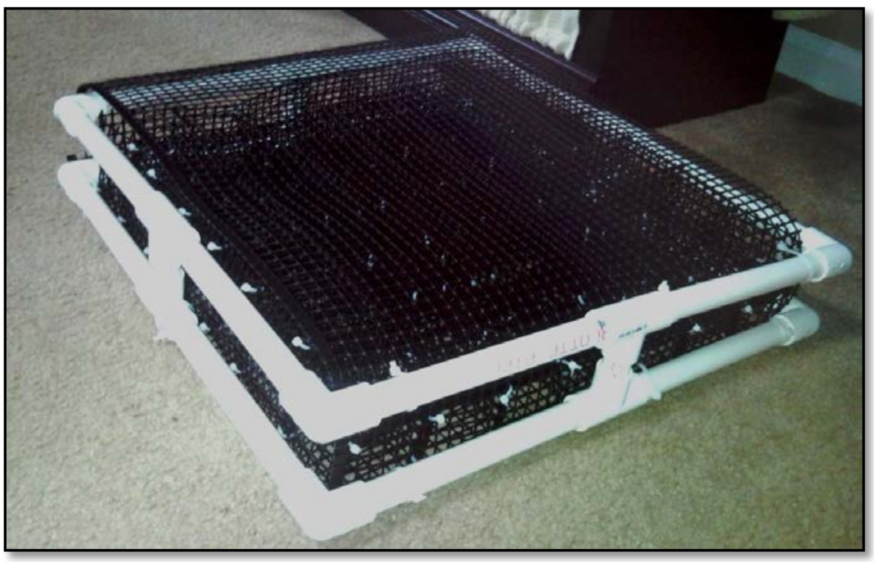

Figure 10-8 -- Freshwater cages for freshwater mussel exposures.

Metals (aluminum, antimony, arsenic, cadmium, chromium, molybdenum, nickel, selenium, and zinc) and radionuclides (radium-226, radium-228) were quantified in mussel tissues and water from each station. Three replicates of mussel tissues and two replicates of water samples were collected from each river station during each sampling event.

The objective of these tests was to evaluate the potential bioaccumulation of the metals and radionuclides listed above in the tissues of this mussel species (*E. buckleyi*). **Tables 10-42** through **10-47** summarize the background levels of selected chemicals in the freshwater mussels, water and mussel tissues.

Table 10-42 -- Trace Metal and Radium Analyses in Laboratory Control and Kissimmee River Water Samples
Samples obtained prior to cycle test 2 recovery

Analyte	Equip Blank	Lab Control Water	ASR 1			ASR 3A			ASR 3B			ASR 5		
			Rep 1	Rep 2	Avg	Rep 1	Rep 2	Avg	Rep 1	Rep 2	Avg	Rep 1	Rep 2	Avg
Aluminum (µg/l)	0.4 U	14.2	90.8	97.4	94.1	87.0	83.2	85.1	119	131	125	84.6	73.0	78.8
Antimony (µg/l)	0.002 J	0.023	0.091 J	0.110	0.1005	0.097 J	0.102	0.0995	0.076 J	0.069 J	0.0725	0.082 J	0.078 J	0.08
Arsenic (µg/l)	0.04 U	1.13	0.63 J	0.97	0.8	0.92	0.99	0.955	1.54	1.56	1.55	0.81	1.07	0.94
Cadmium (µg/l)	0.004 U	0.008 J	0.021 U	0.021 U	0.0105	0.021 U	0.021 U	0.0105	0.021 U	0.021 U	0.0105	0.021 U	0.021 U	0.0105
Chromium (µg/l)	0.03 U	0.04 J	0.43 J	0.38 J	0.405	0.26 J	0.22 J	0.24	0.28 J	0.35 J	0.315	0.35 J	0.37 J	0.36
Mercury (ng/g)	0.28 J	0.86	1.61	1.27	1.44	0.91	1.29	1.1	1.21	1.22	1.215	0.99	1.19	1.09
Methyl Mercury (ng/g)	0.023 U	0.043 J	0.211	0.177	0.194	0.203	0.226	0.2145	0.160	0.126	0.143	0.224	0.205	0.2145
Molybdenum (µg/l)	0.02 J	0.06	0.63	1.26	0.945	1.35	1.21	1.28	2.79	2.71	2.75	0.60	0.57	0.585
Nickel (µg/l)	0.01 U	0.18	0.28 J	0.26 J	0.22	0.17 J	0.13	0.15	0.21 J	0.19 J	0.2	0.15 J	0.24	0.195
Ra-226 (pCi/g)	0.20 +/- 0.22 U	0.10 +/- 0.30 U	0.02+/-0.13 U	0.47 +/- 0.29 LT	0.24	0.48 +/- 0.32 LT	0.25 +/- 0.27 U	0.3025	0.94 +/- 0.42 U	0.70 +/- 0.33 LT	0.585	0.18 +/- 0.26	--	0.18
Ra-228 (pCi/g)	0.37 +/- 0.44 U	0.48 +/- 0.42 U	0.34 +/-0.34 U	-0.01 +/- 0.32 U	0.0825	0.52 +/- 0.37 U	0.41 +/- 0.34 U	0.2325	0.37 +/- 0.37 U	0.32 +/- 0.35 U	0.1725	-0.01 +/- 0.47 U	--	-0.005
Selenium (µg/l)	0.19 U	0.19 U	0.97 U	0.97 U	0.485	0.97 U	0.97 U	0.485	1.15 J	0.97 U	0.8175	1.10 J	1.88 J	1.49
Zinc (µg/l)	0.14 J	3.28	0.55 J	0.89 J	0.72	0.71 J	0.66 J	0.685	1.02	0.92 J	0.97	0.76 J	0.98 J	0.87

Table 10-31 -- Trace Metal and Radium Analyses in Kissimmee River Water Samples
Samples obtained at midpoint of the bioconcentration study (December 1, 2009)

Analyte	Equip Blank	ASR 1			ASR 3A			ASR 3B			ASR 5		
		Rep 1	Rep 2	Avg	Rep 1	Rep 2	*Avg*	Rep 1	Rep 2	*Avg*	Rep 1	Rep 2	*Avg*
Aluminum (µg/l)	0.4 U	64.9	65.4	65.15	68.5	61.5	65	65.8	66.6	66.2	61.5	69.4	65.45
Antimony (µg/l)	0.002 U	0.154	0.116	0.135	0.011 U	0.141	0.071	0.011 U	0.011 U	0.0055	0.011 U	0.011 U	0.0055
Arsenic (µg/l)	0.04 U	1.00	1.08	1.04	1.05	1.31	1.18	1.15	1.17	1.16	1.03	1.09	1.06
Cadmium (µg/l)	0.004 U	0.021 U	0.021 U	0.0105	0.021 U	0.021 U	0.0105	0.021 U	0.021 U	0.0105	0.021 U	0.021 U	0.0105
Chromium (µg/l)	0.03 U	0.14 U	0.14 U	0.07	0.14 U	0.14 U	0.07	0.14 U	0.14 U	0.07	0.14 U	0.14 U	0.07
Mercury (ng/g)	2.36	1.68	1.70	1.69	1.33	1.37	1.35	1.35	1.41	1.38	1.70	1.64	1.67
Methyl Mercury (ng/g)	0.023 U	0.146	0.159	0.1525	0.110	0.100	0.105	0.100	0.123	0.1115	0.152	0.130	0.141
Molybdenum (µg/l)	0.01 U	1.08	0.93	1.005	5.97	4.70	5.335	4.21	3.41	3.81	1.39	1.43	1.41
Nickel (µg/l)	0.01 U	0.07 U	0.07 U	0.035	0.07 U	0.07 U	0.035	0.07 U	0.07 U	0.035	0.07 U	0.07 U	0.035
Ra-226 (pCi/g)	-0.02 +/- 0.20 U	0.42 +/- 0.30 LT	-0.06 +/- 0.31 U	0.195	0.62 +/- 0.41 LT	0.52 +/- 0.35 LT	0.57	0.38 +/- 0.34 U	0.75 +/- 0.42 LT	0.047	0.37 +/- 0.32 U	0.23 +/- 0.35 U	0.15
Ra-228 (pCi/g)	0.01 +/- 0.37 U	0.20 +/- 0.40 U	0.31 +/- 0.37 U	0.1275	0.16 +/- 0.35 U	0.35 +/- 0.41 U	0.1275	-0.15 +/- 0.34 U	0.21 +/- 0.35 U	0.015	-0.04 +/- 0.39 U	0.37 +/- 0.39 U	0.0825
Selenium (µg/l)	0.19 U	0.97 U	0.97 U	0.485	0.97 U	0.97 U	0.485	0.97 U	0.97 U	0.485	0.97 U	0.97 U	0.485
Zinc (µg/l)	0.41	0.50 U	0.50 U	0.25	0.50 U	0.50 U	0.25	0.50 U	0.50 U	0.25	0.50 U	0.50 U	0.25

Table 10-30 -- Trace Metal and Radium Analyses in Kissimmee River Water Samples
Samples obtained at completion of study (January 4, 2010)

Analyte	Equip Blank	ASR 1			ASR 3A			ASR 3B			ASR 5		
		Rep 1	Rep 2	Avg	Rep 1	Rep 2	*Avg*	Rep 1	Rep 2	*Avg*	Rep 1	Rep 2	*Avg*
Aluminum (µg/l)	0.6 J	74.8	70.8	72.8	75.2	75.1	75.15	75.4	82.6	79.0	89.8	82.8	86.3
Antimony (µg/l)	0.002 U	0.072	0.074	0.073	0.073	0.072	0.072	0.070	0.352	0.211	0.076	0.075	0.0755
Arsenic (µg/l)	0.04 U	0.75	0.72	0.735	0.77	0.77	0.77	0.79	0.80	0.795	0.89	0.86	0.875
Cadmium (µg/l)	0.004 J	0.004 U	0.004 U	0.002	0.004 U	0.004 U	0.002	0.004 U	0.004 U	0.002	0.004 U	0.004 U	0.002
Chromium (µg/l)	0.11	0.38	0.40	0.39	0.37	0.37	0.37	0.43	0.35	0.39	0.42	0.41	0.415
Mercury (ng/g)	0.09 J	1.68	1.61	1.645	1.62	1.88	1.75	1.80	1.63	1.715	1.74	1.71	1.725
Methyl Mercury (ng/g)	0.023 U	0.092	0.104	0.098	0.102	0.092	0.097	0.077	0.095	0.086	0.077	0.073	0.075
Molybdenum (µg/l)	0.01 U	0.69	0.67	0.68	0.74	0.74	0.74	0.75	0.75	0.75	0.85	0.88	0.865
Nickel (µg/l)	0.06 J	0.28	0.31	0.295	0.30	0.30	0.3	0.31	0.29	0.3	0.31	0.30	0.305
Ra-226 (pCi/g)	0 +/- 0.21 U	0.29 +/- 0.27 U	0.47 +/- 0.32 LT	0.3325	0.43 +/- 0.30 LT	0.14 +/- 0.29 U	0.25	0 +/- 0.30 U	0.38 +/- 0.33 U	0..095	0.55 +/- 0.37 LT	0.18 +/- 0.36 U	0.32
Ra-228 (pCi/g)	0.07 +/- 0.35 U	0.40 +/- 0.36 U	0+/- 0.32 U	0.1	0.27 +/- 0.37 U	0.19 +/- 0.36 U	0.14	0.10 +/- 0.34 U	0.12 +/- 0.37 U	0.055	0.10 +/- 0.33 U	0.06 +/- 0.36 U	0.04
Selenium (µg/l)	0.19 U	0.57 J	0.54 J	0.555	0.55 J	0.51 J	0.53	0.55 J	0.62 J	0.585	0.63	0.63	0.63
Zinc (µg/l)	0.68	0.50	0.49	0.495	0.55	0.59	0.57	0.49	19.4	9.945	4.67	0.54	2.605

Table 10-32 -- Trace Metal and Radium Analyses in Mussel Tissue Metal
Samples obtained prior to cycle test 2 recovery.

Analyte	Replicate			Average
	1	2	3	
Aluminum (mg/kg)	5.7	11.1	4.5	7.1
Antimony (mg/kg)	0.041 J	0.019 J	0.018 J	0.026
Arsenic (mg/kg)	0.54	0.48	0.58	0.0533
Cadmium (mg/kg)	0.166	0.244	0.212	0.2073
Chromium (mg/kg)	0.25 U	0.21 U	0.19	0.14
Mercury (ng/g)	28.2	52.3	37.0	39.167
Methyl Mercury (ng/g)	7.1	5.8	8.5	7.133
Molybdenum (mg/kg)	0.04 J	0.04 J	0.05	0.043
Nickel (mg/kg)	0.051 J	0.082	0.049 J	0.061
Ra-226 (pCi/g)	1.06 +/- 0.48	0.950+/- 0.43 LT	4.05 +/- 0.93	2.02
Ra-228 (pCi/g)	0.48 +/- 0.67 U	0.18 +/- 0.74 U	1.21 +/- 0.65 LT	0.513
Selenium (mg/kg)	0.29 J	0.26 J	0.29 J	0.28
Zinc (mg/kg)	11.2	22.5	16.6	16.77

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Table 10-46 -- Trace Metal and Radium Analyses in Mussel Tissue Metal
Samples obtained after 35 days of exposure during cycle test 2 recovery.

Sample		Aluminum (mg/kg)	Antimony (mg/kg)	Arsenic (mg/kg)	Cadmium (mg/kg)	Chromium (mg/kg)	Mercury (ng/g)	Methyl mercury (ng/g)	Molybdenum (mg/kg)	Nickel (mg/kg)	RA-226 (pCi/g)	RA-228 (pCi/g)	Selenium (mg/kg)	Zinc (mg/kg)
EQUIP BLANK		0.4 U	0.002 U	0.04 U	0.004 U	0.03 U	2.36	0.023 U	0.01 U	0.01 U	-0.02 +/- 0.20 U	0.01 +/- 0.37 U	0.19 U	0.41
ASR 1	**REP 1**	71.7	0.011 U	0.76	0.272	0.45	67.3	11.9	0.08	0.124	0.80 +/- 0.31 LT	0.09 +/- 0.49 U	0.14 U	14.2
	REP 2	64.9	0.012 U	1.03	0.204	0.49	61.7	11.3	0.07	0.268	0.76 +/- 0.30 LT	0.81 +/- 0.52 U	0.13 U	76.2
	REP 3	33.5	0.008 U	0.78	0.261	0.64	80	11.8	0.06	0.105	0.73 +/- 0.34 LT	0.44 +/- 0.51 U	0.13 U	25.8
	AVG	56.7	0.0052	0.857	0.246	0.527	69.7	11.7	0.07	0.166	0.763	0.223	0.067	38.73
ASR 3A	**REP 1**	69.6	0.011 U	1.22	0.337	0.31	93.8	0.8 U	0.09	0.174	0.70 +/- 0.30 LT	0.15 +/- 0.48 U	0.66	45.5
	REP 2	49.2	0.009 U	1	0.321	0.21	136	0.8 U	0.1	0.147	1.22 +/- 0.41 LT	0.79 +/- 0.57 U	0.73	45.3
	REP 3	33.6	0.010 U	0.8	0.234	0.3	86..4	0.8 U	0.07	0.146	0.65 +/- 0.29 LT	0.80 +/- 0.51 U	0.10 U	47.2
	AVG	50.8	0.005	1.007	0.297	0.273	114.9	0.4	0.087	0.156	0.857	0.29	0.48	46
ASR 3B	**REP 1**	74.6	0.012 U	0.78	0.211	0.34	75.8	0.8 U	0.07	0.126	0.72 +/- 0.31 LT	0.90 +/- 0.56 U	0.54	15.4
	REP 2	148	0.009 U	1.32	0.146	0.33	72.6	0.8 U	0.1	0.295	1.28 +/- 0.41	0.10 +/- 0.49 U	0.83	137
	REP 3	53.7	0.012 U	1	0.278	0.81	74.6	0.8 U	0.08	0.154	1.50 +/- 0.41	0.49 +/- 0.48 U	0.62	47.9
	AVG	92.1	0.0055	1.033	0.212	0.493	74.33	0.4	0.083	0.192	1.167	0.265	0.663	66.77
ASR 5	**REP 1**	42.8	0.011 U	0.83	0.171	0.33	97.1	10.4	0.07	0.15	0.87 +/- 0.33 LT	0.24 +/- 0.46 U	0.12 U	55.1
	REP 2	35.1	0.011 U	0.95	0.178	0.26	29	9.4	0.06	0.114	0.61 +/- 0.37 LT	0.86 +/- 0.62 U	0.13 U	30.3
	REP 3	74.5	0.011 U	1	0.128	0.25	47.1	7.2	0.06	0.188	0.70 +/- 0.29	0.51 +/- 0.63 U	0.11 U	30.6
	AVG	50.8	0.011	0.927	0.159	0.28	57.73	9	0.063	0.151	0.727	0.268	0.06	38.67

Table 10-47 -- Trace Metal and Radium Analyses in Mussel Tissue Metal
Samples obtained after 69 days of exposure during cycle test 2 recovery.

Sample		Aluminum (mg/kg)	Antimony (mg/kg)	Arsenic (mg/kg)	Cadmium (mg/kg)	Chromium (mg/kg)	Mercury (ng/g)	Methyl Mercury (ng/g)	Molybdenum (mg/kg)	Nickel (mg/kg)	Ra-226 (pCi/g)	Ra-228 (pCi/g)	Selenium (mg/kg)	Zinc (mg/kg)
Equip Blank											0 +/- 0.40	0.07 +/- 0.35 U		
ASR 1	**Rep 1**	78.9	0.011 U	0.69	0.148	0.19 U	67.4	10.9	0.06	0.080	0.71 +/- 0.36 LT	1.14 +/- 0.67 LT	0.16 J	12.8
	Rep 2	77.5	0.030 J	0.62	0.113	0.20 U	60.5	9.8	0.06	0.060	0.80 +/- 0.40 LT	0.48 +/- 0.49 U	0.18 J	12.3
	Rep 3	133	0.015 J	0.80	0.201	0.19	65.7	10.3	0.05 J	0.042 J	1.06 +/- 0.46	1.46 +/- 0.70 LT	0.24 J	31.0
	Avg	*96.46*	*0.0169*	*0.703*	*0.154*	*0.128*	*64.53*	*10.33*	*0.0567*	*0.0607*	*0.857*	*0.947*	*0.193*	*18.7*
ASR 3A	**Rep 1**	68.3	0.012 U	0.60	0.155	0.21 U	78.3	0.8 U	0.07	0.067	1.68 +/- 0.60	0.98 +/- 0.59 U	0.36 J	21.0
	Rep 2	77.3	0.012 U	0.73	0.171	0.19 U	101	1.0 J	0.06	0.083	0.89 +/- 0.35 LT	1.10 +/- 0.57 LT	0.35 J	15.5
	Rep 3	99.1	0.011 U	0.83	0.146	0.34	76.0	0.8 U	0.07	0.125	1.52 +/- 0.51	1.11 +/- 0.59 LT	0.50 J	33.1
	Avg	*81.57*	*0.0058*	*0.72*	*0.1573*	*0.18*	*85.1*	*0.6*	*0.067*	*0.0917*	*1.363*	*0.9*	*0.403*	*23.2*
ASR 3B	**Rep 1**	52.8	0.012 U	0.82	0.219	0.24	88.2	1.6 J	0.07	0.062	0.53 +/- 0.31 LT	0.55 +/- 0.50 U	0.30 J	15.9
	Rep 2	66.4	0.011 U	0.83	0.173	0.30	88.3	0.8 U	0.07	0.051 J	0.46 +/- 0.30 LT	0.86 +/- 0.56 U	0.46 J	35.8
	Rep 3	51.6	0.012 U	0.85	0.198	0.19 U	45.0	0.8 J	0.08	0.249	1.44 +/- 0.50	0.73 +/- 0.48 U	0.35 J	22.2
	Avg	*56.93*	*0.00583*	*0.833*	*0.1967*	*0.212*	*73.83*	*0.933*	*0.0733*	*0.1207*	*0.81*	*0.35*	*0.37*	*24.63*
ASR 5	**Rep 1**	205	0.012 U	0.47	0.091	0.17 U	75.4	9.2	0.04 J	0.152	1.58 +/- 0.55	1.00 +/- 0.66 U	0.16 J	8.30
	Rep 2	74.4	0.011 U	0.63	0.257	0.36	71.1	12.3	0.06	0.166	1.13 +/- 0.43	0.86 +/- 0.54 U	0.31 J	21.5
	Rep 3	58.7	0.011 U	0.73	0.241	0.21 U	92.9	13.3	0.04 J	0.092	0.52 +/- 0.33 LT	0.97 +/- 0.61 U	0.13 J	0.17 J
	Avg	*112.7*	*0.0057*	*0.61*	*0.196*	*0.1833*	*79.8*	*11.6*	*0.047*	*0.1367*	*1.077*	*0.472*	*0.2*	*9.99*

10.5.6 *In-situ* Specific Conductance and Water Quality Measurements

Based on the cycle test 1 field studies, there was a need to verify that the field equipment deployed in front of the KRASR discharge point was exposed to the recovered water mixing zone **(Figure 10-7)**. Specific conductance was selected as the best tracer of recovered water in the Kissimmee River due to the contrast in specific conductance values between surface water (223 +/- 50 µS/cm) and native UFA water (1270 +/- 156 µS/cm). Data sondes were deployed in the Kissimmee River to record basic water quality parameters (temperature, specific conductance, and dissolved oxygen) throughout the cycle test 2 recovery period. Sondes were co-located with caged mussels and periphytometers (**Figure 10-7**). Data sondes were programmed to log all three water quality parameters on an hourly basis.

Four data sondes were deployed in the Kissimmee River, three at the POD and one located approximately 2,000 ft downstream, near the 2,350-ft SZMW. Stations 3A and 3B are within the mixing zone of the recovered water plume, within 50 feet of the POD and cascade aerator. Two sondes were deployed at station ASR 3A: one near the surface (approximate depth of 30 cm), and one approximately 30 cm above the bottom. The third sonde was deployed at station ASR 3B (approximate depth of 30 cm). The fourth data sonde was located at station ASR 5 (approximate depth of 30 cm) and was considered to be representative of background conditions within the Kissimmee River at a point well beyond influence of recovered water. Time series data from each station are presented in **Figures 10-9** through **10-12**. All sonde data are summarized in **Appendix L**. Means for each parameter are presented in **Table 10-48**.

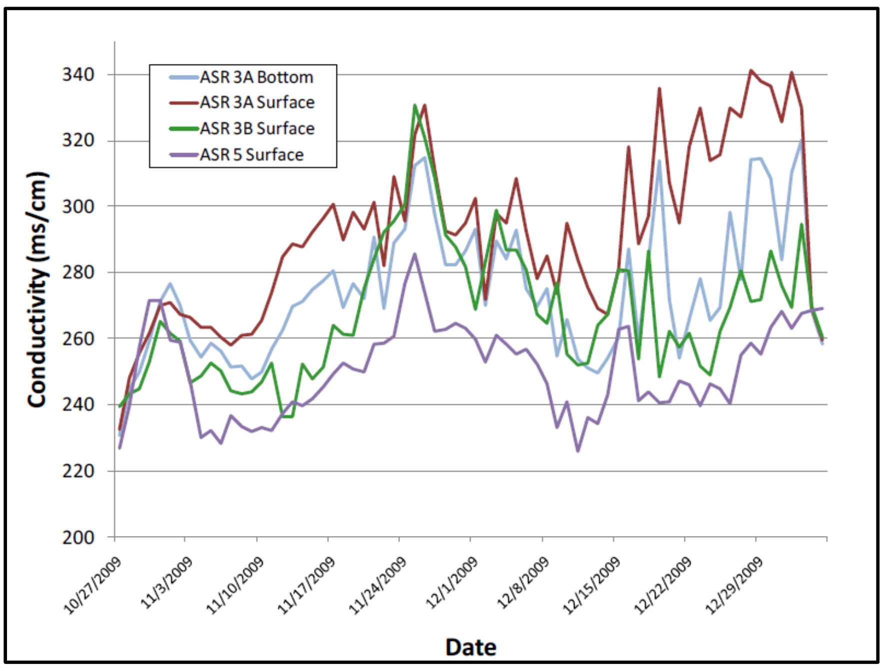

Figure 10-9 -- Specific conductance (ms/cm) at sampling stations in the Kissimmee River

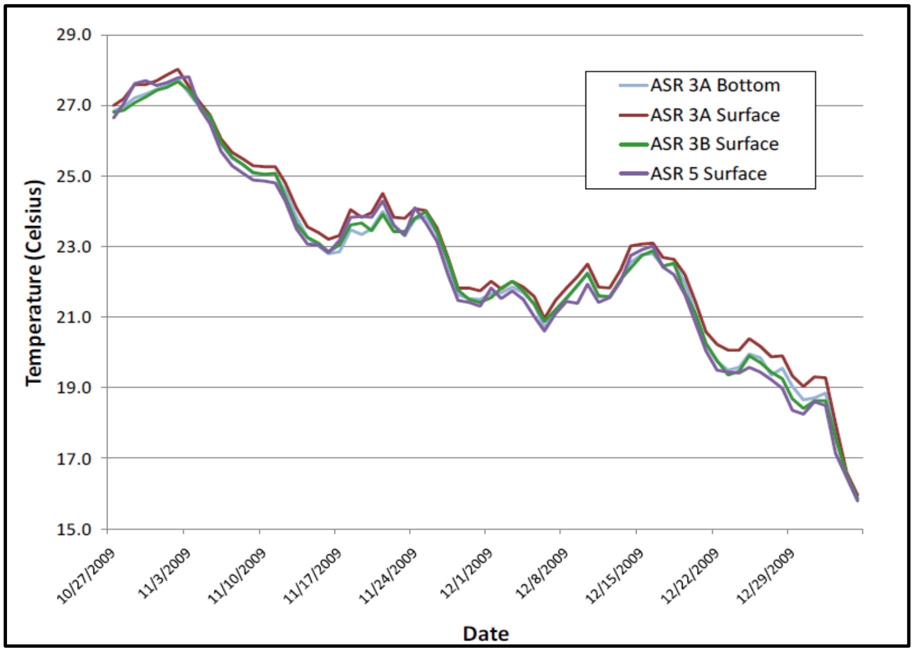

Figure 10-10 -- Temperature at sampling stations in the Kissimmee River

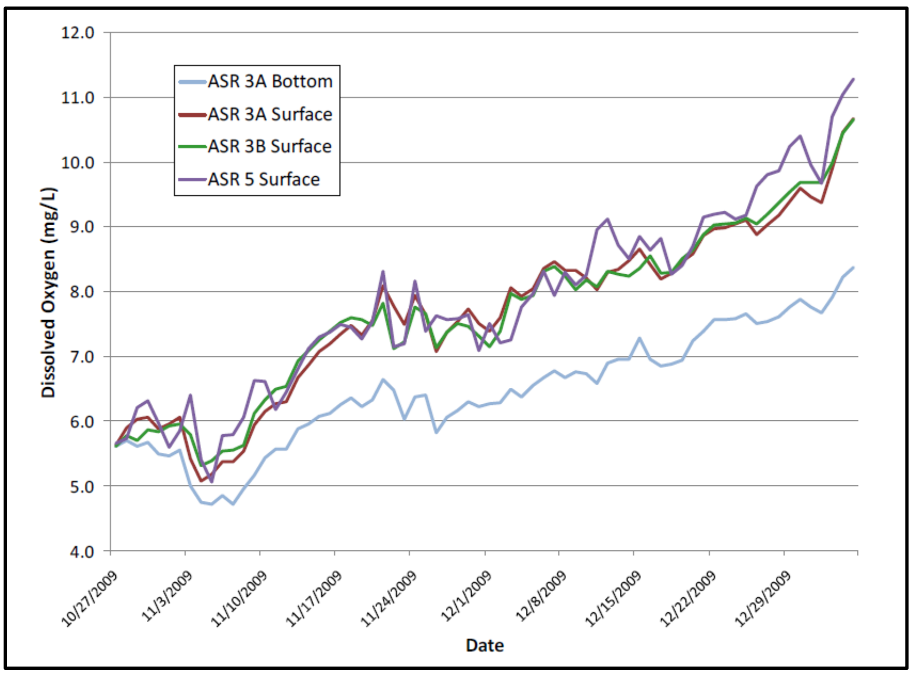

Figure 10-11-- Dissolved oxygen (mg/L) at sampling stations in the Kissimmee River.

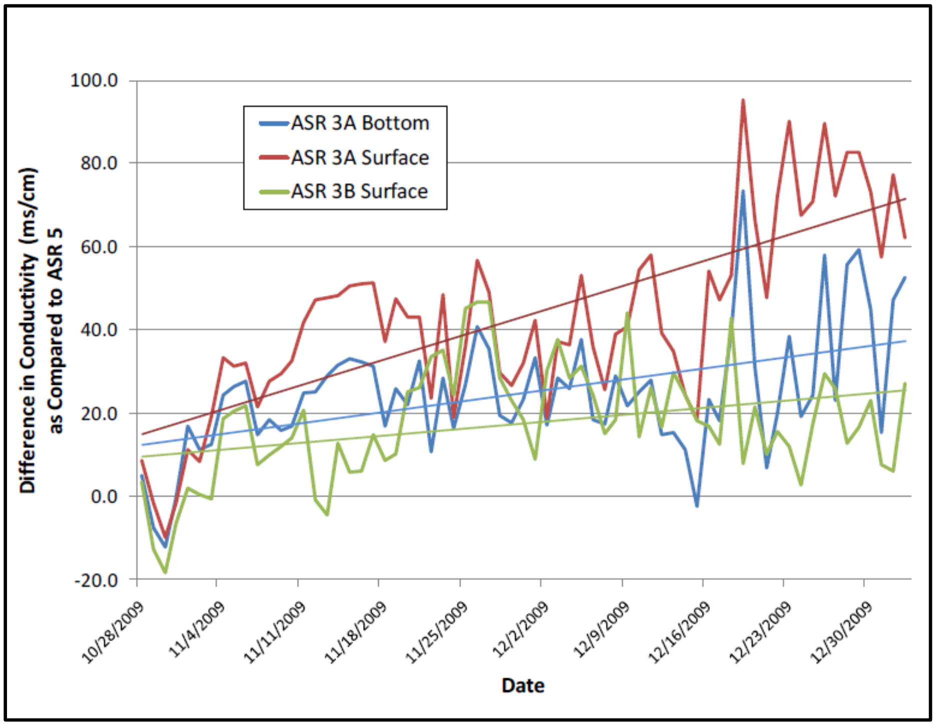

Figure 10-12 -- Difference in specific conductance (ms/cm) between stations at the ASR POD and station ASR 5 (downstream) at sampling stations in the Kissimmee River

Table 10-33-- Average Specific Conductance, Temperature, and Dissolved Oxygen as measured by Data Sondes

Sonde	Specific Conductance (ms/cm)	Temperature (Celsius)	Dissolved Oxygen (mg/L)
ASR 3A – surface	293.6	23.1	7.6
ASR 3A – bottom	275.3	22.8	6.4
ASR 3B – surface	268.0	22.7	7.6
ASR 5 – surface	250.5	22.7	7.8

10.5.6.1 Periphyton Study

Periphyton communities were sampled using periphytometers using methods similar to those in the cycle test 1 studies. Periphytometers were deployed for 28-day periods over the duration of the cycle test 2 recovery. Three consecutive deployments were conducted to cover the recovery period. The first and second sets were retrieved after 28 days; the third set was retrieved after a 14-day exposure because the cycle test 2 recovery ended at that time. All exposures were conducted in triplicate at each station. Data from the third deployment is not included because it did not fulfill the FDEP recommended 28-day exposure. **Figure 10-6** shows the timing of these exposures.

Periphytometers were deployed at four locations in the Kissimmee River as shown in **Figure 10-7**. Station ASR 1 is located near the flow control structure approximately 4,000-ft up-river of the KRASR. Periphytometers were also deployed in front of the KRASR discharge (ASR 3A and ASR 3B). The fourth station was on the west bank of the Kissimmee River, approximately 2,000-ft down-river from the KRASR (ASR 5). The periphytometers were deployed along the shoreline in water approximately 1 to 2 m deep.

Periphytometers were deployed on October 27, November 23, and December 21, 2010. Half of the exposure slides were collected for analysis at the mid-point of each study, on day 14, and the other half were collected on day 28. **Table 10-49** shows the diversity and evenness indices generated from these data. **Table 10-50** provides the ash free dry-weights for each sampling event. The full taxonomy reports for each sampling event are included in **Appendix L**.

All of the indices as well as the number of taxa identified, density of periphyton, and ash-free dry weights at each station were compared across stations within deployments using a one-way ANOVA, p=0.05 (NCSS, 2007). There were no statistically significant differences between the sites for any of the parameters tested.

Given the lack of statistical significance when treating the stations individually, data were grouped as either 'Discharge' (ASR 3A and ASR 3B) or 'Control' (ASR 1 and ASR 5). This allows comparison of the two stations at the discharge collectively to those further upstream and downstream. Again, no statistically significant differences were observed.

Table 10-34 --Diversity and Evenness Indices for the Periphyton Species.

Samples collected in Kissimmee River in the vicinity the of the KRASR POD during cycle test 2 recovery

		Recovery					
		11/23/2009			12/21/2009		
Station ID	Replicate	Shannon-Wiener Diversity Index	Pielou's Evenness Index	Hulbert Evenness Index	Shannon-Wiener Diversity Index	Pielou's Evenness Index	Hulbert Evenness Index
ASR 1	1	3.187	0.621	0.576	3.374	0.687	0.640
	2	3.580	0.745	0.689	3.060	0.643	0.590
	3	3.075	0.646	0.578	2.844	0.591	0.521
ASR 3A	1	3.643	0.750	0.719	3.224	0.713	0.662
	2	3.126	0.631	0.569	3.168	0.700	0.650
	3	3.533	0.720	0.675	3.316	0.676	0.616
ASR 3B	1	3.508	0.695	0.652	3.088	0.636	0.577
	2	3.523	0.657	0.608	2.804	0.629	0.574
	3	4.131	0.812	0.772	3.152	0.656	0.593
ASR 5	1	3.443	0.695	0.651	3.074	0.670	0.611
	2	3.377	0.688	0.653	2.876	0.627	0.581
	3	3.673	0.756	0.722	3.253	0.709	0.663

Table 10-35 -- Ash-Free Dry Weights for the Periphyton Species

Samples collected in Kissimmee River in the vicinity the of the KRASR POD during cycle test 2 recovery

		11/23/2009	12/21/2009
Periphyton Station ID	**Replicate**	**Ash-Free Dry Weight (g/m²)**	**Ash-Free Dry Weight (g/m²)**
ASR 1	1	1.01	1.49
	2	2.90	3.95
	3	3.46	3.46
ASR 3A	1	1.94	3.78
	2	1.63	4.11
	3	1.76	2.87
ASR 3B	1	4.03	4.35
	2	2.53	3.89
	3	4.88	1.28
ASR 5	1	2.67	2.74
	2	1.19	2.59
	3	0.92	3.63

g/m^2 – grams per square meter

Periphyton is considered to be a useful indicator of changes in water quality. In this assessment, standard indices of biodiversity and growth were evaluated relative to the discharge of recovered water from the KRASR. No statistically significant differences in these indices were detected between the periphyton collected immediately in front of the ASR discharge and that collected from stations located both upstream and downstream.

10.6 Fish Fry Entrainment Study at KRASR

10.6.1 Background

The pumping of surface water during recharge represents a potential threat to fish and other aquatic resources through entrainment and impingement at the intake structure. Entrainment occurs when an organism is drawn into a water intake and cannot escape. Impingement occurs when an entrapped organism is held in contact with the intake screen and is unable to free itself. The severity of the impact on the fisheries resource and habitat depends on the abundance, distribution, size, swimming ability, and behavior of the organisms in the vicinity of the intake, as well as water velocity, flow and depth, intake design, screen mesh size, installation and construction procedures, and other physical factors (Canadian Department of Fisheries and Oceans, 1995). The significance of this potential threat in Florida is presently undetermined.

Subsistence fishing could occur at any of the ASR pilot project sites. The recreational fisheries of the lower Kissimmee River are likely the most significant of all ASR pilot sites, and include black crappie (locally known as ‘specks”), largemouth bass, red-ear sunfish, and two forage species (gizzard and threadfin shad). Other native fish families potentially at risk are killifish (Fundulidae), flagfish (Cyprinodontidae), mosquito fish (Poeciliidae), silversides (Atherinidae), catfish (Ictaluridae), and other sunfish (Centrarchidae, *e.g.*, warmouth, bluegill, and spotted sunfish).

The larval and post-larval stages of black crappie likely have the greatest risk potential for harm from entrainment and impingement by intake pump operations. After the channelization of the Kissimmee River, the lower Kissimmee River became a favorite spawning location for this species. The typical spawning period for black crappies at this location is rather protracted, from January to May. Adults prefer to nest in colonies in shallow water near aquatic vegetation. A few days after hatching, post-larvae disperse from the nest area and eventually move to deeper water near the middle of the channel. Fry move vertically throughout the water column primarily to forage on zooplankton and secondarily to avoid predation. They follow the currents downstream into Lake Okeechobee. Their spawning requirements increase the likelihood that nest sites will be near both intake and discharge pipes (assuming that these structures will also be near or on the stream bank). The larval and post-larval stages are poor swimmers and would probably be unable to escape intake velocities. This is important to note not only for those fish hatching near the intakes, but also for those that may be drifting down from upstream spawning locations (including open water spawners like threadfin or gizzard shad). If the pumping rate is high enough, fry that were near the center of the stream channel may be pulled towards the shoreline and be at greater risk of entrainment or impingement.

As originally designed, the KRASR system has an intake velocity at the bar screen of 2 to 3 feet per second (ft/sec), with a maximum in-pipe velocity of 5 ft/sec. Assuming that many fish species would be small enough to bypass a bar screen, that design would have entrained most larval, juvenile, and even adult fish near the intake. The intake structure at KRASR was redesigned to be most protective and minimize entrainment of larval fish. The intake consists of a 48-inch diameter T-shaped, cylindrical, wedge wire, screen with a 1-mm mesh size, designed for a flow velocity of 0.25 ft/sec. This intake is at the end of a 24-in pipe that conveys water into the wet well (**Section 6.1.2.1**). That screening mechanisms should protect a 1-in fish. Also, included in the KRASR design was a small shunt pipe that can be metered between the intake structure and the water treatment facility to allow for periodic sampling of entrained fish eggs and larvae.

A decision was made to have the same intake design at the proposed Moore Haven ASR system, but only be protective of a 2.5-in fish at the Port Mayaca and Hillsboro ASR systems (*i.e.,* an intake velocity of 0.5 ft/sec at the screen face and a mesh size of 6 mm). No intake screening was deemed necessary at the proposed Caloosahatchee ASR system, because the intake would be constructed in the Header Canal. However, consideration should be given to exploring opportunities for entrainment protection at the lift pump at Townsend Canal.

10.6.2 Experiment Design and Results

A fish fry entrainment study was conducted at the KRASR system during January 2012 (cycle test 4 recharge), to qualitatively assess the extent of fish fry entrainment during routine recharge phase operation (Reynolds, 2012). These sampling events were conducted in cooperation with the USFWS and the Florida Fish and Wildlife Conservation Commission (FFWCC).

Two sampling events were conducted during daylight and nighttime conditions, in the season when crappie spawning was expected. Bulk samples were collected with a 300-µm mesh plankton tow suspended for 5-min in the wet well during recharge pumping. Sampling proved difficult due to the proximity of the 6-ft long plankton tow and the pump impellers. However, one bulk sample was obtained during each event, and the contents were preserved then identified by FFWCC ichthyologists.

The most abundant organisms found in both day and night samples were zooplankton, including Chironomidae (non-biting midges), *Chaoborus* sp. (glassworm midge), and amphipods (planktonic crustaceans), all being common freshwater invertebrates. Two individual fish larvae were found in the night sample, one each of a shad and black crappie. These results suggest that there is a potential for fish larvae entrainment, particularly during night time recharge operation. However, a better sampling method is needed to quantify entrainment to determine if this issue is significant at ASR intake structures. Determination of larval fish densities in surface waters near ASR sites at various times of the year would also be prudent. While the important freshwater fish species spawn primarily from January to May in south Florida, there is generally no month where no species is spawning. For additional information on this topic including the life history and economic importance of various fisheries, refer to USFWS (2004).

10.7 Ecological Effects of Recovered Water in the Surface Water Body

The potential exists for both beneficial and adverse effects on water quality from discharge of recovered water at an ASR system, particularly if the discharge rate represents a significant component of stream flow. In-stream effects are defined primarily using permit-required toxicity tests and ecotoxicological studies that are described earlier in this section. The potential for adverse effects from recovered water on fisheries resources and selected threatened and endangered species is described in the following subsections. This evaluation focuses primarily on the effect of recovered water on the ecological condition of the Kissimmee River, adjacent to the KRASR system.

10.7.1 Characterization of the Recovered Water Plume

In order to assess the ecological impacts of recovered water entering the Kissimmee River, the characteristics and extent of the plume of recovered water needs to be examined. Flow measured daily at the S65E structure during cycle test 3 from January to May 2011 averaged 415 $\pm$ 355 cfs. The minimum and maximum flow values, in cfs, over that time frame were 1.05 and 1,121.87, respectively. According to the NPDES permit for the KRASR system, a minimum flow of 30 cfs was to be released through the S65E structure to meet a dilution ratio requirement of 3.9 during the recovery phase. This minimum flow was achieved by a large margin on all occasions except during 3 daily measurements in January (N=134). The recovered water flow volume from KRASR was 7.7 cfs (5 MGD). When compared with the average flow in the river (at S65E), recovered water made up less than 1 percent of the total flow and was subject to a dilution ratio of 53.6. As noted from the wide range of river flow values above, the dilution ratio fluctuated by several orders of magnitude over the course of cycle test 3, but exceeded the minimum dilution ratio at all sampling times except for the 3 instances stated above. These data indicate that, at most times, a large degree of mixing is expected to occur within the river. Despite this mixing, portions of the river in close proximity to the outfall may have water quality characteristics that are heavily influenced by the characteristics of the recovered water.

Field examinations of the flow field during recovery revealed a plume that was conservatively estimated as being 12-m wide and 61-m long, covering approximately 744 m^2 (USFWS, personal communication). For analysis purposes, a conservative assumption is that habitat within the 744 m2 will be subject to the water quality of the recovered water and that negligible mixing will occur in this area. A sampling event on January 5, 2011, revealed that temperature, conductivity, and dissolved oxygen (DO) returned to ambient levels within 15 m, towards the river channel, of the point of discharge. Measurements taken 200-m upstream and downstream of the point of discharge also reflected ambient river conditions. Flow from the S65E structure on the January 5, 2011 was 135 cfs. This value is 4.5 times the minimum flow in the river (30 cfs) required by the NPDES permit for recovery operations, therefore the field-measured characteristics of the plume do not represent a worst-case scenario where the ratio of recovered water volume to total river volume would be at a maximum. The potential exists for the plume of recovered water to constitute a significantly higher fraction of the total flow in the river than was observed during field operations. The characteristics of the plume from KRASR need to be better determined under varying environmental conditions (wind speed, wind direction, variable flows) to fully evaluate the impact of recovered water on the Kissimmee River. The USFWS did not have access to observations for the Hillsboro ASR plume, but assume a similar situation may exist, and therefore also recommend to the Corps and SFWMD that plume be accurately characterized too.

10.7.2 In-Stream Effects of Recovered Water on Dissolved Oxygen and Temperature

Monthly mean DO concentrations calculated from biweekly measurements in the Kissimmee River at the S65E structure over a time period from 2000 to 2013 ranged from a minimum of 2.21 mg/L in September to a maximum of 7.84 mg/L in February and are presented in **Figure 10-13**. Monthly mean DO concentrations calculated from biweekly measurements in 2011 in the Kissimmee River at the S65E structure and from weekly measurements at the point of discharge (POD) for cycle test 3 recovered water are also plotted on the figure. Recovered water DO concentrations were relatively constant during cycle test 3, ranging from a minimum of 6.99 mg/L to a maximum of 7.84 mg/L with an overall mean DO concentration of 7.42 $\pm$ 0.16 mg/L.

Dissolved oxygen concentrations at the point of discharge during cycle test 3 were appreciably higher than ambient Kissimmee River water DO concentrations through the months of March, April, May, and June. River water mean DO concentrations were still above 5.00 mg/L throughout the entire recovery phase of cycle test 3. While the more highly oxygenated recovered water may serve as an attractant to aquatic species, most notably fish, it is unclear whether the difference in DO concentration between the

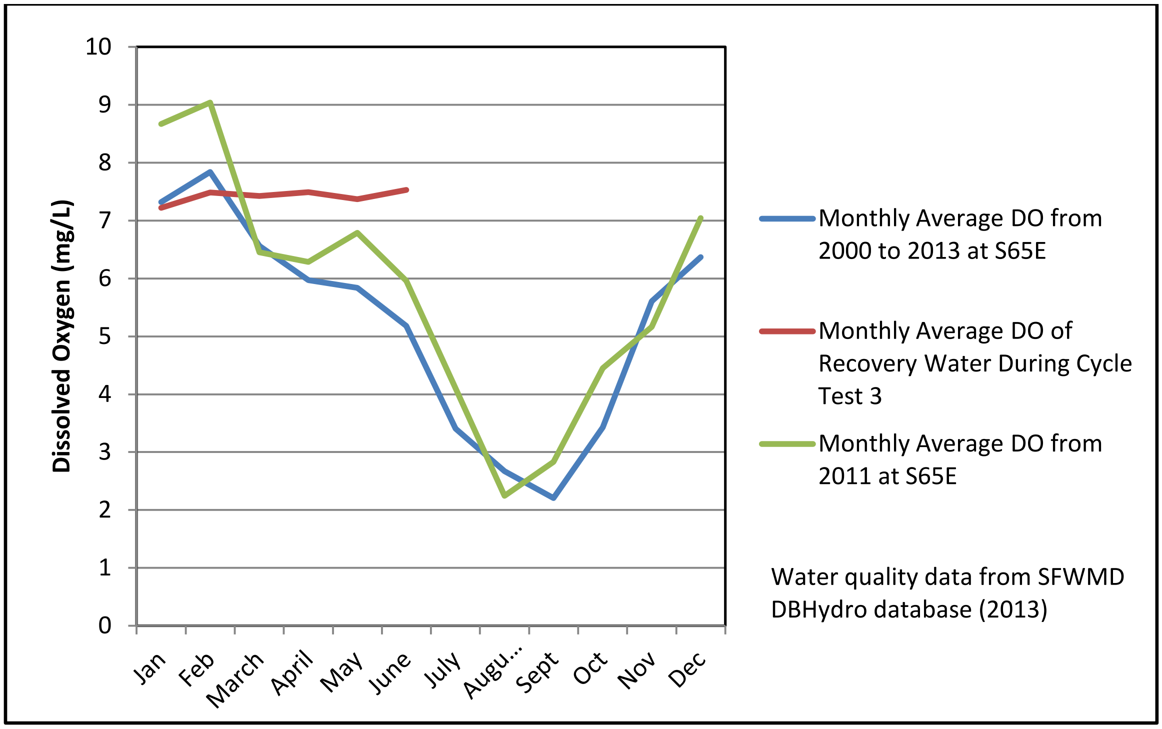

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Figure 10-13 -- Dissolved oxygen concentrations from 2000 to 2013 at the S65E structure, from recovered water during cycle test 3, and from 2011 at S65E.

river and at the point of discharge in the spring and early summer is dramatic enough to attract fish. Certainly, if the cycle test 3 recovery period had extended into the late summer and early fall, the DO difference between river water and at the point of discharge would be expected to attract an assemblage of fish species to the immediate discharge area.

Monthly mean surface water temperatures calculated from biweekly measurements in the Kissimmee River at the S65E structure over a time period from 2000 to 2013 ranged from a minimum of 17.6°C in January to a maximum of 30.0°C in August and are presented in **Figure 10-14**. Monthly mean temperatures calculated from biweekly measurements in 2011 in the Kissimmee River at the S65E structure and from weekly measurements of cycle test 3 recovered water also are plotted. Recovered water temperatures were relatively constant during cycle test 3, ranging from a minimum of 25.2°C to a maximum of 27.5°C with an overall mean temperature of 25.7 $\pm$ 0.5°C.

Recovered water temperatures during cycle test 3 were appreciably higher than ambient Kissimmee River water monthly mean temperatures at S65E for the months of January and February. Temperatures in March and April were similar between the two sources of water, while river water temperatures in May and June were noticeably higher than recovered water temperatures. Although cycle test 3 only produced recovered water from January to June of 2011, extrapolating the relatively constant temperature of the recovered water to the other months of the year would reveal a trend of higher temperatures in river water in the summer, similar temperatures in the fall, and lower temperatures in river water in the winter.

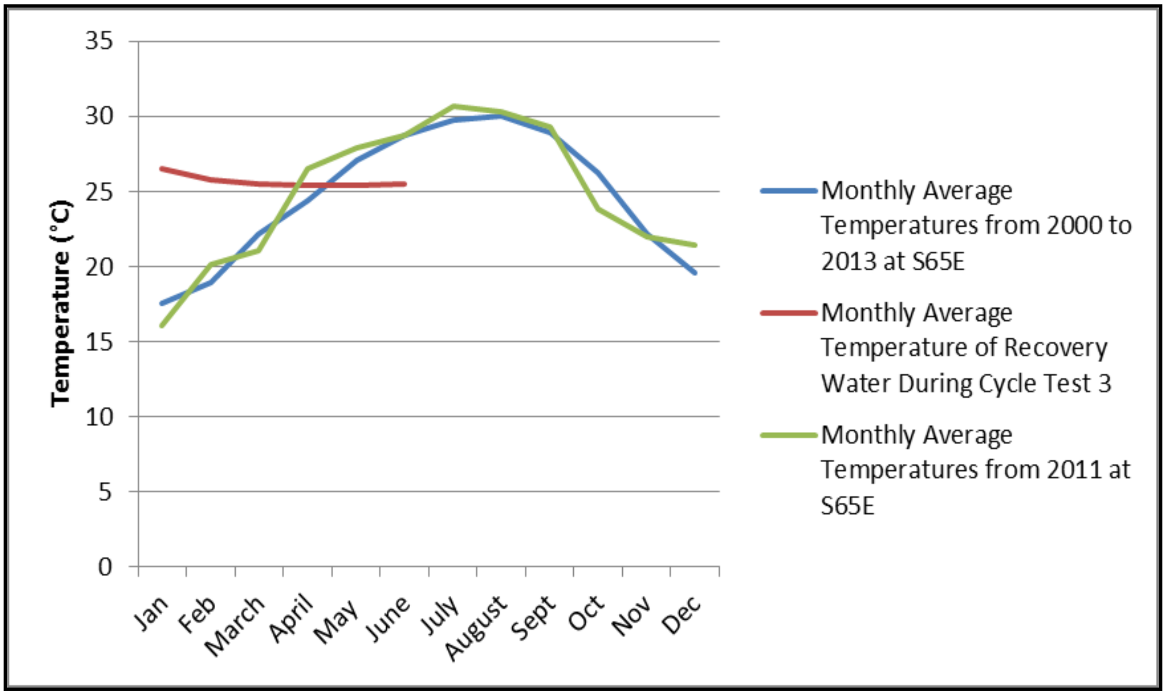


Figure 10-14 -- Temperature from 2000 to 2013 at the S65E structure, from recovered water during cycle test 3, and from 2011 at S65E.

The marked temperature differences during the summer and winter months may serve as an attractant to fish species, particularly in the summer months, when recovered water is cooler and more oxygenated. Creation of an oxygenated refugium adjacent to the POD would be limited in size. It is unlikely that a large or significant fish kill would occur if recovery was abruptly discontinued.

The impact of altered water temperatures on native fish spawning activity also needs to be examined. The considerably warmer temperatures observed in recovered water during January and February of cycle test 3 when compared to ambient river temperatures may impact the spawning activity of species such as black crappie and largemouth bass, both of which initiate spawning activities at temperatures below 20°C and prefer shallow areas which could be in close proximity to the outfall of KRASR. As mentioned above, a better understanding of the extent of the plume of recovered water will better define the area of fish spawning habitat that may be impacted during the recovery phase. It is also possible that typical ASR operations would not discharge water until later in the dry season (when there is a water supply need) and so some of these concerns in January and February may be alleviated.

10.7.3 Dissolved Gas Concentrations and Potential Impacts on Kissimmee River Fisheries

The concentrations of dissolved gases carbon dioxide (CO_2), hydrogen sulfide (H_2S), and un-ionized ammonia (NH_3) in ASR recovered water can differ from that in the receiving surface water body. As discussed in **Section 10.2.1**, the recovered water plume has a limited areal extent and volume compared to flow in the Kissimmee River. However, because future ASR system expansion is possible at the KRASR system, the potential impacts on surface water quality and Kissimmee River fisheries from dissolved gases in recovered water are evaluated.

The dissolved gas concentrations in recovered water were calculated using water quality data from POD samples collected during the recovery phase of cycle test 3 (January-July 2011; n = 16). POD samples were obtained at the base of the cascade aerator after maximum aeration has occurred. Dissolved gas concentrations in Kissimmee River surface water were calculated using water quality data from samples collected at the S65E structure located approximately 5 miles upstream from the KRASR system (DBHydro, 2013; January-July 2011; n = 4). For all samples, dissolved gas and solute concentrations were calculated using the geochemical speciation module of PHREEQC v. 2.17 (Parkhurst and Appelo, 1999). Only samples having charge balance errors +/-7 percent or less were used. Saturation indices (SI) also were calculated in PHREEQC to determine whether each species would in-gas (negative SI) or degas (positive SI) from that water sample. Results are tabulated in **Table 10-36**.

The dissolved gas compositions of ASR recovered water differ from those of Kissimmee River surface water. Recovered water has a similar concentration of dissolved carbon dioxide, and higher concentrations of dissolved hydrogen sulfide and un-ionized ammonia compared to surface water **(Table 10-36).** Dissolved carbon dioxide is statistically similar in recovered water and surface water. Negative saturation indices in all samples indicate that atmospheric carbon dioxide will in-gas from the atmosphere into all waters.

Dissolved sulfide species (solute and gas) are higher in recovered water due to sulfate-reducing reactions in the aquifer. At a pH range of 7 to 8, most of the total dissolved sulfide occurs as the bisulfide ion (HS^-; 0.01 to 0.006 millimolar, or 0.20 to 0.67 mg/L concentration range). Dissolved sulfide gas concentrations ($H_2S_{(g)}$) are about an order of magnitude lower (0.001 to 0.0004 millimolar; 0.01 to 0.15 mg/L). No dissolved sulfide measurements were available for the Kissimmee River; however, sulfide species (solute and gas) are unstable in the presence of dissolved oxygen so sulfide most likely is not detectable in surface water. Negative SIs indicate that hydrogen sulfide will in-gas into all waters, which is what happens in the FAS prior to recovery. The national recommended water quality criteria compiled by the EPA recommends a chronic hydrogen sulfide concentration of 2 µg/L for the protection of aquatic life (USEPA, 1986). Concentrations of hydrogen sulfide at the POD were consistently an order of magnitude (occasionally two) higher than the recommended criterion. The national recommended criterion is not specific to Florida species and is provided to serve as a guide to states when adopting water quality standards. Currently, the State of Florida does not have surface water quality criteria for hydrogen sulfide. While it is likely that hydrogen sulfide will be oxidized in the presence of dissolved oxygen, the area immediately surrounding the POD may not be suitable for aquatic organisms. During

Table 10-36 -- Concentrations of Dissolved Gases and Selected Solutes in Recovered Water and Kissimmee River Surface Water Samples

Sample	Location	Percent Charge Balance Error	pH	CO_2 (g), in mg/L	CO_2 (g) Sat. Index	Dissolved Bisulfide, HS-, in mg/L	Dissolved H_2S (g), in mg/L	H2S (g) Sat. Index	Ammonium, NH_4^+, in mg/L	Un-ionized Ammonia, NH_3(g), in mg/L	NH_3(g) Sat. Index
POD_1/17/2011	POD	6.56	7.91	1.43	-3.01	0.35	0.03	-4.99	0.42	0.018	-7.72
POD_1/21/2011	POD	-2.26	8.03	1.12	-3.11	0.20	0.01	-5.34	0.27	0.015	-7.79
POD_1/27/2011	POD	-2.03	8.02	1.18	-3.09	0.24	0.02	-5.26	0.29	0.016	-7.79
POD_2/16/2011	POD	0.76	7.43	4.10	-2.56	0.40	0.12	-4.45	0.33	0.004	-7.82
POD_3/3/2011	POD	6.15	7.97	1.16	-3.11	0.37	0.03	-5.03	0.19	0.009	-8.04
POD_3/10/2011	POD	-0.97	7.37	4.92	-2.48	0.44	0.15	-4.35	0.19	0.002	-8.65
POD_3/16/2011	POD	2.0	7.96	1.20	-3.09	0.67	0.06	-4.76	0.22	0.010	-8.00
POD_3/22/2011	POD	-1.63	8.03	1.03	-3.16	0.37	0.03	-5.09	0.18	0.010	-8.02
POD_3/30/2011	POD	-2.71	8.00	1.13	-3.12	0.41	0.03	-5.01	0.25	0.013	-7.90
POD_4/7/2011	POD	-0.33	8.02	1.07	-3.15	0.26	0.02	-5.23	0.15	0.007	-8.13
POD_4/28/2011	POD	0.27	7.92	1.53	-2.99	0.22	0.02	-5.21	0.28	0.011	-7.94
POD_5/5/2011	POD	-2.67	7.94	1.41	-3.02	0.53	0.05	-4.84	0.23	0.010	-8.01
POD_5/10/2011	POD	-0.3	7.90	1.45	-3.01	0.29	0.03	-5.07	0.24	0.009	-8.03
POD_5/25/2011	POD	-0.45	7.88	1.55	-2.99	0.33	0.03	-4.99	0.22	0.008	-8.09
POD_6/2/2011	POD	-2.47	8.02	1.26	-3.07	0.58	0.04	-4.89	0.23	0.012	-7.94
POD_6/7/2011	POD	-1.59	7.33	6.27	-2.38	0.26	0.10	-4.55			
POD_6/15/2011	POD	4.84	7.87			0.23	0.02	-5.14			
S65E_17FEB11	RIVER	0.71	7.40	3.38	-2.73				0.04	0.0003	-9.63
S65E_9MAR11	RIVER	3.03	7.00	8.03	-2.32				0.03	0.0001	-9.97
S65E_18MAY11	RIVER	1.67	7.80	1.06	-3.11				0.01	0.0004	-9.31
S65E_8JUNE11	RIVER	1.29	7.40	3.21	-2.64				0.01	0.0001	-9.87

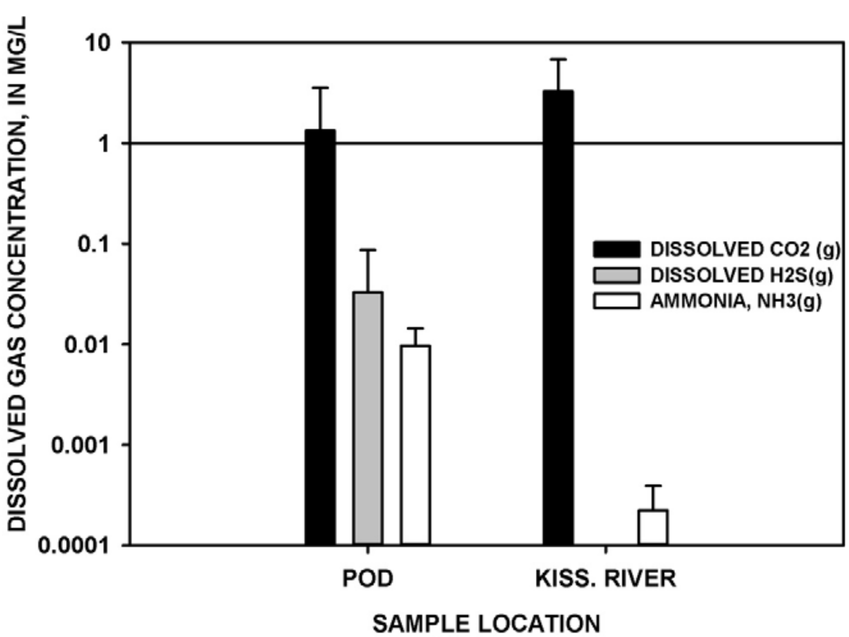


Figure 10-15 -- Bar graph comparing mean dissolved gas concentrations between KRASR system Point of Discharge (POD) samples, and Kissimmee River surface water samples obtained at S65E. Error bars are standard deviations.

periods of time when dissolved oxygen is low in the river, hydrogen sulfide may not be oxidized as quickly. In the future, cascade aerator design should consider not only aeration for dissolved oxygen addition, but also aeration for hydrogen sulfide removal prior to discharge into a surface water body.

Ammonia and ammonium concentrations increase during storage in the UFA, so recovered water concentrations are higher than those of Kissimmee River surface water. Total ammonia concentration is the sum of two dissolved ammonia species: ionized ammonium (NH_4^+) and un-ionized ammonia (NH_3). Ammonia toxicity to freshwater fish is based on un-ionized ammonia concentration (as mediated by temperature and pH). The surface water quality criterion for un-ionized ammonia is 0.02 mg/L for both Class I and Class III Florida surface waters. Most of the ammonia nitrogen in recovered water occurs as ionized ammonium (0.01 to 0.006 millimolar; 0.15 to 0.42 mg/L). Un-ionized ammonia concentrations are about an order of magnitude lower (0.001 to 0.0001 millimolar; 0.002 to 0.016 mg/L). Although un-ionized ammonia concentrations are higher in recovered water, concentrations do not exceed the surface water quality criterion of 0.02 mg/L.

10.7.4 Potential Effects of ASR Discharges on Manatees

There were three manatee mortalities reported to the USFWS during 2012 (April 24, May 24, and July 9) in the Kissimmee River (vicinity of S65E and S-84). All deaths were of “undetermined” cause. One manatee injury was reported on July 17, 2012 at the S-84. Also on that date, there were three live manatees observed at the same location. Two days later one live manatee was observed downstream of the S-65D and another near the mouth of the Kissimmee River. It is not clear if these live individuals were the same as those observed two days prior or different individuals. Regardless, there were at least seven manatees that were observed in the Kissimmee River in 2012 that would have had to swim past the KRASR system.

In previous years (1980, 2003, 2009, 2010 and 2011) there were at least six additional manatee mortalities reported to the USFWS in Lake Okeechobee within 3 miles of the mouth of the Kissimmee River. These mortalities were reported from January to April, and November.

The USFWS expects manatees to be in Lake Okeechobee and the Kissimmee River primarily during warmer months of the year. The USFWS also expect them to migrate to coastal areas as water temperatures drop coincident with the onset of winter. Waters colder than 20°C increase the manatees’ susceptibility to cold-stress and cold-induced mortality. Because of this temperature restriction, manatees seek out warm water refugia to help reduce energetic maintenance costs.

The temperature of the KRASR discharge ranges from 25.2 to 27.5°C (January to June 2011; *i.e.,* cycle test 3, single weekly temperatures). Based on the data in **Figure 10-14**, manatees are expected to leave the Kissimmee River in December as the water temperature approaches 20°C, and would not return until February or March. However, data exists for at least two manatee mortalities in January and February near the KRASR system. It is not clear at this time if manatees can find thermal refugia in Lake Okeechobee during the winter, primarily because the lake is not part of the winter survey area.

However, the risk of manatee mortality from thermal stress from one ASR well at KRASR is probably minimal. The rationale for this is that we expect ASR discharges to occur when there is a water shortage, typically at the middle to end of the dry season (March-May), when the background water temperature is already greater than 20°C. If future ASR systems discharge warmer than 20°C water into areas inhabited by manatees when the surrounding water is less than 20°C, it could create a manatee refugia and this should be coordinated with the USFWS and NOAA prior to the start of the recovery phase.

10.7.5 Stream Sensitivity Index Results

Results will be discussed in the ASR Regional Study Technical Data Report, in preparation.

10.8 Ecotoxicological Studies at HASR

All toxicity tests conducted for HASR were permit-driven and are discussed in **Section 7.**

10.9 “First Flush” Analysis

During the first few hours of the recovery phase, water showing high turbidity (several hundred NTU) is discharged from the ASR well. Fine-grained solids from well construction and particulates that are entrained in the aquifer collect at the base of the ASR well over time. Recovery draws these particulates up from the base of the open interval. “First flush samples” were collected to characterize dissolved and total constituents of these turbid samples. Turbid water exceeds surface water quality criterion (turbidity < 29 NTU above background), so discharge cannot occur into either Kissimmee River or Hillsboro Canal. At KRASR, less than an hour’s worth of initial recovered water flow (approximately 0.2 million gallons) is diverted to on-site backwash equalization and backwash solids ponds until turbidity values stabilize to <29 NTU. At HASR, a similar volume is diverted to a former quarry pit (now flooded) that has no connection to Hillsboro Canal or the L-40 canal.

10.9.1 “First Flush” Data from KRASR

Prior to the initiation of cycle testing in January 2009, a few short recharge and recovery events (a few weeks in duration) were conducted to test several ASR system components. During recovery in one of these “performance tests”, two sets of samples were collected to characterize the initial turbid water released from an ASR system: 1) sediment-water slurries from the initial turbid water recovered from the ASR well, known as the “first flush”; and 2) filtered and unfiltered water samples obtained throughout the month of recovery (January-February 2008).

The “first flush” samples consisted of total and dissolved (filtered) subsamples, plus sediment for Toxicity Characteristic Leaching Procedure (TCLP; EPA Method 1311) analysis. These were collected on 6 February 2008 during the recovery phase of a system performance test **(Table 10-37)**. TCLP analyses are performed to determine the concentration of “bioavailable” or leachable analytes in a sediment-water slurry. In this dataset, transition metals (cadmium, chromium, lead, mercury, and selenium) were below the detection level in filtered (dissolved) and unfiltered (total) groundwater. Cadmium, chromium, mercury, and selenium were below the detection level in the TCLP extract as well. Lead was the only transition metal detected, at a concentration below the MCL, and probably was sorbed to solids because there was no detection of lead in the filtered sample. Arsenic and barium exist primarily in the dissolved phase, rather than sorbed or in the particulate phase, and arsenic concentrations exceeded the MCL. Data from these analyses are shown in **Table 10-38.**

Filtered and unfiltered groundwater samples were analyzed for metals during the recovery phase of ASR system performance testing (23 January through 11 February 2008). Filtered analyses quantify dissolved metals concentrations, while unfiltered analyses quantify dissolved plus particulate metals concentrations. These results show metals concentrations resulting from the first contact of recharge water with the native FAS in the storage zone, and provided some insight to future cycle testing trends. The suite of metals and descriptive statistics are shown in Table **10-38**.

Table 10-37 -- "First Flush" Water Quality Analysis at KRASR, 6 Feb 2008

Constituent	Unit	MCL	SAMPLE FF-1		SAMPLE FF-2		TCLP Extraction
			Filtered	Total	Filtered	Total	
Total Alkalinity	mg/L			79		81	
Total Dissolved Solids	mg/L			545		489	
Total Suspended Solids	mg/L			< 2.0		< 2	
Gross Alpha	pCi/L	15		1.8+/-1.0		3.0+/-1.3	
Phosphorus	µg/L			32.2		18.8	
o-Phosphate	µg/L			22		18.2	
Arsenic	µg/L	10	49.3	59.9	59.0	63.2	5.72
Barium	µg/L	2000	37.1	48.3	39.0	42.9	4.46
Cadmium	µg/L	5	< 0.37	< 0.37	< 0.37	< 0.37	< 0.37
Chromium	µg/L	100	< 0.99	< 0.99	< 0.99	< 0.99	< 0.99
Lead	µg/L	15	< 2.0	5.5	< 2.0	4.8	10.1
Mercury	µg/L	2	< 0.065	< 0.065	< 0.065	< 0.065	< 0.065
Selenium	µg/L	50	< 5.4	< 5.4	< 5.4	< 5.4	< 5.4
Silver	µg/L	100					< 1.0

Dissolved and total metals concentrations were below the detection limit for the following metals: antimony, beryllium, cadmium, cobalt, copper, lead, mercury, nickel, silver, thallium, and vanadium. Of the remaining suite, iron, arsenic, and molybdenum showed significant increases over native FAS water concentrations, indicating that these metals are mobilized during cycle testing. For each metal, the ratio of concentrations between the dissolved (filtered) and total sample indicates whether this metal will be transported in the dissolved versus particulate phase. A value of 1 indicates that the metal occurs in the dissolved phase. Arsenic ratios range between 0.76 and 1.2, while molybdenum ratios range between 0.91 and 1.06. Arsenic and molybdenum remain in the dissolved phase after mobilization in the storage zone, although the arsenic ratio declines later during recovery. Iron ratios range between 0.29 and 0.95, with lower values occurring later during recovery. Declining arsenic and iron ratios (and concentrations) toward the end of this short recovery phase suggests precipitation of these metals in a solid phase.

Table 10-38 -- Major and Trace Dissolved Constituents in Filtered and Unfiltered Recovered Groundwater Samples, Performance Testing (pre-Cycle Test 1), at KRASR (Jan - Feb 2008)

Analyte	Unit	MCL or Secondary Criteria	Mean	Std Dev	Max	Min	N
Calcium	mg/L		43.2	5.58	63.6	36.7	20
Iron	mg/L	0.3	0.24	0.16	0.74	0.05	20
Magnesium	mg/L		21.6	5.58	30.8	13.2	20
Potassium	mg/L		5.41	0.78	7.19	4.3	20
Sodium	mg/L		77.1	23.7	114	43.6	20
Aluminum	mg/L	0.05 - 0.2	0.03	0.04	0.08	0.01	3
Antimony	µg/L	(4,300)	< 5				20
Arsenic	mg/L	0.010 (0.050)	0.069	0.041	0.139	0.016	20
Barium	mg/L	2	0.037	0.005	0.057	0.032	20
Beryllium	µg/L	4 (0.13)	< 5				20
Cadmium	µg/L	5(0.76)	< 5				20
Chromium	µg/L	100 (10)	5	0	5	5	6
Cobalt	µg/L		< 5				20
Copper	µg/L	1,000 (30.5)	< 5				20
Lead	µg/L	15 (18.6)	< 5				20
Manganese	µg/L	50	9	4.5	18	5	12
Mercury	µg/L	2 (0.12)	< 0.01				20
Molybdenum	µg/L		122	22.6	152	76	20
Nickel	µg/L	(168)	< 5				20
Selenium	µg/L	50 (5)	5.3	0.5	6	5	4
Silver	µg/L	100 (0.07)	< 5				20
Thallium	µg/L	2 (6.3)	< 5				20
Vanadium	µg/L		< 5				20
Zinc	µg/L	500 (383)	< 20				20

Note: All samples collected from the cascade aerator (outfall at top) during the performance test recovery phase. Turbidity in all samples was less than 107 NTU. Concentrations reported as "less than" are below the method detection limit. N, number of samples. ORP, oxidation-reduction potential. Units: mg/L, milligram per liter; µg/L, microgram per liter; pCi/L, picocuries per liter. Primary and secondary drinking water criteria are from State of Florida F.A.C. 62-302.550 and the Federal SDWA. Criteria in parentheses are hardness-corrected criteria from the Federal CWA.

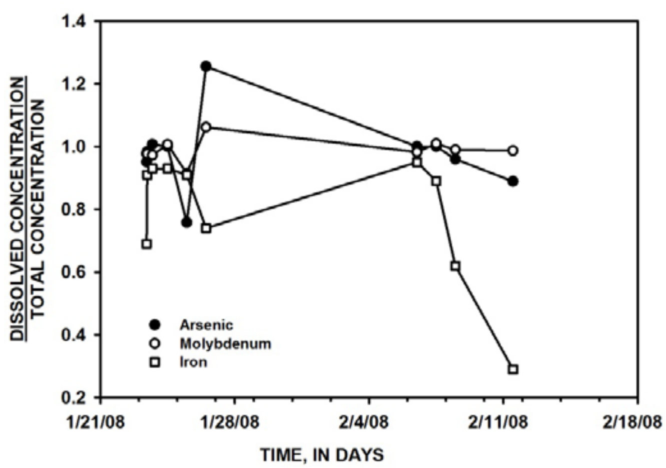


Figure 10-16 -- Metals concentrations in the ratio of dissolved to total sample in recovered groundwater during performance testing prior to cycle test 1.

The following conclusions can be drawn from the KRASR "first flush" data sets. During the initial recovery phase, turbid groundwater is diverted to on-site storage until the turbidity is less than 29 NTU. Subsequent discharge of recovered water must then meet surface water quality criteria. Metals concentrations invariably are highest during the initial reactions of recharge water with rock in the aquifer, and that condition is observed at KRASR. Of all metals analyzed, those that are most likely to appear in the earliest phases of recovered water are arsenic, barium, molybdenum, and iron. Other transition metals (antimony, beryllium, cadmium, chromium, cobalt, copper, lead, mercury, nickel, selenium, silver, thallium, vanadium and zinc) usually were not detected in any water sample. Lead was detected in a single TCLP extract.

Arsenic occurs in primarily as a dissolved constituent, at concentrations greater than the 10 μg/L drinking water criterion, and sometimes above the 50 μg/L surface water criterion. Molybdenum also occurs as a dissolved constituent at concentrations significantly greater than that of the native FAS (28 +/- 31 μg/L), indicating that this metal also is mobilized. At present there is no drinking water or surface water regulatory criterion for molybdenum. Initially, iron concentrations are similar to that of the native FAS (68+/-69 μg/L). As recovery progresses, iron concentrations and the proportion of iron in the dissolved phase decrease. Decreased iron can result from mixing with iron-poor native FAS water, or reactions that precipitate iron during cycle testing.

10.9.2 "First Flush" Data from HASR

The "first flush" of recovered water from HASR cycle testing is characterized by a single turbid sample (881 NTU) collected on the first day of the cycle test 1 recovery phase. This sample was not filtered, so data represent a bulk "water plus particulate" analysis. Of these metals, concentrations of the following exceeded drinking water and surface water quality criteria: iron, 2.42 mg/L; arsenic, 111 μg/L; beryllium, 0.23 μg/L; copper, 100 μg/L; and silver, 0.079 μg/L **(Table 10-39)**.

Table 10-39 -- Major and Trace Inorganic Constituents in an Unfiltered Recovered water at HASR

Analyte	Unit	Value	FDEP Class III Surface Water Standard
Aluminum	μg/L	1170	
Antimony	μg/L	0.68	≤ 4,300 μg/L
Arsenic	μg/L	**111**	**≤ 50 μg/L**
Barium	μg/L	1020	
Beryllium	μg/L	**0.23**	**≤ 0.13 μg/L**
Cadmium	μg/L	2.8	≤ 0.76 μg/L
Calcium	mg/L	288	
Chromium	μg/L	22.6	≤ 0.01 mg/L
Cobalt	μg/L	1.3	
Copper	μg/L	**100**	**≤ 30.50 μg/L**
Cyanide	μg/L	< 5.0	5.2 μg/L
Iron	μg/L	**2420**	**≤ 1.0 mg/L**
Lead	μg/L	2.4	≤ 18.58 μg/L
Magnesium	μg/L	16000	
Manganese	μg/L	36.6	
Mercury	μg/L	0.0106	0.012 μg/L
Nickel	μg/L	13.5	≤ 168.54 μg/L
Potassium	μg/L	6080	
Selenium	μg/L	2.0	≤ 5.0 μg/L
Silver	μg/L	**0.079**	**≤ 0.07 μg/L**
Sodium	μg/L	57200	
Thallium	μg/L	< 0.50	< 6.3 μg/L
Vanadium	μg/L	39.7	
Zinc	μg/L	39.3	≤ 387.83 μg/L

10.10 Summary and Preliminary Conclusions

An extensive ecotoxicological and ecological data collection effort was completed at KRASR to evaluate site-specific effects of recovered water quality on representative aquatic organisms. This effort exceeded those tests that are required for NPDES and CERPRA permits. In this document, the results of these tests are presented, with some preliminary interpretations. A more intensive evaluation of the effects of recovered water on surface water ecology and aquatic organisms will be presented in the ASR Regional Study technical data report, currently in preparation.

Ecotoxicological tests were performed during cycle test 1 recharge, using source water from the Kissimmee River adjacent to the ASR system. These results characterize organism responses to exposure with recharge water. The following tests showed no statistically significant difference in test results when surface (recharge) water and controls are compared. The NOEC of each test is 100 percent recharge water.

- 7-Day *Ceriodaphnia dubia* (water flea) static renewal chronic toxicity test
- 7-Day *Pimephales promelas* (fathead minnow) embryo-larval static renewal chronic toxicity test
- 21-Day *Daphnia magna* (water flea) life cycle toxicity test
- Frog embryo Teratogenesis – *Xenopus* test

One of the two 96-hour algal tests conducted using *Selenastrum capricornutum* showed a response to the recharge water with an estimated 96-hour NOEC of 25 percent recharge water (reduced reproduction). The other algal test had a NOEC of 100 percent recharge water.

Identical ecotoxicological tests were performed using recovered water during cycle tests 1 and 2. The majority of the tests showed no statistically significant difference in test results when recovered water and controls are compared. The NOEC of each test is 100 percent recovered water, with the exception of *C. dubia (*discussed below).

- 96-hour chronic growth test with *S. capricornutum* (green algae)
- 7-Day *C. dubia* (water flea) static renewal chronic toxicity test
- 7-Day *P.s promelas* (fathead minnow) embryo-larval static renewal chronic toxicity test
- 21-Day *D. magna* (water flea) life cycle toxicity test
- Frog embryo Teratogenesis – *Xenopus* test

One of the *C. dubia* tests showed a minimal effect reproduction (IC_{25} of 95.52 percent recovered water during cycle 1. During cycle test 2, two tests (the second and third) showed an effect on reproduction (NOEC of 50 percent recovered water); with an IC_{25} of 76.41 percent recovered water for the third test.

Bioconcentration studies were performed and during cycle test 1 recharge and recovery, using *Lepomis machrochirus* (bluegill fish) and *Elliptio buckleyi* (Florida shiny spike mussel), using an onsite flow-through mobile bioconcentration laboratory. The primary study objective is to evaluate changing metals concentrations in fish and mussel tissue prior to and after a 28-day exposure to 1) recharge water and 2) recovered water. Radionuclides (radium-226 and radium-228) also were evaluated in mussels. Considering the recharge water experiments, comparison of fish tissues before and after exposure to recharge water shows that arsenic, chromium, mercury, and molybdenum are statistically greater at the end of the experiment.

Bioconcentration studies performed during cycle test 1 recovery were more complex, using three water types: 100 percent surface water, a 50-50 percent mix of surface water and recovered water, and 100 percent recovered water. Bioconcentration studies were performed in-situ during cycle test 2 recovery by exposing caged freshwater mussels (*E. buckleyi*) at sites located upstream and downstream in the Kissimmee River, and at the POD. These large datasets will be evaluated more fully in the ASR Regional technical data report.

Periphyton studies were conducted during cycle test 1 recharge and recovery, and cycle test 2 recovery at upstream, POD, and downstream stations. Samples obtained during cycle test 1 recharge and recovery were identified by taxa, and evaluated for diversity and evenness indices, and growth (as density and ash-free dry weight). The cycle test 1 periphyton study was constrained by disruption of several stations during the 28-day recovery test period, which precludes detailed statistical analysis. Samples obtained during cycle test 2 recovery from upstream, POD and downstream stations show no statistically significant difference in diversity, density or ash-free dry weights. Despite the lack of statistical significance of these results, these datasets provide useful taxonomic characterization of the Kissimmee River before and during the recovery phase.

A qualitative fish fry entrainment study was inconclusive due to difficulty sampling the intake stream. Few larval fish but abundant zooplankton appeared in the few samples that were obtained through the intake screen into the wet well during recharge. More entrainment is likely during nighttime. A better sampling method is necessary to quantify fish fry entrainment.

Discharge of recovered water into the Kissimmee River can affect stream fisheries due to contrasting specific conductance, dissolved gas concentrations, and temperature. The contribution of recovered water is approximately 2 percent of total flow in the river. The dimension of the recovered water plume is estimated at 744 m^2, so effects of recovered water discharge are estimated to occur within 15-m of the POD. Recovered water is usually more oxygenated than river water, particularly during the summer. The recovered water plume of could attract fish, and serve as a refugium. The recovered water plume has a limited area of occurrence during recovery. Impacts to local fisheries resources are expected to be minimal in the Kissimmee River adjacent to the KRASR POD.

The temperature contrast between recovered water and the Kissimmee River are greatest during the winter. The mean recovered water temperature is 25.7 +/- 0.5 °C, and mean river temperature varies between 17.6°C (January) and 30.0 °C (August). The recovered water plume could attract fish and manatees, and serve as a refugium on the basis of temperature and dissolved oxygen. Warmer recovered water during winter could affect spawning activity of black crappie and largemouth bass, particularly close to the POD. More data are needed to evaluate the effects of recovered water on fish spawning activity. Expanded discharge of ASR recovered water in this area will require USFWS and NOAA coordination so that manatee activity can be evaluated.

The dissolved gas composition of recovered water differs from that in the Kissimmee River. Recovered water has greater dissolved oxygen, dissolved sulfide, and total dissolved ammonia concentrations. The presence of dissolved oxygen and dissolved sulfide is a disequilibrated condition, because oxygen will oxidize hydrogen sulfide over time. However, dissolved sulfide concentrations exceed the EPA guideline at the POD during recovery. Concentrations of un-ionized ammonia (the toxic species of the total ammonia analysis) are always below the surface water criterion (0.02 mg/L). Elevated concentrations of dissolved sulfide and ammonia may require re-evaluation of the cascade aerator design to enhance sulfide oxidation for the protection of aquatic species.

11. ASR System Costs of Operation

The KRASR and HASR systems were planned, designed, and operated to achieve and test different operational strategies. The KRASR system design was more complex, and required more operational oversight. In the initial plan, the KRASR system served as a “central SCADA center” to receive data from several ASR systems. Thus, higher costs encountered at KRASR would benefit from economy of scale because all data acquisition would be directed to a single system. In addition, operational testing was more extensive in the number of cycles, number of wells, and frequency of surface and groundwater sampling. This effort resulted in the compilation of large hydrologic and water-quality datasets that exceeded permit requirements. Products of the KRASR cycle testing program have reduced uncertainty of large-capacity well ASR system operation in Florida. However, operational costs for the KRASR system are significantly higher than typical ASR operations, and this aspect should be considered during planning or assessing the feasibility for future facilities.

In comparison, he HASR system was designed to be operated remotely, without significant operational oversight. The cycle testing program was implemented to evaluate system operation and regulatory compliance at an ASR system that could be located in remote areas where frequent O&M is not feasible. Construction costs are presented for HASR. Operational costs have not been determined for the operation of this facility.

KRASR operational costs include operation and close-out plans preparation, cycle test operations (including power), labor, maintenance, and management support. Costs associated with regulatory reporting (for example, compilation of monthly operating reports for UIC and NPDES permit compliance) are not included here because these activities were performed by the USACE or SFWMD (at HASR). Costs for water-quality monitoring are separated from operations, and are quantified separately in **Section 11.3**. Costs from value engineering for system optimization and those not associated with standard plant operations are quantified separately in **Section 11**.

11.1 Kissimmee River ASR System Operational Costs

The operational cost information presented here is subdivided into three phases of operation: recharge, storage, and recovery. Cost estimates were developed using data obtained during cycle tests 2, 3, and 4. Cycle test 1 costs were not included due to concurrent on-site system optimization tasks that were beyond normal cycle testing operation and this short cycle is not truly representative of ASR system operations. Detailed cost breakdowns are tabulated in **Appendix G**.

The monthly (30-day) average cost for each cycle test phase (recharge, storage and recovery) is shown in **Figure 11-1**. The main cost categories reported for each cycle test phase are:

- Labor cost of plant operation
- Energy cost and requirement for plant operation and maintenance
- Parts, supplies and services required for system maintenance

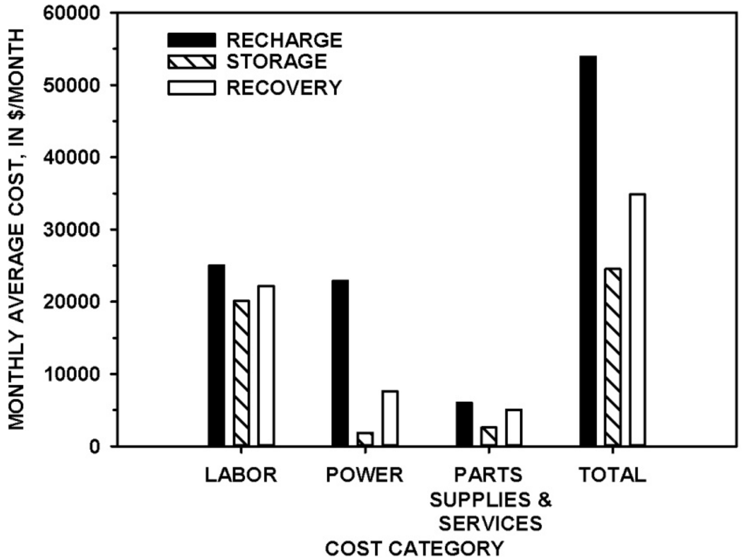


Figure 11-1 -- Monthly average costs by category for each cycle test phase.

Total monthly average costs shown graphically in **Figure 11-1** are normalized per unit of stored volume in **Table 11-1.** An important metric of plant operational cost and efficiency is the cost normalized by the volume stored for a specific phase. This metric is only relevant to recharge and recovery phases since no water is stored or released during the storage phase. These metrics are summarized in **Table 11-1**. A significant portion of these costs are based on operational labor requirements that vary less per phase than might be anticipated. This is due to maintenance and optimization activities performed during the storage phase when major mechanical units are offline. Operational labor is described and itemized in **section 11.1.1**.

Table 11-1 -- Total Monthly Average Cost Per Unit of Stored Volume, for Each Cycle Test Phase at KRASR

Phase	Cost ($/month)	Volume (MG/month)	Cost ($/volume)
Recharge	$ 50,000	125	$401 /MG or $148/acre-ft
Storage	$ 24,250	-	-
Recovery	$ 37,750	146	$256/MG or $79 /acre-ft

11.1.1 Operational Labor Costs

The KRASR system was intended to evaluate ASR feasibility above and beyond regulatory requirements, so cycle testing executed a more extensive data acquisition program than was required by permits. Given the experimental nature of the KRASR system, both on- and off-site labor is warranted to ensure consistent operation and data acquisition. The labor costs vary as they are dependent on the cycle test phase. Labor cost for each phase includes costs for project management, on-site operation, and engineering support costs.

Average monthly labor costs for each cycle test phase are presented in **Table 11-2**. Decreasing labor costs over the 3-year duration of cycle testing is attributed to increased productivity from continued operation and maintenance procedural optimization. Average monthly labor costs for cycle test 4 are not available for this report. The estimated cost for operational labor is approximately $24,700, $20,000, and $22,200 per month respectively, during recharge, storage, and recovery.

Table 11-2 -- Operational Labor Cost Summary

Cycle Test Phase	Average Monthly Labor Cost ($/month)			Average All Cycle Tests ($/month)
	Cycle Test 2	Cycle Test 3	Cycle Test 4	
Recharge Phase	31,800	28,100	18,200	**24,700**
Storage Phase	32,400	18,100	17,100	**20,000**
Recovery Phase	21,300	22,600	NA	**22,200**
Total Cycle Test Cost	**85,500**	**68,800**	**(35,300)**[1]	

[1] Cycle test 4 recovery incomplete when cost estimates were defined.

11.1.1.1 Recharge

The recharge phase at the KRASR system requires simultaneous operation of most system components, and requires a greater labor effort to operate, maintain, and monitor pumps, filters, and the UV disinfection system. Average monthly labor costs for the recharge phase of cycle tests 2 through 4 are tabulated in **Table 11-3.** The level of labor effort during recharge for cycle tests 2 through 4 are discussed in the following text.

Management: Overall management of the KRASR system requires staffing of a part-time Project Manager. Typical management duties at the KRASR system include but are not limited to the following:

- Management of operational budgets and schedules
- Oversight of plant operations and maintenance activities
- Cost management
- Performing quality control and assurance tasks
- Issuing and supervising quotes, purchase orders, and associated documentation.

On-site operation: The KRASR system was staffed by a full-time certified, Class A Operator for weekday operations. This staffing decision was made prior to cycle testing to ensure consistent operations at an experimental ASR system. Subsequent upgrades to the SCADA facility enabled greater remote control of the ASR system after cycle test 2. Consequently, future operations will not require full-time staff at this facility. The duties of the Operator include:

- Monitor daily operations
- Non-regulatory water quality testing to evaluate UV disinfection system performance
- Completing routine and scheduled maintenance.
- Preparing daily, weekly, monthly and annual inspection reports.

Engineering: Technical or engineering support services include tasks such as collection and analysis of water quality and operational data, evaluating influent and effluent water quality conditions, and process optimization. Specific examples of engineering tasks include:

- Verifying pump vibration testing procedures and results
- Assembling and organizing the operations data from the SCADA system.
- Review of water quality results to evaluate effects on the treatment components

Support services: Specific operations and maintenance tasks performed during recharge require support from various sub-contractors. Support duties during recharge include, but are not limited to:

- Monitoring tasks to assist with permit compliance.
- Administrative tasks and record keeping.
- Support for maintenance activities such exterior light replacement and grounds-keeping

Table 11-3 -- Average Monthly Labor Cost Breakdown for the Recharge Phase

Labor Cost Component	Cycle Test 2	Cycle Test 3	Cycle Test 4	Average
Length of Recharge Phase (days)	109	173	207	163
Monthly management cost	$8,700	$9,200	$3,700	$6,700
Monthly on-site operation cost	$17,700	$12,200	$11,300	$13,000
Monthly engineering cost	$4,700	$5,300	$1,900	$3,800
Monthly support cost ($)	$700	$1,400	$1,200	$1,200

11.1.1.2 Storage

The storage phase at the KRASR system includes repair and maintenance activities when most major components of the system are shut-down. The level of effort declines during the storage phase. Average monthly labor costs for the storage phase of cycle tests 2 through 4 are tabulated in **Table 11-4.** The level of labor effort during storage for cycle tests 2 through 4 are discussed below:

Management: Overall operational management of the KRASR system requires staffing of a part-time Project Manager. Typical management duties are similar to those required during the recharge phase but focus on acquisition and coordination of maintenance and repair activities.

On-site operation: The KRASR system was staffed by a full-time certified, Class A Operator on-site to oversee weekday operations. With most major equipment shutdown during the storage phase, the duties of the Operator focus specifically on maintenance to ensure plant operation for future phases. These duties include routine daily functions such as completing routine and scheduled maintenance, (particularly on the filter and UV disinfection system components), and preparing daily, weekly, monthly and annual inspection reports.

Engineering: Technical or engineering support services include tasks such as compiling operational data, and supporting on-site repair and maintenance activities. Tasks performed at the KRASR system during storage result from maintenance and repair needs, and typically include repairs and replacement of UV disinfection system components, and oversight during ASR well rehabilitation.

Support services: Some operations and maintenance tasks during storage require support from different trades. Support staff duties during storage are similar to those listed for the recharge phase.

Table 11-4 -- Average Monthly Labor Cost Breakdown for the Storage Phase

Labor Cost Component	Cycle 2	Cycle 3	Cycle 4	Average
Length of cycle (days)	60	173	333	189
Monthly management cost by cycle ($)	7,000	4,300	2,400	4,570
Monthly on-site operation cost by cycle ($)	19,000	10,300	11,300	13,533
Monthly engineering cost by cycle ($)	5,100	2,400	2,200	2,800
Monthly support cost of cycle ($)	1,400	1,200	1,100	1,200

11.1.1.3 Recovery

The recovery phase of the KRASR system primarily focuses on the operation of the KRASR well and processes related to distribution and discharge of recovered water. Water is recovered from the ASR well and discharged directly to the cascade aerator without any additional treatment. Average monthly labor costs for the recovery phase of cycle tests 2 and 3 (cycle test 4 recovery was in progress at the time of writing) are tabulated in **Table 11-5.** The level of labor effort during recovery for cycle tests 2 and 3 are discussed below:

Management: Overall operational management of the KRASR system requires staffing of a part-time Project Manager. Typical management duties at the KRASR system during the recovery phase are similar to those required during the recharge phase with the focus on ASR well discharge operations instead of intake operations.

On-site operation: The KRASR requires staffing of a full-time certified, Class A Operator on-site to facilitate day to day operations. During recovery the duties of the Operator focus on well operation, and are similar to those duties listed for the recharge phase.

Engineering: Technical or engineering support services include tasks such as compilation of water quality and operational data,

Support services: Specific and/or unique operations and maintenance tasks during recovery require support from various outlets depending on trade. Support staff duties during the recovery phase are similar to those of the recharge phase.

Table 11-5 -- Average Monthly Labor Cost Breakdown for the Recovery Phase			
Labor Cost Component	**Cycle 2**	**Cycle 3**	**Average**
Length of cycle (days)	67	165	116
Monthly management cost of cycle ($)	4,200	4,600	4,400
Monthly on-site operation cost of cycle ($)	12,500	13,300	13,000
Monthly engineering cost of cycle ($)	2,600	3,600	3,300
Monthly support cost of cycle ($)	2,100	1,200	1,400

11.1.2 Electrical Energy Demand and Costs

During operation of the KRASR facility, many services are implemented to ensure proper system function. Since each phase of a cycle test has substantially different energy profiles and services required, costs are broken down by phase. Electrical costs for each phase of cycle tests 2 through 4 are tabulated in **Table 11-6**.

Energy costs for industrial facilities are billed on two measurements of energy usage: energy demand and energy consumption. Energy demand is the rate at which power is used (in kilowatts, kW) while consumption is the rate of demand over a period of time (kilowatt-hours, kWh). Florida Power & Light Utility has different tiers of electricity cost on various schedules dependent on electricity usage. The KRASR facility is classified under schedule GSD-1. Schedule GSD-1 consists of fuel and non-fuel charges for total kWh used, a cost per kW for the peak demand used during the month, and a monthly customer charge.

Table 11-6 -- Electrical Energy Cost Summary For Each Phase in a Cycle Test				
Phase	**Electrical Service Cost**			
	Cycle 2	**Cycle 3**	**Cycle 4**	**Average**
Average Recharge Services Cost ($/month)	19,500	20,600	18,000	19,300
Average Storage Services Cost ($/month)	6,700	1,300	500 (partial)	1,850
Average Recovery Services Cost ($/month)	7,200	7,800	Not Available	7,600

11.1.2.1 Recharge

The recharge phase has the highest electricity demand as all pre-treatment components of the KRASR surface facility are operational, along with the recharge pump. Electricity costs are approximately 35 percent of total costs of the recharge phase **(Table 11-6).** Energy costs vary depending on rates from utilities, variable heating and air conditioning usage, and demand requirements from all applicable equipment. **Section 12.1** details potential energy savings that have been found through value engineering.

Pumps and Associated Equipment: Based on a review of pump efficiency data (R2T, Inc., 2011) a plant operating at 5 MGD having this size and piping configuration should use approximately 30 percent of its total energy consumption during the recharge phase. The average energy cost to operate the pumps and associated equipment during the recharge phase is approximately $5,600/month.

UV Disinfection: The UV system disinfects the source water prior to recharge in the aquifer. Engineering estimates and operational testing were used to estimate the energy required for the UV disinfection system. The UV disinfection system accounts for approximately 65 percent of the total energy used during the recharge cycle. The average energy cost to operate the UV disinfection system is approximately $12,200/month.

Control and Electrical Facilities: As stated earlier, any shutdown or interruption of service decreases energy consumption for a given phase or period. These events cause data to appear to increase efficiency if total water intake for the given cycle is disregarded. Additionally, because the electrical systems need to remain cool, especially during operation of the UV system, air conditioning costs are variable depending on the season in which the cycle test occurs. The energy costs associated with control and electrical facilities, as well as any associated equipment with these systems (HVAC, SCADA, etc.), account for approximately 5 percent of the total energy usage for the recharge phase. The average energy cost to operate the control and electrical facilities is approximately $1,000/month.

11.1.2.2 Storage

The average electric energy demand for the storage phase of ASR operations is presented in **Table 11-6**. The estimated energy cost during the storage phase is approximately $2,000/month.

Control and Electrical Facilities: The control and electrical buildings comprise nearly all energy demand during storage. Therefore costs vary with the season, due to heating and air conditioning costs. Additional sources of energy demand during this phase include maintenance and service operations, testing of equipment, security system operations, and lighting.

11.1.2.3 Recovery

The ASR system component with the greatest energy demand during recovery is the ASR recovery pump. The decant pumps do not operate except at the initial startup of the ASR system, to divert a small volume of turbid water. The average energy cost during the recovery phase is approximately $7,600/month **(Table 11-6)**.

Pumps and Associated Equipment: From engineering estimates, the monthly energy demand to continuously pump water from the aquifer to the cascade aeration system is roughly 75,000 kWh, which accounts for approximately 90 percent of the energy demand during recovery. The average energy cost to operate the ASR recovery pump and associated equipment during the recovery phase is approximately $7,000/month.

Control and Electrical Facilities: Since no UV system disinfection is required, the power consumption for the control and electrical facilities is substantially less during the recovery phase compared to the recharge phase. System components that operate during the recovery phase include: heating and air conditioning, maintenance and service operations, testing of equipment, security system operations, lighting, and other related operations. The control and electrical facilities account for 5 to 10 percent of the energy demand during the recovery phase. The average energy cost to operate the control and electrical facilities during the recovery phase is approximately $500/month.

11.1.3 System Maintenance, Services, and Miscellaneous Operations Costs

The KRASR system requires varying amounts of preventative and scheduled maintenance that are phase-dependent. Most of the preventative and scheduled maintenance costs incurred are related to operation of major system components. Average monthly costs below are actual costs incurred during ASR operation for cycle tests 2 through 4 normalized by the length of cycle during which they were incurred. Final average monthly costs are composites of all phases weighted by length of the phase.

11.1.3.1 Major Equipment Maintenance

The KRASR system relies on major infrastructure components for filtration, disinfection, and water management. Monthly maintenance costs for major system components are tabulated in **Table 11-7**. Several maintenance activities are conducted for each system to ensure proper function and are detailed below.

Recharge Pump: The main preventative maintenance task required for the recharge pump is vibration monitoring. The machine vibration readings are compared to past levels, using significant change as an indicator of developing machinery faults. The objective of this monitoring is to provide lead-time for maintenance planning. Vibration monitoring is performed every month during pump operation for both the recharge and recovery phases. Cost is identical for service during recharge and recovery. While this measure does incur additional maintenance costs, the alternative cost to perform repairs mid-phase with lost pumping time make vibration monitoring an overall cost-saving measure for system operation. A 3rd party company performed vibration monitoring on the recharge pump at the KRASR system. The rate for these services was approximately $730/month. This rate has increased a total of 9 percent over the last 32 months from an initial rate of $670/month. Additional maintenance services such as part replacement and service calls increase the average recharge pump maintenance cost during the recharge phase to approximately $1,000/month.

Table 11-7 -- Major Equipment Maintenance Costs

Component	Recharge ($/month)	Storage ($/month)	Recovery ($/month)
Recharge Pump	925	0	0
UV Disinfection System	2,100	0	0
Recovery Pump	NA	0	850
Electrical Gear	320	320	320
SCADA	570	220	1,880
Process Piping & System Disinfection	160	0	0
Total	4,075	540	3,050

UV Disinfection System: Maintenance on the UV disinfection system was provided at KRASR through a service agreement with the UV system manufacturer. From 2010 through 2013, UV maintenance costs have averaged $2,200 per month during recharge. This maintenance is typically either for scheduled part replacements during recharge or for maintenance in preparation for a future recharge phase. Major component replacements for the UV system include lamp replacement, wiper assembly, and quartz sleeve replacement. Example costs for UV system maintenance are listed in **Table 11-8**.

Table 11-8 -- Example Major Maintenance Costs for the UV Disinfection System

Date	Cycle	Description of Service	Cost ($)
5/23/2011	3	36 replacement UV bulbs replaced as needed	18,000
7/11/2011	4	2 Temperature Sensors 1 UV Sensor	2,600
10/28/2011	4	2 Motor Wiper for 5 UV Lamps	3,100

ASR Recovery Pump: The main preventative maintenance task required for the ASR recovery pump was vibration monitoring, which is performed for the same purposes as defined for the recharge pump. The average cost of maintenance required for the ASR pump during the recovery phase is approximately $900/month.

SCADA and IT Support: Maintaining a properly working SCADA system is essential for fully functional ASR operation and data acquisition. Maintenance and repairs on the SCADA system during cycle testing were performed by Rocha Controls (Tampa, FL). Monthly average SCADA maintenance costs during recharge, storage, and recovery phases were $570, $220, and $1880 respectively.

Electrical Gear: Maintenance on the electrical switchgear, which is used to control, protect, and isolate the electrical equipment as part of the electric power system, has been provided through several 3rd party vendors. The average maintenance cost for critical electrical gear during cycle tests 1 through 4 is approximately $400/month.

System Disinfection: Routine system disinfection (beyond the UV disinfection system) is required during the recharge phase to prevent biofouling of the piping and other pump-related equipment. The disinfection is performed by backwashing the system with calcium hypochlorite, which kills any microflora and bacteria that are growing inside the equipment. The sodium hypochlorite is sourced by a 3rd party at a cost of $160/month.

11.1.3.2 Additional Services Required for ASR System Operation

Services that are not unique to the operation of the ASR system but are required for overall site and plant operations are summarized in **Table 11-9** and the subsequent sections.

Table 11-9 -- Average Monthly Cost for General Maintenance and Operations			
Task	**Recharge ($/month)**	**Storage ($/month)**	**Recovery ($/month)**
Well Rehabilitation	*see well cleaning section below*		
Sludge Removal & Disposal	*see sludge removal and disposal section below*		
HVAC	20	20	20
Materials, Small Tools & Supplies	150	150	150
Data Services	375	375	375
Total	**515**	**515**	**515**

ASR Well Rehabilitation: ASR well rehabilitation was performed twice, during cycle test 2 storage and between cycle tests 2 and 3, by a 3rd party contractor (Entrix, 2009; Cardno Entrix, 2011). Well rehabilitation was required in response to increasing wellhead pressure that probably resulted from biofilm growth in the ASR well. This assessment was confirmed when significant algal and biofilm growth was observed during inspection of the recharge pipeline and UV system, located within 10 ft of the ASR wellhead. ASR well rehabilitation is performed with introduction of a weak acid into the well through an existing port in the recharge line. Flow rates during acid introduction range from approximately 300 to 600 GPM, which is significantly lower than the typical operating flow rate. The weak acid solution is pumped for a few days to dissolve organics and calcium carbonate in the well bore, thus improving permeability and well capacity. This process is performed to ensure that no acidic water is released into the surrounding area. No production of hazardous waste occurred during this procedure. The cost for the KRASR well cleaning is summarized in **Table 11-10**.

Table 11-10 -- ASR Well Rehabilitation Cost Per Event	
Well Rehabilitation Phase	**Average Anticipated Cost**
Mobilization and Pilot Scale Testing	$ 6,000.00
Draw-Down and Rehabilitation	$ 35,000.00
Reporting	$ 10,000.00
Total Well Rehabilitation	**$ 51,000.00**

Sludge Removal and Disposal: Pressure filter effluent is discharged periodically into the solids management and backwash equalization ponds for optimum operation, because small volume of effluent could have turbidity values that exceed regulatory compliance levels (29 NTU). Pond maintenance tasks include sludge removal, solids testing, and disposal in the Okeechobee Landfill operated by Waste Management which is a permitted, Subtitle D non-hazardous waste facility. Sludge removal and disposal were performed twice during cycle tests 1 through 4. The costs for each disposal are summarized in **Table 11-11**.

Site-specific experience at KRASR indicates that roughly 6 months of recharge produces moderate amounts of sludge. Each site will need to have a unique sludge removal and disposal schedule depending on the rate at which it is generated.

Table 11-11 -- Sludge Removal and Disposal Costs		
Task	**Removal (Lump Sum $)**	**Disposal (Lump Sum $)**
First Sludge Removal & Disposal	4,400	3,700
Second Sludge Removal & Disposal	7,600	3,400

Operations Building: No significant maintenance was required on the operations building during this project. Standard building maintenance tasks will be required to ensure system stability during long term system operation. These tasks include exterior cleaning and painting, among others.

HVAC: The average cost for HVAC maintenance is approximately $25/month. The expected costs for future HVAC maintenance is not expected to vary during a cycle test. This system is not expensive to maintain but is critical for all electrical equipment operations. HVAC maintenance at the KRASR facility was offered through a 3rd party vendor.

Materials, Small Tools, and Supplies: Operation of the KRASR system requires frequent maintenance, cleaning, and general site up-keep. Performance of these tasks requires several direct expenses such as small tools, consumables, and other general supplies. The average cost of miscellaneous materials is approximately $150/month. Historically, these costs have ranged between $50/month to $600/month during cycle testing depending on equipment needs.

Data Services: Average cost for data and cellular services for site operations can be expected to range within $320 to $375 per month depending on current utility rates at a given location. At KRASR, rates increased approximately 15 to 20 percent during cycle tests 1 through 4.

11.1.3.3 Additional General Service Costs

Miscellaneous operational costs are those costs required for general system operation, but do not directly impact the KRASR operations. These costs are summarized in **Table 11-12**.

Table 11-12 -- Estimated Average Monthly General Service Costs Per Phase			
Line Item	**Recharge ($/month)**	**Storage ($/month)**	**Recovery ($/month)**
Shipping and Postage	60	60	60
Travel and Vehicle	800	800	800
Site and Facility Security	30	30	30
Septic System Disposal	100	100	100
Mowing	350	350	350
Total	**1,350**	**1,350**	**1,350**

Shipping and Postage: The average monthly cost for shipping and postage is $60.

Travel and Vehicle: Average mileage and vehicle costs depend on the frequency of mobilization required of the operators and include site inspection, site maintenance, and retrieval of equipment. The average total monthly cost for both mileage and vehicle rental is $800/month.

Site and Facility Security: Currently, the KRASR facility has a semi-annual security agreement with a local 3rd party alarm company. Current average costs are approximately $30/month. Over the past 3 cycles of testing, the aggregate increase in security costs has been less than $1/month.

Septic System Disposal: During operations, the septic tank requires periodic cleaning. At current labor levels, emptying of the septic system is required about 4 times per year at a cost of $1,100/year. This cost is dependent on the amount of staff as more staff requires more frequent removal.

Mowing: The cost for the lawn mowing service is $350/month. This rate has remained constant during cycle tests 1 through 4.

11.2 Hillsboro ASR System Cost

The operational cost information presented in this section for the HASR site is categorized by recharge, storage, and recovery. Operational costs were developed utilizing average historical cost information, which includes data collection, regulatory compliance, cycle test operations, equipment maintenance and facility support. Overall, the HASR system design utilizes a more consolidated and simplified approach to ASR than that of KRASR, resulting in lower overall costs **(Figure 11-2** and **Table 11-13)**. Use of two in-line disinfection chambers at HASR (instead of three at KRASR) also reduces power consumption. The estimated operational expenses for this site are based on 1) two operational cycle tests (cycle test 1 and cycle test 2) where applicable cost data was collected and made available; and 2) additional anticipated costs estimated for the operation and maintenance of an ASR facility.

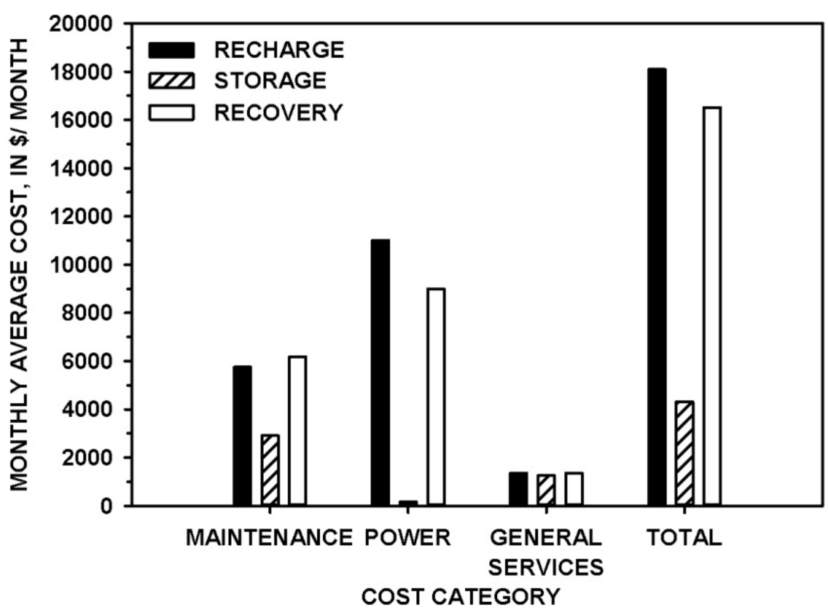


Figure 11-2 -- Monthly average costs by category for each cycle test phase.

Table 11-13 -- Total Monthly Average Cost Per Unit of Stored Volume For Each Cycle Test Phase			
Phase	**Cost ($/month)**	**Volume (MG/month)**	**Cost ($/volume)**
Recharge	$16,050	110	$145/MG or $47/acre-ft
Storage	$ 3,350	-	-
Recovery	$17,250	145	$119/MG or $38/acre-ft

11.2.1 Operational Labor Costs

The HASR facility was designed for mostly unattended operation, unlike the KRASR facility. Operational controls on the ASR system would be monitored remotely through the SFWMD SCADA system. An operator would visit the site periodically during recharge and recovery phases to ensure that the system was operating consistently, and to perform any required maintenance. Regulatory reporting requirements (such as completing monthly operating reports) would be performed by SFWMD personnel. As such, operating costs are significantly lower at HASR compared to KRASR, but it should be recognized that the testing objectives differed between these two systems. Because this ASR system was largely unattended during cycle testing, no labor cost estimates are provided because operations and maintenance were conducted mostly by SFWMD personnel.

11.2.2 Electrical Energy Demand and Costs

For effective ASR plant operation, there are various energy demands placed on the facility by any operational equipment. Additionally, since each phase of each cycle has substantially different energy profiles and power requirements, each phase must be examined individually to adequately estimate operational costs incurred.

Energy costs for large scale facilities are billed on two measurements of energy usage – energy demand and energy consumption. Energy demand is the peak rate at which power is used (kW) while consumption is the rate of demand over a period of time (kWh). Florida Power and Light has different tiers of electricity cost on various schedules dependent on electricity usage. The HASR facility is classified under schedule GSD-1. Schedule GSD-1 consists of fuel and non-fuel charges based on total kWh, a cost per kW for the peak demand used during the month, and a monthly customer charge. Based on the kWh used per day and the peak demand recorded during the billing cycle (monthly), the cost of electricity was calculated for each phase during cycle test 3 as described below.

11.2.2.1 Recharge

The recharge phase has the highest electricity use due to operation of components with high energy demands. The main components that operate during recharge include the recharge pump, Amiad filtration system, UV disinfection system, and control and electrical facilities. In addition to the energy demands of these components, other power-related costs during recharge include the repair, calibration and preventative maintenance activities for the electrical system, HVAC, pumps, air scour system, UV units, filtration system, and the SCADA control system. The significant differences between the KRASR and HASR site layout and implementation yield substantially different energy profiles. Based on daily electric meter readings the cost for energy use was calculated for the recharge phase of cycle tests 1 and 2. The cost per month (30 days) was then calculated and averaged as shown in **Table 11-14**.

Table 11-14 -- Electrical Energy Cost Summary For Recharge Phase, Cycle Tests 1 and 2

	Cycle Test 1	Cycle Test 2	Average
Recharge Phase Duration (days)	31	92	
Energy Cost Per Cycle ($)	$9,162	$26,859	
Energy Cost Per Month ($/30 days)	$8,866	$8,758	$8,812

UV Disinfection System: The UV disinfection system inactivates microbes in source water prior to aquifer recharge. The HASR site has two UV disinfection units, in-series. Electrical energy usage was estimated based on system technical data. Based on the configuration of the units and operating parameters, the two in-line units use approximately 2,100 kWh per day. **Table 11-15** illustrates that the UV system accounts for approximately 41 percent of the energy used during the recharge phase. The estimated energy cost to operate the UV disinfection system during the recharge phase is approximately $3,700/month.

Table 11-15 -- Electrical Energy Required for the UV System During the Recharge Phase, Cycle Tests 1 and 2

	Cycle Test 1	Cycle Test 2
Days in Recharge Phase of Cycle	31	92
Energy used for UV (kWh)	64,056	190,102
Metered Energy Use (kWh)	155,760	455,400
Percent of Energy Used for UV System	41	42

Control and Electrical Facilities: The control and electrical facilities account for approximately 11 percent of the energy used. This can be inferred from the amount of electricity used during the storage phase of each cycle, when the control and electrical facilities are the only components of the system requiring energy. The estimated energy cost to operate the control and electrical facilities during the recharge phase is approximately $1,000/month.

Pumps and Associated Equipment: The cost of electrical energy required to operate the pumps and associated equipment can be estimated by subtracting the energy required for the UV system and the control/electrical facilities from the total energy used. Since the UV system and the control/electrical facilities use approximately 42 percent and 11 percent, respectively, the pumps and associated equipment consume approximately 48 percent of the electricity used during the recharge phase. The estimated energy cost to operate the recharge pump and associated equipment during the recharge phase is approximately $4,100/month.

11.2.2.2 Storage

During the storage phase, energy costs are at their lowest because most major system components are shut-down. During storage, the energy demand is for operation of the SCADA system and remote telemetry equipment located in the control building and electrical facilities, which require climate control. Additional energy demands during storage consist of any electrical system maintenance and service operations, testing of equipment, and lighting. The estimated cost for energy during storage of cycles 1 and 2 is summarized in **Table 11-16**. The estimated energy cost during storage is approximately $1,000/month.

Table 11-16 -- Electrical Energy Cost Summary For Storage Phase, Cycle Tests 1 and 2

	Cycle Test 1	Cycle Test 2	Average
Storage Phase Duration (days)	30	1	
Energy Cost Per Cycle ($)	$ 998	$0	
Energy Cost Per Month ($/30 days)	$ 998	No storage phase	$ 998

11.2.2.3 Recovery

During the recovery phase, the recovery pump is activated to convey water from the ASR well through the facility to the discharge structure and into the Hillsboro Canal. Recovered water can be conveyed directly or through the filtration system. The estimated cost for energy demands during recovery of cycles 1 and 2 are summarized in **Table 11-17.**

Table 11-17 -- Electrical Energy Cost Summary For Recovery Phase, Cycle Tests 1 and 2

	Cycle Test 1	Cycle Test 2	Average
Recharge Phase Duration (days)	25	20	
Energy Cost Per Cycle ($)	$6,416	$4,884	
Energy Cost Per Month ($/30 days)	$7,699	$7,326	$7,513

The estimated cost of energy for the control/electrical facilities, $1,000 per month, can be subtracted from the average cost per month listed in **Table 11-17** to isolate the average cost of operating the recovery pumps. The estimated energy cost during recovery is approximately $7,500/month.

11.2.3 System Maintenance, Services, and Miscellaneous Operations Costs

11.2.3.1 Major Equipment Maintenance

The HASR system, though more simplified than that of the KRASR, does require preventative and standard operational maintenance depending on the phase of operation. The HASR system relies on several pieces of major equipment for proper operation and effective treatment. Little maintenance data was available for HASR and most of the estimated monthly costs are derived from KRASR monthly cost estimates. The estimated cost for maintenance of major equipment and associated operational costs are provided in **Table 11-18**.

Table 11-18 -- Major Equipment Maintenance Costs

Component	Recharge ($/month)	Storage ($/month)	Recovery ($/month)
Recharge Pump	925	0	0
UV	1,400	0	0
Recovery Pump	0	0	850
HVAC	20	20	20
Electrical Gear	320	320	320
SCADA	570	220	1,880
Materials, small tools, and supplies	2,500	840	5,300
System Disinfection ($/month)	160	0	0
Well Rehabilitation	***see well rehabilitation section below***		
Total	$5,895	$1,400	$8,370

Recharge Pump: No site specific maintenance data on the recharge pump at HASR is currently available. However, the recharge pump at HASR can be expected to have similar average maintenance costs as the KRASR recharge pump. The estimated cost for maintenance of the recharge pump is approximately $1000/month, and consists primarily of vibration monitoring during the recharge phase.

UV Disinfection System: The UV disinfection system at HASR utilizes two Aquionics (Erlanger, KY) In-Line 7500 UV units that are identical to the UV units used at the KRASR. Since the HASR has 1 fewer unit, the maintenance costs are estimated to be approximately 30 percent less than those at the KRASR. The estimated cost for maintenance of the UV disinfection system is approximately $1,450/month and is incurred only during the recharge phase.

ASR Recovery Pump: No site specific maintenance data on the recovery pump at HASR is currently available. However, the ASR recovery pump at HASR has a 250 HP motor and can be expected to have approximately similar average maintenance demand costs during months of operation as the KRASR recovery pump which has a 150 HP motor. The estimated cost for maintenance of the ASR recovery pump is approximately $900/month, and consists of vibration monitoring during the recovery phase.

HVAC, Electrical Gear, and SCADA: There are no directly reported costs for maintenance on the HVAC, electrical gear or SCADA at HASR, but these systems are similar to the one used at KSASR and can be expected to require similar maintenance expenditures.

As with KRASR, the expected costs for future HVAC maintenance are not expected to vary during a cycle test. The estimated cost for maintenance of the HVAC system is approximately $25/month and is incurred during each phase of a cycle.

Maintenance on the electrical switchgear, which is used to control, protect and isolate the electrical equipment as part of the electric power system, will be provided through 3rd party vendors. The estimated cost for maintenance of the electrical switchgear is approximately $350/month and is incurred during each phase of a cycle.

Maintaining a properly working SCADA system is essential for fully functional ASR operation. Maintenance of the SCADA system would be expected to vary with phase since data acquisition and system control requirements vary from recharge to storage to recovery. This probably would be performed in-house by the SFWMD.

Materials, Small Tools, and Supplies: Operation of the HASR site requires maintenance, cleaning, and general facility up-keep that entails several direct expenses on products such as small tools, consumables, and other general supplies. These specific tools and equipment often need to be either rented or purchased. The estimated cost for equipment is approximately $2,500, $2,200, and $3,000 per month incurred respectively during Recharge, Storage, and Recovery.

System Disinfection: Routine system disinfection (beyond the UV disinfection system) is required during the recharge phase to prevent biofouling of the piping and other pump-related equipment. The disinfection is performed by backwashing the system with calcium hypochlorite which kills any microflora and bacteria that are growing inside the system. The estimated cost for system disinfection is approximately $160/month and is incurred only during the recharge phase.

ASR Well Rehabilitation: One ASR well rehabilitation event was performed at HASR between cycle tests 2 and 3 (Mactec, 2011). Well rehabilitation is required in response to increasing wellhead pressure that probably resulted from biofilm growth in the ASR well. This assessment was confirmed when significant algal and biofilm growth was observed during inspection of the recharge pipeline and UV system, located within 10 ft of the ASR wellhead. ASR well rehabilitation is performed with introduction of a weak acid into the well through an existing port in the recharge line. Flow rates during acid introduction range from approximately 300 to 600 GPM, which is significantly lower than the typical operating flow rate. The weak acid solution is pumped for a few days to dissolve organics and calcium carbonate in the well bore, thus improving permeability and well capacity. This process is performed to ensure that no acidic water is released into the surrounding area. No production of hazardous waste is anticipated in this procedure. As this procedure is anticipated to be performed once every 3 to 5 years depending on recharge duration, this one-time cleaning cost was not included in the overall monthly cost summaries outlined at the beginning of this section. The cost for the HASR well cleaning is outlined in **Table 11-19**.

Table 11-19 -- ASR Well Rehabilitation Cost Per Event	
Well Rehabilitation Phase	**Average Anticipated Cost**
Mobilization and Pilot Scale Testing	$ 8,200.00
Draw-Down and Rehabilitation	$ 30,000.00
Reporting	$ 6,500.00
Total Well Rehabilitation	$ 44,700.00

11.2.3.2 Additional General Service Costs

General direct service costs account for a small percentage of expenses at the HASR system due to simplified system design and operation. These costs are outlined below as monthly averages in **Table 11-20**.

Table 11-20 -- Estimated Average Monthly General Service Costs per Phase

	Recharge Cost ($/month)	Storage Cost ($/month)	Recovery Cost ($/month)
Travel and Vehicle	650	250	650
Data Services	350	350	350
Mowing/Landscaping	350	350	350
Total	1,350	950	1,350

The estimated cost for additional general services is approximately $1,350, $1,250, and $1,350 per month incurred respectively during Recharge, Storage, and Recovery. Individual components of these costs are outlined below.

Travel and Vehicle: Average monthly travel and vehicle costs at the HASR system as reported from base year information for the recharge, storage, and recovery phases are $650, $550, and $650 respectively.

Data Services: Monthly data and cellular services for site operations can be expected to range within $300 to $400 depending on current utility rates (dependent on facility location) as well as the extent that remote telemetry communications are utilized in addition to any IT support necessary. The estimated cost for data services is approximately $350/month and is incurred during each phase of a cycle.

Landscaping Services: The HASR system did not incur any direct costs for mowing or landscaping. However such activities should be implemented in order to improve general site operation and maintenance conditions around major facility equipment. The estimated cost for lawn mowing and landscaping service is approximately $350/month and is incurred during each phase of a cycle.

11.3 Groundwater and Surface Water Quality Monitoring Costs During Cycle Testing

A primary objective for the CERP ASR pilot projects is to evaluate water quality changes that occur in the storage zone during cycle testing, and also to evaluate the toxicity of recovered water on the selected test organisms. The water quality monitoring program for each cycle test and ASR system differs slightly. Variables that affect monitoring costs include the duration of each phase, the frequency of sampling during each phase, the number of analyses in each sample during weekly or monthly sampling, and the number of wells sampled **(Table 11-21).** Therefore, the compilation here represents costs for representative cycle testing scenarios, based on cycle tests 3 and 4 at KRASR, and cycle test 3 at HASR.

Table 11-21 -- Water Quality Sampling Frequency During Cycle Tests at KRASR and HASR

Phase	Duration, in months	Dates	Sampling Frequency	Number of sampling weeks
KRASR CYCLE TEST 3				
Recharge	6.5	Jan-July 2010	weekly	25
Storage	6	July 2010-Jan 2011	weekly	25
Recovery	5.5	Jan-June 2011	weekly	24
KRASR CYCLE TEST 4 (1)				
Recharge	7	July 2011-Feb 2012	bi-monthly then monthly	12
Storage	11	Feb 2012-Jan 2013	monthly	11
Recovery	6	Jan-July 2013	bi-monthly then monthly	12
HCASR CYCLE TEST 3 (2)				
Recharge	4	Nov 2011- Mar 2012	weekly	12
Storage	2	Mar-May 2012	weekly	12
Recovery	1	June 2012 -	weekly	5

NOTES: (1) KRASR sampling weeks are estimated from the negotiated contract. Cycle test 4 storage and recovery phases have not been completed yet. (2). HASR cycle test 3 operations ceased for two months (Nov-Dec 2011) during recharge due to system malfunction. The recharge phase lasted 4 months, but only included 3 months of actual sampling.

11.3.1 Water Quality Monitoring Cost Breakdown Methods

The total cost of the water quality monitoring programs is reported for each cycle test. USACE in-house costs are excluded. The total cost is subdivided into three components: analytical costs, labor costs, and miscellaneous costs **(Table 11-22)**.

- Analytical costs. Include cost of all laboratory analyses, sample shipment, and sampling expendables (bottles, labels, calibration standards)
- Labor costs. Include contractor's labor costs for field sampling technicians, the project manager, and the chemist serving as quality control manager.
- Miscellaneous costs. Includes mileage to and from the field site and equipment rental.

Analytical costs include water quality analyses to show compliance with the UIC, CERPRA, and NPDES permits at each ASR system. A supplementary data collection effort includes water quality analyses to support groundwater geochemical modeling. These analyses exceed regulatory requirements, so these costs are broken out of the total analytical cost component. All component costs are subdivided by phase (recharge, storage, recovery) to be consistent with cost estimates for operations and maintenance of each ASR system.

11.3.2 Cycle Test Scenarios

Total costs of the water quality monitoring programs from three representative cycle tests conducted between January 2010 and June 2013 are presented. Three cycle tests were completed at KRASR when the cost estimate was developed, and one cycle test was completed at HASR. While these initial costs are relatively high, future costs are expected to decline as 1) single ASR wells become ASR wellfields (economy of scale); 2) larger volumes are stored; 3) less research is needed and remaining unknowns are better understood; and 4) energy efficiency is optimized.

KRASR cycle test 3 is characterized by an intensive groundwater quality sampling program conducted during a cycle test that closely represents a typical CERP cycle lasting over one year. Samples were obtained weekly from four storage zone monitor wells (two of which were constructed after cycle test 2), the ASR well, a surficial aquifer well, and an APPZ well. The duration of the cycle and the intensive sampling frequency make this the most expensive cycle completed at KRASR. Analytical costs for permit compliance are 60 percent of the total cost, with the remaining 40 percent for geochemical evaluation. Unfortunately, labor and miscellaneous costs for cycle test 3 are not included in **Table 11-22** because these costs are a single sum for earlier cycle tests 1 through 3.

KRASR cycle test 4 is intended to duplicate cycle test 3 to show reproducible water quality and hydrogeologic changes during long, large volume tests. Modification of the UIC and CERPRA permits reduced sampling frequency from weekly to monthly, resulting in a 58 percent savings in analytical costs while maintaining data collection objectives.

HASR cycle test 3 was intended to duplicate KRASR Cycle test 2, with recharge, storage and recovery durations of 3 months each. Unfortunately, problems with the UV disinfection system required a system shut down from 3 December 2011 through 17 January 2012. Weekly sampling was suspended between 6 December 2011 and 17 January 2012. The analytical cost component includes sampling primarily for regulatory compliance (83 percent of analytical cost), although additional geochemical analyses also were obtained (17 percent of analytical cost). Labor costs for this cycle test are high compared to the longer duration KRASR cycle test 4. A greater labor effort is required at HASR because monitor wells are deeper and require greater purge times.

Table 11-22 -- Water Quality Sampling Cost Breakdown

Cost Class	ASR System and Cycle Test	Recharge	Storage	Recovery	Total
Analytical Costs		**Monitoring Cost for Regulatory Compliance**			
	KRASR Cycle Test 3	$ 65,724.75	$ 28,947.19	$ 79,529.50	**$ 174,201.44**
	KRASR Cycle Test 4	$ 35,733.08	$ 6,304.68	$ 39,901.70	**$ 81,939.46**
	HASR Cycle Test 3	$ 32,852.73	$ 12,452.02	$ 20,151.16	**$ 65,455.91**
		Monitoring Cost for Geochemistry			
	KRASR Cycle Test 3	$ 40,212.88	$ 33,116.49	$ 44,943.81	**$ 118,273.19**
	KRASR Cycle Test 4	$ 9,335.62	$ 14,873.04	$ 17,405.04	**$ 41,613.70**
	HASR Cycle Test 3	$ 6,805.62	$ 2,862.45	$ 3,805.82	**$ 13,473.89**
Labor Costs	KRASR Cycle Test 3	Not available			
	KRASR Cycle Test 4	$ 66,700.00	$ 38,400.00	$ 66,700.00	**$ 171,800.00**
	HASR Cycle Test 3	$ 74,290.00	$ 67,875.00	$ 25,660.00	**$ 167,825.00**
Miscellaneous Costs	KRASR Cycle Test 3	Not available			
	KRASR Cycle Test 4	$ 12,000.00	$ 3,300.00	$ 1,700.00	**$ 17,000.00**
	HASR Cycle Test 3	$ 3,175.00	$ 2,250.00	$ 3,175.00	**$ 8,600.00**
Total Cost of Each Cycle Test	KRASR Cycle Test 3	Not available			
	KRASR Cycle Test 4	$114,433.08	$ 48,004.68	$108,301.70	**$ 270,739.46**
	HASR Cycle Test 3	$110,317.73	$ 82,577.02	$ 48,986.16	**$ 241,880.91**

NOTE: Total cost for KRASR cycle test 3 is incomplete when costs were developed.

12. Value Engineering (VE) Studies

12.1 Studies at the Kissimmee River ASR System

This section details the value engineering studies conducted by the operations contractor (R2T, Inc.) at the KRASR facility and also includes suggested modifications to design, construction, and operation of similar facilities in the future. In these VE studies, the existing plant conditions were reviewed and analyzed. The objectives of these improvements are to minimize the overall cost, and increase the value and quality of the operation. Value engineering studies included water treatability testing **(Section 6.3.1)**, the ASR artesian well analysis, pressure filter media bed analysis, recharge pump modification and on-site power generation. Lessons learned from the KRASR facility will improve the design and operation of future ASR facilities. As such, the following case studies are presented (R2T, Inc., 2011).

12.1.1 Pumping with Variable Frequency Drive

The objective of this value engineering study was to optimize the recharge pump performance to maintain a required recharge flow rate of 5 MGD at the raw water piping system, but at a low pumping cost. A summary of the recharge pump modification and value engineering study results is provided below. For further details please see the related technical memorandum (R2T, Inc., 2009c; **Appendix E**).

The operating condition of the recharge pump has a discharge pressure limit of 90 psi with a maximum flow rate of 5 MGD. Flows in excess of 5 MGD were re-circulated back to the raw water (wet) well. This resulted in an apparent pumping rate higher than the required 5 MGD, which increased pumping cost primarily due to increased power consumption. The pump was initially sized for a maximum backpressure at the ASR well of 66 psi.

To optimize pump performance and to reduce cost, pump curves were developed for the following scenarios and compared to the current pump curve:

- Removing a pump stage resulting in a four-stage pump.
- Operating the pump at 92 percent speed, which is the speed needed to produce a flow of 5 MGD at maximum ASR backpressure conditions. This is accomplished using a variable frequency drive (VFD).
- Operating the pump at 86 percent speed – the speed needed to produce a flow of 5 MGD at average ASR backpressure conditions. This is accomplished using a VFD.

System curve conditions were simulated at:

- Maximum backpressure of 66 psi.
- Backpressure of 50 psi, observed at the beginning (average) of cycle testing.
- Backpressure of 40 psi observed after well rehabilitation.

Simulated pump and system curves were used to characterize the actual pump operating condition during these scenarios. Cost savings resulting from two options: 1) the removal of one stage; or 2) the use of a VFD. These options were based on the anticipated reduction of horsepower (HP) and subsequent power cost reduction. This analysis showed that either removal of the 5th stage or the addition of a VFD would meet the required flow rate of 5 MGD at the maximum backpressure at the ASR well of 66 psi. **Table 12-1** summarizes the advantages and disadvantages associated with each option (R2T, Inc., 2009c). The results of the scenario calculations are shown in **Table 12-2** (R2T, Inc., 2009c).

<table>
<tr><th colspan="4">Table 12-1 -- Analysis of Pump Stage Removal and VFD Addition to Pump</th></tr>
<tr><th colspan="2">REMOVAL OF 5th PUMP STAGE</th><th colspan="2">VFD PUMP</th></tr>
<tr><th>ADVANTAGES</th><th>DISAVANTAGES</th><th>ADVANTAGES</th><th>DISAVANTAGES</th></tr>
<tr><td>5 MGD flow rate maintained without recirculation at 66 psi</td><td rowspan="6">Limited potential benefit and results in “overpumping” at the average backpressure conditions</td><td>Continuous flow control without recirculation</td><td rowspan="2">Higher capital cost than removal of 5th pump stage option</td></tr>
<tr><td>5th stage can be re-installed if necessary</td><td>Power cost savings at ASR backpressure less than the maximum of 66 psi</td></tr>
<tr><td>No impact to pump motor</td><td rowspan="4">Cost recouped in 23 to 38 months of recharge pump operation depending on backpressure conditions</td><td rowspan="2">Long implementation time due to VFD installation and pump modifications</td></tr>
<tr><td>Short implementation schedule</td></tr>
<tr><td rowspan="2">Cost recouped within 6-8 months of recharge pump operation depending on backpressure conditions</td><td>Replacement of non-invertor duty motor required for retrofit at KRASR</td></tr>
<tr><td>Additional well and pump design input needed to ensure VFD pump compatibility at KRASR</td></tr>
</table>

Table 12-2 -- Operational Cost Savings for Various Pumping Scenarios at KRASR

Pumping Condition	Savings Compared to current condition ($/month)	Savings Compared to current condition ($/year)	Capital cost	Payback (in months of operation)
90 psi at pump, 66 psi at well, 1190 rpm, original case	-	$ 0	-	-
4 stage pump – max backpressure of 66 psi	$ 3,190	$ 38,287	$ 20,000	6
4 stage pump – max backpressure of 50 psi	$ 2,535	$ 30,427	$ 20,000	8
92% speed at max 66 psi backpressure	$ 3,190	$ 38,286	$ 120,000	38
86% speed at 50 psi backpressure	$ 5,189	$ 62,263	$ 120,000	23

12.1.2 UV Power Consumption

This UV power consumption data was collected during a value engineering analysis conducted by the operations contractor during 2010 and early 2011. The real power usage shown in these studies by the three UV units and their comparison in the various modes of operation are shown in **Table 12-3**.

Table 12-3 -- Real Power Usage for UV Lamps at the Different Power Settings									
Mode	Unit	kW	24 Hour Usage (kWh)		30 Day Usage (kWh)		Price ($/kWh)	Daily Cost	Monthly Cost
High	A	43.64	1047.24	3099.48	31417.30	92984.54	$0.102	$340.94	$10,228.30
	B	43.59	1046.27		31388.24				
	C	41.92	1005.97		30179.00				
Medium	A	38.96	934.97	2757.14	28049.01	82714.19		$303.29	$9,098.56
	B	38.83	931.89		27956.70				
	C	37.10	890.28		26708.48				
Low	A	33.77	810.41	2390.67	24312.39	71719.99		$262.97	$7,889.20
	B	33.80	811.16		24334.65				
	C	32.05	769.10		23072.94				

From these data, it is clear that running the UV lamps in the Low or Medium power setting reduces energy consumption. A change in the power setting from High to Medium mode results in an energy reduction of approximately 11 percent (R2T, Inc., 2011).

Unfortunately, operation of the UV disinfection system on Low or Medium power results in incomplete coliform inactivation. Early testing of the UV disinfection system at lower flow rates (3.5 to 5 MGD) at lower power settings showed detectable total coliforms at the ASR well during recharge. Another option was to re-circulate the raw water back into the wet well to achieve a flow rate between 3-4 MGD. Lower flow rate resulted in lower total coliform concentrations. However, operations at 3 MGD instead of 5 MGD reduced the capacity of the recharge pump by nearly 40 percent, with concomitant power wastage of 40 percent for the UV disinfection system operation. The estimated wasted power and money for such an annual operation of the UV units is shown below in **Table 12-4** (R2T, Inc., 2011).

Table 12-4 -- Annual Dollar Wastage for Operation of UV Units at 3-MGD Instead of 5-MGD Recharge Flow Rate.						
UV unit	Mode	24 hrs (kWh)	30 day (kWh)	Operation Cost, 30 days at $ 0.102/kWh	Extra cost of power at reduced capacity for 30 days	Annual wasted cost due to reduced capacity ($)
A	High	1047.24	31417.3	$3,204.57	$1,281.83	$15,381.91
B	High	1046.28	31388.2	$3,201.60	$1,280.64	$15,367.68
C	High	1005.97	30179	$3,078.26	$1,231.31	$14,775.64

The UV disinfection system at the KRASR facility consists of three in-line UV units, connected in series. The following is a list of the various issues encountered with the UV units while in operation (R2T, Inc., 2011):

- **Sleeve scaling**: Scaling of the interior of the UV sleeves was observed, with less than 3000 hours of UV lamp operation.

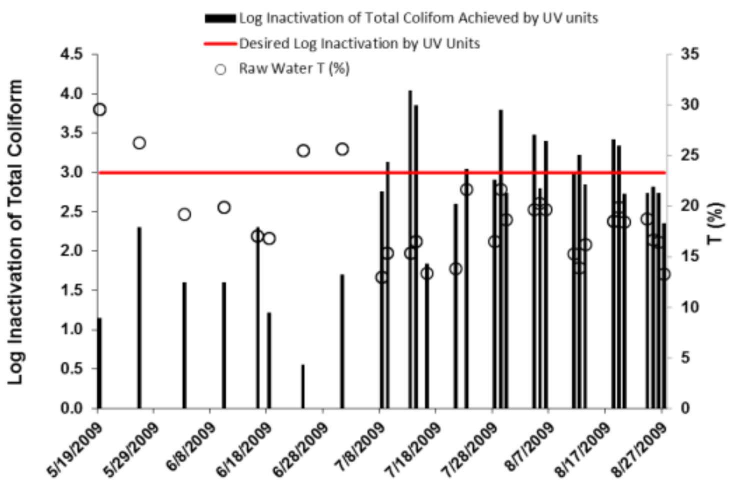
- **UV unit shaft:** The shafts of the UV units were defective during the run of cycle test 2 and were replaced.
- **UVectors:** The UVector connection cables were not water-tight and water intrusion caused the UV units to fail on frequently during cycle tests 1 and 2. Such failures can cause a plant shut down, thus jeopardizing plant operations and data acquisition.
- **Lamp life:** UV unit lamps burned out after only about 1000 operational hours. These lamps are expected to operate for at least 5000 hours. The lamps were replaced once during cycle test 2 and again during cycle test 3.
- **Inconsistent bearing composition:** It was found that the bearings on the wiper mechanisms within UV units B and C were not sealed. The manufacturer was contacted for this defect and the bearings were eventually replaced under the warranty.
- **UV power adjustment:** Adjustments to the power setting of the UV disinfection system could only be performed manually on-site rather than remotely through the SCADA system. This limited the operator's ability to completely control the ASR facility remotely, and required additional labor cost for a full-time operator.

To ensure reliable operation of the UV disinfection system, proper material selection and weather rating of equipment was essential. The UV unit's intensity meter, UVector, is mounted on top of the UV units **(Figure 12-1** -- **)** and is essential for proper operation of the exposed units (R2T, Inc., 2011).

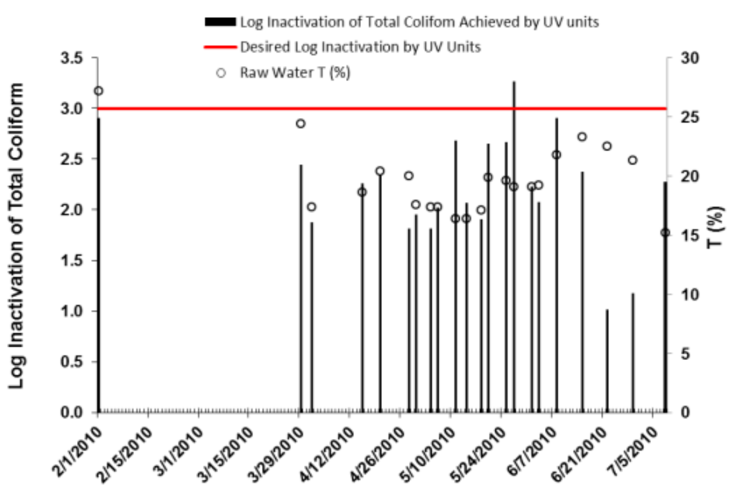
Figure 12-1 -- The UV disinfection system enclosure.

Since the UVectors were not waterproof or rated for outdoor service, the units failed or misread the intensity settings, resulting in frequent alarms and system shut downs. This problem was solved by providing a metal enclosure on top of the UV units at a minimal cost **(Figure 12-1)**. Since the addition of the enclosures, the UVector intensity meters have operated adequately.

UV disinfection system performance testing was conducted during the recharge phase of cycle test 2 (2009 and 2010) at KRASR. The performance test results were unsatisfactory, in that the disinfected recharge water did not meet the 3-log_{10} removal or a consistent concentration of 4 CFU/100ml or less for total coliforms, prior to injection to the Floridan Aquifer. This was a design criterion for the ASR system. The log_{10} inactivation achieved by the UV disinfection system during cycle tests 2 and 3 is shown in **Figure 12-2 (A and B) --** Chemical testing using various coagulants was considered as an option in order to increase transmittance levels and improve performance of the UV disinfection system **(Section 6.3).**



A) Cycle test 2



B) Cycle test 3

Figure 12-2 (A and B) -- Time-series plots showing UV disinfection system performance (as log inactivation) and percent transmittance.
A, Cycle test 2; B., Cycle test 3.

12.1.3 Filter Media Alternatives

The objective of this study was to determine whether the existing pressure filter media bed could be modified to optimize plant performance and improve consistency of coliform inactivation. A summary of the filter pilot testing and results are provided. For further detail, see the technical memorandum (R2T, Inc., 2009a; **Appendix E**).

Pilot filters were used to determine optimum coagulant dosage. Pilot-scale testing consisted of the following major components.

- Pretreatment chemical feed systems.
- Raw water piping simulating existing conditions.
- Raw water piping simulating typical mixing and slower velocities.
- Large pipe to simulate the benefit associated with additional contact time prior to filtration.
- Four filter columns to test various media configuration, track individual performance and identify operation issues such as filter head loss and impact on filter run and backwash frequency.

Jar- and full-scale testing results collected at KRASR indicated a potential solution to most of these issues, however the data was not conclusive and inconsistencies were observed. The need for further testing continued as routine water sampling and analysis during full-scale cycle testing in 2009 indicated that the plant did not provide consistent and sufficient coliform inactivation. Probable causes for coliform inactivation were identified as low UVT values and the extensive biofilm growth and fouling that were observed in-line due to the high organic carbon concentrations in the recharge (surface) water (R2T, Inc., 2009b).

The CERP ASR PDT decided that chemical addition for the pre-treatment of recharge water was not consistent with CERP ASR operational goals, specifically those requiring minimal operational oversight and reduced O&M costs. Although chemical addition is commonly applied in drinking and wastewater treatment facilities, the intent at CERP ASR systems is for minimal pre-treatment while complying with UIC permit criteria. For the sake of completeness, the following pilot-scale testing was recommended for ASR systems that recharge using treated surface water (R2T, Inc., 2009a).

- **ACH and hydrochloric acid feed rates:** Full-scale testing was conducted with 20 mg/L of ACH when subsequent jar tests employed indicated that coagulant doses up to 40 mg/L with hydrochloric acid may be used to achieve higher transmittance values.
- **Aluminum concentration:** To confirm the effectiveness of the ACH/HCl treatment program at increasing transmittance without causing aluminum concentrations to exceed the UIC permit criterion of 0.2 mg/L.
- **Impact on filter:** During performance at the higher feed rate of 40 mg/L.
- **Impact on filter backwash rate and residuals production:** Should be clearly understood to ensure that the plant operation in recharge is sustainable.
- **Pre-treatment conditions:** Optimum pre-mixing conditions and the impact of additional contact/flocculation time.
- **Alternate media configurations:** The use of various filtration media configurations and the feasibility of modifying the existing filter performance.

Pursuant to the recommendations above, alternate media configurations were analyzed and tested. To evaluate various media configurations, a four filter column configuration was requested from suppliers (TONKA and Intuitech, Inc.). A copy of the available equipment from Intuitech, Inc. and TONKA is provided in R2T, Inc. (2009a).

12.1.4 Utilization of Artesian Pressure for the Recovery Phase at KRASR

The objective of this engineering analysis was to determine whether water stored in the FAS at KRASR could be recovered through the ASR well at a flow rate of 5 MGD under natural artesian pressure without pumping. This analysis evaluates artesian flow from a fresh aquifer where there is no density dependent flow in the aquifer owing to generally fresh water quality in the native aquifer. Recovery using artesian pressure would also require flow through the existing discharge piping system to the cascade aerator. A summary of the artesian well value engineering study is provided. Additional information is provided in a technical memorandum (R2T, Inc., 2009d; **Appendix E**).

The hydraulic analysis for this study was based on friction losses in the discharge piping system, which included pipe length and fittings. The backpressure was based on the water level elevation at the inlet distribution weir at a flow rate of 5 MGD. Based on the KRASR system configuration, a total pressure of about 9 ft is needed at the pump discharge to deliver 5 MGD to the cascade aerator. This is less than the 12 psi static (no flow) pressure reading at the ASR wellhead during storage. Assuming the recovery pump was removed and the entire well column was used to deliver 5 MGD from an estimated depth of 560 ft., the total head required would be increased by 1.20-ft to a total of 10.2-ft to account for friction losses (R2T, Inc., 2009d).

Based on operations costs of the current 150 HP recovery pump, the removal of the recovery pump and reliance on artesian pressure would result in an estimated monthly savings of $8,320 when recovery phase operation is 24 hours per day. In order to test the effectiveness of the artesian pressure, the recovery pump would have to be removed as it would result in excessive head loss in its current position. If the recovery pump is removed for maintenance or any well operation, the use of the artesian pressure should be confirmed.

It should also be noted that the hydrologic capacity of the well, the impact of natural flow on the artesian pressure, and long-term operating condition was not determined by the operations contractor during this evaluation. The feasibility of recovery using artesian pressure over the long term should be carefully evaluated before permanent ASR systems are designed for this application (R2T, Inc., 2009d).

12.1.5 Onsite Power Generation

The increasing cost of energy prompted the operations contractor to consider onsite power generation options to reduce the operational costs of the ASR system operations. Onsite power generation using renewable energy sources such as sunlight, wind, or water can minimize or completely eliminate the need for an external power source for the ASR system, thereby greatly reducing the carbon footprint associated with the plant operations. Some technologies in place at several utilities include on-site gas turbines and reciprocating engine generators, photovoltaic systems, small wind turbines, wellhead gas and landfill methane. Considering the location of the KRASR system, the most feasible option available is a solar and/or hydro system that would either completely or partially reduce the load on the conventional system in place (R2T, Inc., 2011).

12.2 Common Value Engineering Considerations for Future ASR Sites

Expanded use of ASR technology for the CERP has been proposed on a large, unprecedented scale as a cost-effective water supply alternative to traditional, more expensive surface water storage reservoirs. As such, value engineered alternatives for these future ASR systems should be considered, especially given the regulatory demands imposed by Florida state agencies for recharge and recovered water quality.

Value engineering (VE) introduces innovative design ideas, construction techniques or operational methods for the purposes of reducing overall project cost or completion time. For typical USACE Civil Works projects, VE is an important and common component of project implementation. VE reviews are undertaken at all phases of a typical USACE project. However, the CERP ASR Pilot Projects only required limited VE reviews as these projects were selected as pilot projects needed to gain additional understanding of the site hydrogeology, groundwater quality, and water treatment processes. The technologies that were evaluated were not necessarily the most cost effective in every case due to their innovative nature or operation. It is anticipated that during the bidding process for future ASR CERP projects, the Government will encourage value engineering proposals based on the knowledge base ascertained from pilot projects, including the KRASR and HASR systems. The following outlines various common VE considerations identified during cycle testing and optimization of the pilot projects that could be entertained for future CERP ASR sites:

- **Increased Recovery Efficiency:** Recovery efficiency is defined as the percentage of the water volume stored in an operating cycle that is subsequently recovered in the same cycle while meeting a target water quality criterion in the recovered water. Additional considerations that would affect the amount available to be returned and or recharge include well plugging (lack of cleaning and rehabilitation), varying aquifer characteristics, specific site hydrogeology, and regulatory requirements.

- **Source Water Supply Planning**: Locate ASR sites to minimize pre-treatment and need for color and TDS reduction, thus minimizing UV dosage and energy demand for effective coliform inactivation.
- **Site Location Selection:** Potential use of existing well, local economic health, proximity to other sites for efficient operation and maintenance, sludge storage availability, proximity of landfill and other critical resources, proximity to existing wells for potential re-use for monitoring and/or recharge during ASR operations.

13. The CERP ASR Pilot Projects Address Key Stakeholder Issues

During the planning process, many stakeholders in South Florida expressed wide-ranging concerns about implementation of the CERP, including the potential role of ASR. As a result, the South Florida Ecosystem Restoration Task Force (Task Force) was established by Congress in the WRDA 1996, and has two advisory bodies: the Working Group for planning and policy coordination; and the Science Coordination Group for technical issues. In 1998, the Working Group convened an ASR Issue Team, consisting of experts from county, state and Federal entities, the Miccosukee Tribe, and universities along with practitioners. Additional information about the Task Force can be found at DOI (2012).

The teams's original task was to develop an action plan to address uncertainties with regional implementation of ASR. Their report (ASR Issue Team, 1999; Appendix H) defined seven key issues of concern, to be addressed by the CERP. Later (ASR Issue team, 2001), its mandate was extended to "periodically review and monitor the progress [of] the pilot projects and the Regional Study regarding the resolution of issues presented in the Issue Team and CROGEE [i.e., National Research Council, 2001, 2002] reports..."

Many technical issues related to hydrogeologic factors at ASR systems were also identified by CROGEE (National Research Council, 2001), and these generally overlap with concerns identified by the ASR Issues Team. Specifically, CROGEE encouraged evaluation of ASR well design (short versus long open intervals), variations in recharge and recovery rates, and implementing expanded number and sampling frequency in monitor wells at the ASR pilot systems. Completion of a rock fracturing study also was suggested. The CROGEE recommendations were submitted primarily to provide a better characterization of ASR feasibility at the pilot systems, and thus provide additional data for the ASR Regional Study.

Goals and objectives of the two CERP ASR pilot projects were defined in USACE (2004). Briefly, the goals of the Lake Okeechobee ASR pilot projects are: 1) to evaluate ASR feasibility at two locations having different surface water quality characteristics, hydrogeologic conditions, and surface water distribution configurations; and 2) to reduce technical and regulatory uncertainties associated with ASR system operation. The extent to which each ASR system has achieved project objectives will be discussed in the following sections. Specific objectives of each ASR pilot project are summarized in **Table 3-1.** During the planning process, additional hydrological and geotechnical objectives were identified in by the ASR Issues Team (1999, 2001), the National Research Council (2001), and in public workshops. These issues were incorporated into project objectives listed in the PPDR (USACE, 2004). All issues identified by the ASR Issues Team (1999, 2001) and the National Research Council (2001) were incorporated, but some objectives were to be achieved by completion of the CERP ASR Pilot Project, while others were to be achieved in the ASR Regional Study.

13.1 What are the Key Stakeholder Issues?

The uncertainties to be addressed by the CERP ASR Pilot Projects and the ASR Regional Study are shown in **Table 13-1**. The following discussion focuses on the issues addressed by the design, construction, and operational testing at KRASR and HASR pilot systems.

- Issue 1 focuses on the suitability of surface water as a source for ASR recharge. Specifically, is surface water quality sufficient for recharging the UFA with minimal pre-treatment, yet able to maintain regulatory compliance? Can ASR recharge of suitable water quality and quantity be delivered seasonally or throughout the year?
- Issue 2 focuses on hydrogeologic data acquisition to refine the regional hydrogeologic framework, and define hydraulic properties and native water quality of the Upper Floridan Aquifer.
- Issue 3 focuses on the potential for hydraulic fracturing in representative storage zone lithologies at typical operating wellhead pressures, and the potential for upward migration of recharge or formation waters into shallower aquifers. This concern also was raised in the National Research Council (2001) review.

Table 13-1 – Key Issues Identified by the ASR Issue Team (1999, 2001)

Issue	CERP ASR Pilot Projects	ASR Regional Study
1. Characterization of prospective sources waters, spatial and temporal variability	✓	✓
2. Characterization of regional hydrogeology of the upper Floridan Aquifer: hydraulic properties and water quality		✓
3. Analysis of critical pressure for rock fracturing	✓	✓
4. Analysis of site and regional changes in head and patterns of flow	✓	✓
5. Analysis of water quality changes during movement and storage in the aquifer	✓	✓
6. ASR potential effects on mercury bioaccumulation for ecosystem restoration projects	✓	✓
7. Relationship between ASR storage interval properties and recovery rates and recharge volume	✓	✓

- Issue 4 focuses on evaluation of hydraulic head changes from multiple ASR systems recharging into fresh and brackish aquifer systems. The development of a three-dimensional groundwater flow and solute transport model is a major effort of the ASR Regional Study. CROGEE (National Research Council, 2001) recommended more detailed monitoring and simulations to better define the extent of recharge water in the storage zone during ASR cycle testing.
- Issue 5 focuses on quantifying the magnitude, duration, variety of water quality changes that occur during cycle testing. This was also a significant concern expressed by CROGEE (National Research Council, 2001).
- Issue 6 focuses on mercury and methyl mercury transport and fate during cycle testing. The source of mercury and methyl mercury is surface water, but geochemical conditions in the UFA could potentially promote conversion of mercury to more toxic methyl mercury, thus increasing the toxicity of recovered water.
- Issue 7 focuses on optimizing operations to maximize the percent recovery at representative ASR pilot systems. This was also a concern expressed by CROGEE (National Research Council, 2001).

13.2 Responses to Key Stakeholder Issues

The following discussion summarizes how operational testing at KRASR and HASR addresses issues raised by the ASR Issues Team (1999, 2001) and CROGEE (National Research Council, 2001). Many of the issues require consideration of ASR over larger basins; those will be addressed in the technical data report of the ASR Regional Study.

13.2.1 Issue 1 - Characterization and Suitability of Recharge Waters

The CERP ASR pilot projects have addressed this issue with an intensive water quality sampling program. Recharge water quality was characterized prior to cycle testing (n=5, 2002) at all proposed CERP ASR pilot systems for major and trace inorganic constituents, primary and secondary organic constituents, microorganisms, nutrients, and selected radionuclides. Surface water quality also was characterized at the ASR wellhead during recharge at KRASR and HASR. Data acquired during recharge is interpreted to answer two questions. First, can surface-water recharge occur efficiently and without disruption? And second, can minimally treated surface water be recharged and recovered in compliance with UIC and SDWA regulatory criteria?

Both KRASR and HASR systems recharge using minimally treated surface water. Surface waters are highly colored from organic carbon and iron, but show low turbidity. These characteristics can affect performance of the pressure filter, the UV disinfection system, and the ASR well. Organic carbon, iron, and nutrients (phosphorus and nitrogen species) enhance biological activity in the KRASR pressure filter, resulting in more frequent backwashing. Organic carbon and iron concentrations reduce transmittance as water passes through the UV disinfection system, resulting in incomplete coliform inactivation and non-compliance of the total coliform criterion. Both issues are addressed by a regular maintenance program that was developed between cycle tests 2 and 3 at KRASR. However, total coliform detections occurred frequently during recharge in all cycles. Progressive clogging of the ASR well was indicated by rising wellhead pressures during cycle tests 1 and 2 at KRASR and HASR. Two episodes of well rehabilitation were performed on the ASR well at KRASR, resulting in a 45 percent improvement of well capacity. One well rehabilitation event was performed at HASR after cycle test 2, resulting in a 25 percent improvement of well capacity. Most of the clogging was due to development of biofilms, and perhaps calcium carbonate precipitation. Operations improved at both ASR systems after well rehabilitation, as shown by lower wellhead pressures during recharge.

In summary, Kissimmee River and Hillsboro Canal surface water is acceptable for recharge into the UFA but improved regulatory compliance requires improvements in UV disinfection technology. At present, UV disinfection is the preferred method as no chemicals are required, and no residuals are produced. Currently, regular maintenance of the ASR system reduces biological growth along the recharge line and in the ASR well bore. The UV disinfection system must be re-evaluated to ensure complete inactivation of total coliforms during recharge, as this is source of regulatory exceedances at both KRASR and HASR systems.

Kissimmee River and Hillsboro Canal recharge water samples are nearly devoid of anthropogenic organic constituents such as BTEXs, herbicides, and pesticides. Surface water samples also showed low to non-detectable concentrations of uranium and radium isotopes, and gross alpha measurements. There were no exceedances of regulatory criteria for organic constituents, radionuclides, or metals including mercury. Total phosphorus concentrations in surface water samples often exceed surface water quality guidelines at both KRASR and HASR, and probably contribute to biofilm development in the ASR systems.

The volume of surface water available in the Kissimmee River for recharge far exceeds recharge capacity of the KRASR system. However, poor surface water quality (as shown by high iron and color measurements) results in lower UV transmittance, resulting in reduced inactivation of total and fecal coliforms. This condition occurs at the onset of the wet season or high-flow events, and resulted in temporary system shut-down. The volume of surface water available in the Hillsboro Canal is sufficient to recharge excess flows that otherwise would be lost to tide, except during drought conditions.

13.2.2 Issue 2 - Characterization of Regional Hydrogeology of the UFA

Refining a regional hydrogeologic framework is a primary objective of the ASR Regional Study, rather than the CERP ASR pilot projects. However, lithologic and hydrostratigraphic data, and borehole geophysical logs were obtained during construction of the ASR and monitor wells at KRASR and HASR. ASR system-specific hydraulic parameters also were estimated from aquifer performance tests for the storage zones at KRASR **(Section 5.4)** and HASR **(Section 5.5).** These data and interpretations were incorporated into the ASR Regional Groundwater Flow and Solute Transport Model (USACE, 2013). **Table 13-2** lists the hydrogeologic products that resulted from the CERP ASR pilot projects.

Table 13-2 -- CERP ASR Hydrogeologic Framework Investigations

Title	Authors	Description
KRASR		
Hydrogeologic Investigation of the FAS, Kissimmee River Site, Okeechobee County, FL	CH2M Hill, 2004	ASR well construction and testing, geophysical logging, APTs, limited water quality
Installation of MW0010, Lake Okeechobee ASR Pilot project, Kissimmee River Site, Okeechobee County, FL	Golder Associates, 2007	ASR well construction and testing, geophysical logging, limited water quality
Construction of Distal Monitor well MW No. 19 and MW No. 18, Kissimmee River ASR Pilot Site, Okeechobee County	Entrix, 2010 a and b	Storage zone monitor well construction, lithological interpretations and geophysical logs
HASR		
Hydrogeologic Investigation of the FAS, Western Hillsboro Basin, Palm Beach County, FL	Bennett, Linton, and Rectenwald, 2001	ASR well construction and testing, geophysical logging, APTs, limited water quality
High-Resolution Acoustic and Seismic Investigation of Carbonate Rock Properties	Parra et al., 2003	Geophysical characterization for permeability evaluation at HASR
BOTH ASR SYSTEMS		
Geochemical and mineralogical characterization of potential aquifer storage and recovery storage zones in the Floridan aquifer system	Fischler and Arthur, in review; Fischler and Arthur, 2010	Geochemical characterization of storage zone lithologies, including whole rock analysis, mineralogical analysis
Synthesis of the Hydrogeologic Framework of the FAS, and Delineation of a Major Avon Park Permeable Zone in central and southern Florida	Reese and Richardson, 2008	Preliminary hydrogeologic framework
Geologic structure and hydrostratigraphy of the Floridan aquifer system and intermediate confining unit in the Lake Okeechobee area, Florida	Reese, in review	Update of Reese and Richardson (2008) adding new data
Groundwater reorganization in the Floridan Aquifer following Holocene sea-level rise	Morrissey et al., 2010	Groundwater data analyzed for isotopes to estimate age

13.2.3 Issue 3 - Characterization of Rock Fracturing Potential

This risk of pressure-induced fracturing of the aquifer or confining unit lithologies can be significant due to rising head when many ASR wells are located in a small geographic area. This issue will be discussed in greater detail in the ASR Regional Study report. However, Geibel and Brown (2012; **Appendix K**) evaluated geotechnical data from representative storage zone samples at KRASR, HASR, and other proposed CERP ASR systems, to quantify pressures that would induce microfracture, tensile, and shear modes of failure. They concluded that 100 psi should be the maximum wellhead pressure to avoid inducing microfracturing. This pressure was adopted by the ASR regional groundwater flow and solute transport model as the maximum value for head rise in the UFA. A wellhead pressure at or above 100 psi exceeds typical wellhead pressures of 20 to 66 psi at KRASR and HASR. No other failure mode was indicated for typical ASR system operations.

13.2.4 Issue 4 - Analysis of Site and Regional Changes in Head and Pattern of Flow

Characterizing changes in regional patterns of groundwater flow and head due to operation of proposed ASR systems is a major objective of the ASR Regional Study. Simulations of groundwater flow and solute transport that result from regional-scale ASR implementation are interpreted in USACE (2013) and will be presented in the ASR Regional Study technical data report. However, a more finely gridded, calibrated inset model showing variations in head and solute transport during cycle testing at KRASR is presented in this report **(Section 5.4.3).** This model output enables better evaluation of permeability variations with depth at the KRASR storage zone, and estimated configuration of the maximum extent of recharge water away from the ASR well. Water quality and pressure data obtained during cycle testing at HASR were insufficient to calibrate an inset model. HASR wellfield simulations describe relative pressure and head changes from different well arrangements **(Section 5.5.4)**.

13.2.5 Issue 5 - Analysis of Water Quality Changes During Cycle Testing

As with Issue 1, the CERP ASR pilot projects (particularly at KRASR) have addressed this issue with an intensive water quality sampling program. The completion in 2009 of two new storage zone monitor wells farther from the ASR well allows for better characterization of this large volume, single-well ASR system. The ASR Issue Team (1999, 2001) specifically identified the following compound classes that could change, and possibly degrade, water quality in the UFA: nutrients, organic compounds, pesticides, pathogens, metals, salts, suspended solids, dissolved oxygen, and pH. All constituents of concern identified by the ASR Issues Team were analyzed during all KRASR cycle tests. Most constituents have been analyzed during all HASR cycle tests.

Results of the water quality sampling programs for KRASR and HASR are described fully in **Section 9**. To date, the water quality monitoring program at KRASR is probably the most robust for any ASR system in the nation. Cycle testing results and interpretations appear in international peer-reviewed publications **(Appendix K).**

13.2.6 Issue 6 - Mercury, Methyl Mercury, and Mercury Methylation Potential During ASR Cycle Testing

Mercury and methyl mercury were measured frequently at KRASR and HASR as required by NPDES and UIC permits. Recharge water is the source of mercury and methyl mercury, and concentrations are higher in Kissimmee River surface water at KRASR, compared to Hillsboro Canal surface water at HASR. However, mercury concentrations were always below the 12 ng/L surface water quality criterion in all recharge samples measured at the ASR wellhead, at both ASR systems. Interpretations of mercury and methyl mercury trends are presented in **Section 9.8.**

At KRASR, there are statistically significant reductions in mercury and methyl mercury concentrations when recharge water and recovered water samples are compared during cycle tests 1 through 4. The controlling mechanism for this decline has not yet been identified, but reduction could result from: 1) dilution during advective flow; 2) sorption to aquifer lithologies; and or 3) co-precipitation as a solid sulfide. KRASR data clearly show that mercury is not methylated during storage in the UFA, as methyl mercury concentrations in recovered water are always lower than those in recharge water.

At HASR, there are no statistically significant differences in mercury and methyl mercury concentrations when recharge water and recovered water samples are compared during cycle tests 1 through 3. Cycle tests are conducted differently at HASR. This system has lower percent recovery than KRASR, and storage periods were short or non-existent during cycle tests 1 and 2, reducing the time when reactions could occur. While there is no reduction of mercury and methyl mercury during HASR cycle tests, there also is no increase in methyl mercury in recovered water. Rather, methyl mercury concentrations in recovered water are statistically identical to those in recharge water.

13.2.7 Issue 7 - Relationship Between ASR Storage Interval Properties, Recovery Rates and Recharge Volume

Issue 7 focuses on how ASR systems can be operated to maximize the percent recovery of stored water given the hydraulic and water quality characteristics of the storage zone at each ASR system. The relationship between aquifer properties and percent recovery is evaluated at two systems (KRASR and HASR) that are characterized by native FAS water quality “end members”. Storage zone water quality at KRASR is fresh (less than 800 mg/L TDS; 250 mg/L chloride), whereas that at HASR is brackish (approximately 5,300 mg/L TDS; 2,300 mg/L chloride). Fresh native groundwater at KRASR results in 100 percent recovery **(Section 9.2.2).** Brackish native water at HASR reduces the percent recovery during early, short cycle tests because recovered water cannot be discharged into a surface water body with concentrations that exceed 250 mg/L chloride **(Section 9.3.2)**. The larger recharge volumes at HASR of cycle test 3 progressively freshen the aquifer, and improve percent recovery compared to the shorter, smaller volume cycle tests 1 and 2.

The ASR Issues Team recommended that several ASR systems should be constructed, at geographic locations that represent slightly different UFA characteristics, and also the range of application to urban, agricultural, and ecosystem needs. Five sites were proposed initially. Of these, two single-well systems were constructed (KRASR and HASR). Unfortunately, the multi-well ASR system at Port Mayaca was never constructed, so testing of a multi-well cluster ASR system was never realized. Hydraulic response of a multi-well system is simulated in the inset model at KRASR (**Section 5.4.3**, **Appendix A**).

Evaluation of the relationship between aquifer characteristics and recovery rates was proposed, but cannot be evaluated fully at either ASR system because recovery rate is largely controlled for the system design. Recovery pumping rates are fixed, although recovery rate can be adjusted somewhat by restricting flow through various valves. At KRASR, recovery pumping rate was maintained at approximately 5.0 MGD so that water would be fully oxygenated at the cascade aerator prior to discharge into the Kissimmee River. At HASR, recovery pumping rate was reduced to approximately 4 MGD to minimize turbulence in the Hillsboro Canal. Both ASR systems have under-utilized pumping capacity (that is, higher recovery pumping rates are feasible) if higher rates are consistent with system design and permit criteria.

CROGEE (National Research Council, 2001) suggested evaluation of long versus short open intervals for the ASR and SZWM wells. The ASR and SZMW wells at KRASR and HASR were constructed with open intervals that completely penetrated the UFA, resulting in long open intervals of approximately 300-ft (KRASR) and 200-ft (HASR). Analyses of borehole geophysical logs and cores (Reese and Alvarez-Zarikian, 2007; Reese and Cunningham, in review) show discrete zones of groundwater flow in the UFA at KRASR and HASR, and that these discrete flow zones are a sub-regional feature. Use of shorter open interval wells to utilize these discrete should be considered in future applications of ASR surrounding Lake Okeechobee.

14. Major Findings and Conclusions

This section summarizes major findings and conclusions that resulted from cycle testing at KRASR and HASR systems. It summarizes technical recommendations and "lessons learned", but does not make recommendations related to policy or the implementation of ASR at a regional scale.

14.1 Summary of ASR Project Authorization and Cycle Testing Schedule

ASR was envisioned as the largest component of new storage in the CERP. The goals of the CERP ASR Pilot Projects are: 1) to evaluate ASR feasibility at two locations having different surface water quality characteristics, hydrogeologic conditions, and surface water distribution configurations; 2) to reduce technical and regulatory compliance uncertainties associated with ASR system operation; and 3) to quantify cost of operation. The Kissimmee River and Hillsboro ASR Pilot Projects were authorized by Congress in 1999. Cycle testing was initiated in January 2009 at the KRASR system, and in January 2010 at the HASR system. Cycle testing was completed in July 2013 at the KRASR system, and in June 2012 at the HASR system.

14.2 Evaluation of ASR Pilot Site Feasibility Studies

To select the appropriate pre-treatment technologies for the surface facility design, it was necessary to characterize source water quality and availability. Feasibility tests were conducted for several pre-treatment components to evaluate filtration and disinfection effectiveness. As a result, the KRASR system pre-treatment process consists of a pressure filter and UV disinfection system. The HASR system pre-treatment process consists of a centrifugal filter and UV disinfection system.

14.2.1 Source Water Availability at KRASR and HASR

The Kissimmee River serves as source water for the KRASR system. The intake is located approximately 5 miles south of the S65E flow control structure. Kissimmee River surface water has high, variable color values and total organic carbon concentrations. Dissolved oxygen concentrations vary diurnally and with temperature, but generally range between 4 and 8 mg/L. Kissimmee River water quality is poorer during early wet-season flows (April and May) and is characterized by color values that range from 50 to 250 PCU, and total organic carbon concentrations that range from 10 to 27 mg/L.

Though the ASR withdrawal demands on the Kissimmee River are low relative to stream flow, it was necessary to compare this demand against the flow frequency data for the structure that supplies the KRASR. Average monthly flow data recorded between 1958 and 2012 show a mean monthly flow rate of approximately 1,000 cfs through the S65E control structure. The 5 MGD (7.7 cfs) demand for the ASR system represents less than one-tenth of a percent of this flow. This comparison confirms that there is sufficient water in the river to support ASR withdrawals.

The Hillsboro Canal (L-29) serves as source water for the HASR system, where the intake is located approximately 0.5 mile east of the S-39 structure. Hillsboro Canal surface water is characterized by low turbidity and TDS concentrations, and high color and total organic carbon concentrations. Flow through the Hillsboro Canal adjacent to HASR is controlled by water control structure S-39 upstream and G-56 downstream. After water supply demands are met, G-56 discharges excess water to the tide. Historical flow values for G-56 discharges typically represent water that can be captured for the ASR system storage. The average daily discharge at G-56 for any single day recorded between 1986 and 2001 varies from approximately 500 cfs in January to 9 cfs in May. The one MGD (1.55 cfs) flow rate at the HASR intake is sufficient to capture excess flow at G-56 except during extreme drought. Discharge of recovered water into the Hillsboro Canal to augment flow is more likely than recharge during drought periods.

14.2.2 Pre-Treatment Feasibility Study Results and Conclusions

The feasibility studies summarized below supported surface facility designs at the KRASR and HASR sites.

14.2.2.1 Pre-Treatment Using Mechanical and Sand Filtration Plus Disinfection

Carollo Engineers (2003) designed pilot-scale treatment trains consisting of bank filtration with ozonation and/or UV disinfection. The tests were performed near the proposed Port Mayaca ASR site on Lake Okeechobee. The system consisted of a mechanical separation unit (either a wedge-wire screen or cyclone separator) and sand filter (to serve as the bank filtration unit) to remove particulates and turbidity, with ozone or UV disinfection.

Sand filtration improved a number of water quality characteristics while the wedge-wire screen and cyclone separator proved to be ineffective for filtration. The ozone dose required to achieve disinfection goals led to bromate concentrations that exceed drinking water standards. Lower ozone doses were insufficient to consistently meet disinfection goals, but could be used to reduce color, taste, and odor causing compounds to increase the effectiveness of UV disinfection. UV disinfection in this particular system did not result in total coliform concentrations below the drinking water criterion. However, hydraulic short circuiting in the test system and the less than optimal sampling location may have contributed to poor results. The study inferred that a full-scale UV disinfection system was not likely to experience adverse conditions, and would meet the disinfection requirements.

14.2.2.2 Microfiltration Study Conclusions

HSA Engineers and Scientists (2003) tested a microfiltration unit and a serial filtration unit using Lake Okeechobee source water. The performance of the 0.2-µm microfilter successfully met primary and secondary drinking water standards. Fecal coliforms were reduced from an average of 55 CFU/100 mL to below detection level. Turbidity also was reduced to below 0.3 NTU. Backwash times were not excessive, but backwash volume (>88,000 gal) represents 20 percent of the process run volume. This requires that microfilters to be rated 20 percent above design to achieve full performance. The serial filtration unit consisting of a 20-µm multimedia filter followed, by 5-, 1-, and 0.45- µm cartridge filters in series proved to be unreliable for removal of fecal coliform or turbidity in the influent source water.

14.2.2.3 Screen Filtration Study Conclusions

TeKleen filter systems (PBS&J, 2004) were tested at the proposed Port Mayaca and Hillsboro ASR sites. Use of 100-, 50-, and 10- µm filter screens did not achieve significant removal of particulates at the either site.

14.2.2.4 Conclusions Based on Treatment Technology Feasibility Studies

Feasibility studies that are described in **Section 4** were conducted to define appropriate pre-treatment elements for the ASR systems, and to provide data for subsequent USACE design efforts. The final design recommendations for the surface facilities at both KRASR and HASR are defined in the Pilot Project Design Report (PPDR) (USACE, 2004). Based on the studies summarized above plus additional design work by the USACE, the following alternatives were recommended:

KRASR: In-Bank Surface Water Intake + Pressure Media Filter + UV Disinfection

HASR : In-Bank Surface Water Intake + Mechanical Filter + UV Disinfection

14.3 Surface Facility Engineering and Design Summary

The KRASR system consists of the following components in series: a source water intake, recharge pump station and wet well, pressure filter, UV disinfection units, an ASR well with recovery pump, a backwash equalization pond, a decant pump station, a backwash solids pump, and a cascade aerator.

The recharge system consists of a submerged intake structure connected to a recharge pump station to deliver surface water to the treatment components. The pump pressurizes water to pass through the pressure filter, UV disinfection units, then into the aquifer. A pressure filter removes suspended solids and the UV disinfection system disinfects recharge water upstream of the ASR well.

The KRASR surface facility is connected to the aquifer through the ASR well, which transmits treated recharge or recovered water. The UV disinfection system consists of 3 flow-through reactors to attenuate coliforms prior to recharge in the ASR well. The ASR well utilizes a vertical turbine constant speed pump to withdraw water from the well during recovery. Small volumes of recovered water that do not meet surface water quality criteria can be routed to the backwash equalization pond or raw water wet well. Generally recovered water is discharged directly to the cascade aerator. The backwash equalization and solids storage ponds were constructed to manage filter backwash and turbid “first flush” water from the ASR well.

The HASR system consists of a source water intake with recharge pump, mechanical filtration (80 µm screen), UV disinfection units, and ASR well with recovery pump, appurtenances to transfer water from the well to an adjacent pond, and an outflow structure for re-aeration of recovered water.

The HASR surface facility is connected to the aquifer through the ASR well, which transmits treated recharge or recovered water. The UV disinfection system consists of 2 flow-through reactors to attenuate coliforms prior to recharge in the ASR well. The ASR well utilizes a vertical turbine constant speed pump to withdraw water from the well during recovery, identical to that at KRASR. Small volumes of recovered water that do not meet discharge water quality criteria can be diverted to an adjacent pond. Generally, recovered water is discharged directly to the cascade aerator. Filtered water is injected into the well between the pump column and the well casing. The backwash equalization and solids storage ponds were constructed to manage filter backwash and turbid "first flush" water from the ASR well.

14.3.1 KRASR Surface Facility Design – Lessons Learned

Future designs for a single-well, 5-MGD capacity ASR system should consider the following "Lessons Learned" that result from issues resolved during construction and cycle testing operations at the KRASR system. Overall objectives are to improve cost-effective operation by reducing power requirements and on-site labor for operational oversight.

- A more robust UV disinfection system is required so that operations proceed in regulatory compliance. UV disinfection is the preferred technology because residual water treatment solids are not produced, there are no on-site storage requirements for caustic compounds, and no disinfection by-product compounds form during treatment. The UV disinfection system should perform under outdoor weather conditions, unless a shelter is designed for that component. For ASR systems constructed in the Kissimmee River basin, UV disinfection equipment should have a specified disinfection dosage of 80 mJ/cm^2 to overcome high color values. Higher disinfection dose should reduce the occurrence of total coliform detections during recharge.
- The electrical design for the UV power supply should be routed through overhead conduit, rather than underground. Saturated subsurface conduits required replacement and rewiring of all the cables prior to cycle testing.
- The specifications for the SCADA and PLC systems require more detail for remote (off-site) control of the system. The SCADA and PLC at the KRASR system required significant upgrade and programming in order to operate the KRASR facility remotely, and to avoid unnecessary automatic shut-downs. The KRASR system was monitored and controlled remotely during cycle tests 3 and 4.
- The pressure filter is effective for turbidity reduction only during turbid high flow events, but these events are rare. The typical particulate load in the Kissimmee River consists of colloidal (less than 10-µm) particles and turbidity less than 5 NTU. Colloidal particles were not effectively removed by the the sand and gravel media in the pressure filter. Poor recharge water quality (resulting from excessive turbidity and color during storm and wet season flows) can cause rare facility shut-downs. Facility shut-downs result when filter backwash events become so frequent as to impede recharge flow to the ASR well. New ASR system designs should incorporate

current filtration technologies for cost-effective removal of microparticulatesand media that can remove color.

- Use of a variable frequency drive pump, or reducing the 5th pump stage on the existing single-speed turbine pump will result in more cost-effective operation during recharge.
- Sufficient artesian pressure exists at KRASR (12-ft) to enable recovery without pumping. The recovery flow rate through the ASR system pipes and cascade aerator has not been quantified under artesian conditions.
- Include by-pass piping in the original design. The KRASR by-pass piping was installed after construction of the facility, which delayed the onset of cycle testing.
- The manual “butterfly” flow control valve located between the pressure filter and the UV disinfection system was insufficient for throttling the 5 MGD flow. Stronger valve control is needed.
- The power supply for KRASR operation is adequate for the present system configuration. ASR system expansion will require additional power sources to meet demand.
- The KRASR facility was constructed without assistance of the design engineer of record (CH2M Hill). Retention of the design engineer of record through the construction process would contribute to better QA/QC.
- The on-site storage capacity provided by the two-pond water management system probably was excessive. A single pond would provide the storage capacity required for ASR system operation.

14.3.2 HASR Surface Facility Design – Lessons Learned

Future designs for an ASR system that can be readily expanded should consider the following “Lessons Learned”. These conclusions result from issues resolved during construction and cycle testing operations at the HASR system. There are four overall objectives: 1) to improve cost-effective operation by reducing power requirements; 2) to improve operations while reducing the requirement for on-site labor for operational oversight; and 3) to obtain adequate hydrologic and water-quality data for permit compliance; 4) to maximize percent recovery given brackish native groundwater quality.

- Minimize the time between construction of the ASR well and the surface facility so that storage zone permeability obtained during well construction and development will serve as the condition of operation.
- Reconsider the installation of a “permanent” onsite personnel building, especially if water/wastewater issues for that building are a concern.
- Fully evaluate the purpose and flexibility of any filtration system. Fine-mesh filters were originally installed, only to create operational issues due to clogging.
- Installation of a more robust UV disinfection system.
- A valve dedicated to regulating water flow to and from the ASR well is recommended. The isolation-type valves, which were in the original design, were not adequate for efficient flow control.
- Special attention should be paid to the in-line water quality monitors such as those for specific conductance and dissolved oxygen. The reliability of those monitors proved to be suspect.

- Better coordination is needed during installation of instrumentation and controls, especially with their connections to the SCADA system.

14.4 Conclusions From Treatability Tests Conducted During KRASR System Operation

Bench- and field-scale treatability tests were conducted during cycle tests 1 and 2 at the KRASR system. The objective was to define a suitable coagulant compound and dose rate that would reduce high color values for improved UV disinfection performance. Coagulants tested were: 1) ferric chloride; and 2) aluminum chlorhydrate (ACH). Bench-scale testing of an ion-exchange process for color reduction also was conducted.

Addition of ferric chloride as a coagulant during jar testing indicated that a dose of 50 mg/L (active) was needed to improve UV transmittance (UVT) values to the target of 37 percent UVT. However, residual iron concentrations were elevated significantly, often exceeding the iron water quality criterion exemption concentration of 0.8 mg/L. This treatment option also increased solids production and was not considered for future testing.

Use of aluminum chlorhydrate (ACH) was investigated for color reduction at the bench and field scales. Initial jar test results (bench scale) showed that an effective dose of 20 mg/L (active) of ACH will improve UV transmittance to 25 percent UVT, with aluminum concentrations below the regulatory criterion (0.2 mg/L). This dose was applied to field-scale testing, with addition of ACH into the wet well during recharge. Field-scale testing results differed somewhat from bench-scale test results. The 20 mg/L ACH dose improves UVT and results in lower turbidity, but aluminum concentrations sometimes exceed 0.2 mg/L. Bench- and full-scale testing using the ACH coagulant resulted in minor improvements to filtered water UVT, and reduction in the frequency of total coliform detections. However, residuals production and increased O&M requirements to implement ACH addition are not consistent with CERP operational goals. Coagulant addition was not added to the source water pre-treatment process.

Bench-scale testing of an anion ion exchange process was conducted using a packed-bed, porous ion-exchange resin. An overall improvement in UVT resulted from lower color values in the effluent. The best water quality was obtained with 2 parts of filtered water mixed with 3 parts of ion exchange treated water. The blended transmittance was maintained above 33 percent after six days of testing. Following discussion with the manufacturer, it was determined that the most cost-effective configuration for color removal with ion exchange has a 2-MGD design capacity. A 5-MGD design capacity is not feasible with current ion exchange technology.

14.5 KRASR Permitting and Compliance Conclusions

The KRASR system operates under the requirements of three types of permits. The underground injection control (UIC) permit includes a water quality criteria exemption for iron and color. This permit defines compliance criteria in the aquifer. The national pollution discharge elimination system (NPDES) permit includes a mixing zone exemption for arsenic, and defines compliance criteria in the surface water body that receives recovered water (Kissimmee River). The Comprehensive Everglades Restoration Plan Regulation Act (CERPRA) permit defines compliance criteria for water quality and water supply protection. In the CERP ASR Pilot Projects, CERPRA permit criteria overlap with UIC and NPDES criteria.

The UIC permit includes a water quality criteria exemption for secondary water quality constituents (iron and color). The exemptions are for a maximum iron concentration (0.8 mg/L) and maximum color values (15 PCU), in excess of their respective criteria in the Safe Drinking Water Act (SDWA). An administrative order also was obtained in the event that arsenic concentrations exceeded the SDWA criterion of 10 µg/L, to allow for concentrations up to 50 µg/L in the aquifer. The UIC permit also defines compliance criteria for wellhead pressures. ASR wellhead pressures are limited to a value of 66 psi, which is two-thirds that of the casing pressure test.

Cycle testing operations were in compliance with the UIC permit for all primary constituents except for total coliforms and arsenic. During all recharge events, total coliforms were detected at the ASR well in excess of the 4 CFU/100 mL criterion on one or more occasions. High color values in recharge water reduced the effectiveness of the UV disinfection system, so that coliform inactivation was incomplete and inconsistent. To improve permit compliance, the pressure filter was chlorinated monthly, without recharging the chlorinated effluent. This maintenance task reduced the number of non-compliant samples during cycle test 4. A more robust UV disinfection system is needed for future applications at ASR systems.

Arsenic concentrations were measured in storage zone monitor wells at concentrations that exceeded the 10 µg/L criterion, primarily during recharge and early storage phases of each cycle test. The maximum concentration (140 µg/L) was measured during cycle test 1. By cycle tests 3 and 4, arsenic concentrations declined from the cycle test 1 maximum. The maximum arsenic concentration measured during any phase was 46 µg/L (cycle test 3) and 44 µg/L (cycle test 4). The maximum arsenic concentration declines during late storage and recovery phases of cycle tests 2 through 4 were due to microbe-mediated redox reactions in the storage zone (storage phase) and advective transport (recovery phase). Prior to initiation of recovery during cycle tests 2 through 4, arsenic concentrations declined below the 10 µg/L criterion throughout the KRASR storage zone. All groundwater recovered into the Kissimmee River during cycle tests 2 through 4 showed arsenic concentrations that were below the 10 µg/L criterion. Fewer exceedances occurred for secondary constituents iron and color. Exceedances typically occur during recharge at the start of the wet season or during storms, when the surface water is lowest.

ASR wellhead pressures were below the maximum criterion of 66 psi during all phases of each cycle test. Pressures during the recharge phase of cycle test 1 approached the maximum, most likely the result of carbonate precipitation in the aquifer and/or formation of biofilms. Higher pressures necessitated additional back-flushing of the ASR well during cycle test 1, and then two ASR well rehabilitation events during cycle tests 2 and 3. ASR well rehabilitation was effective, increasing the specific capacity of the

ASR well by approximately 130 percent after the second event. ASR wellhead pressures decline through successive cycle tests as the storage zone is developed during recharge and recovery.

The NPDES permit includes a 50-meter mixing zone exemption for arsenic and chronic toxicity. Surface water analyses of arsenic during cycle tests 1 through 3 showed that arsenic concentrations were below the Clean Water Act criterion (50 µg/L). The KRASR facility was relieved of the arsenic mixing zone monitoring requirements during cycle test 4. Effluent monitoring using chronic toxicity of the water flea (*Ceriodaphnia dubia)* within the 30-meter mixing zone adjacent to the KRASR point-of-discharge remained.

The KRASR facility was largely in compliance with the terms of the NPDES permit. Toxicity testing results indicated that recovered water occasionally exhibits an occaisional condition of chronic toxicity during the latter portion of the recovery phase. The constituent that induces the toxicity response has not been identified, but it does not appear to be related to specific conductance because the incidence of toxicity does not correspond with the greatest specific conductance values. Given that NPDES permit conditions address many surface water quality exceedances through the issuance of mixing zones, future CERP ASR facilities should be located at sites where adequate mixing water is available.

14.6 HASR Permitting and Compliance Conclusions

The most significant permit compliance issues associated with operations at the HASR facility were the frequent exceedances of the total coliform criterion during recharge, and a few arsenic exceedances that were observed in the storage zone monitor wells during storage and recovery. Arsenic exceedances observed in monitor wells indicate that the terms of the arsenic administrative order were violated since it is possible that arsenic exceedances occurred off of the project lands. If future ASR operations continue at HASR, a more robust disinfection system is needed to ensure that total coliforms in the recharge water are maintained below the 4 CFU/100 mL drinking water standard. Given the declining concentrations of arsenic observed at HASR, it is probable exceedances of the groundwater quality standard for arsenic during future ASR operations will be infrequent. The probability that elevated arsenic will leave the property boundaries will also decrease.

During the three recovery events at the HASR system, the recovered water met the surface water quality requirements for all parameters defined in the NPDES permit, with the exception of a few arsenic samples obtained during the early portion of the recovery phase. Toxicity testing conducted during the three recovery events all indicated that the water was not acutely toxic.

A water quality criteria exemption was issued for the HASR system in conjunction with the UIC permit. During the three recharge and storage phases, there were several drinking water standard violations observed either in the recharge water as it was being pumped into the aquifer, or at the monitor wells. Gross alpha exceedances were detected occasionally in the storage zone and the Lower Floridan Aquifer during the third cycle test. However, all gross alpha analyses at the point of discharge during recovery were below the regulatory criterion (15 picocuries/L).

14.7 Construction of ASR Pilot Systems

ASR systems consist of two types of infrastructure: a surface facility, and an associated monitoring wellfield. The surface facility houses infrastructure for power supply, water treatment, and pumps and associated appurtenances to convey water between the surface water body and the aquifer. A monitoring wellfield is associated with each ASR system to acquire water quality and hydraulic data for permit compliance and technical evaluations.

14.7.1 KRASR Construction Cost Summary

The design and construction phases at KRASR pilot system differs somewhat from that of a permanent water control structure because the facility has a short, finite period of operational testing. The facility is fully functional for the intended testing period, and in fact has successfully performed longer (4 cycle tests, 4.5 years) than the original 2-year duration. All construction issues were resolved (at extra cost) by refining the design and the plans and specs. The ASR system will be transferred to the SFWMD as fully operational, although additional permits will be required for future cycle tests.

The most difficult problem to resolve during the construction phase was stabilization of the facility foundation and intake structure. This problem was resolved by extending the fabriform apron to a lower elevation in the river, and extending the apron and fill into surface runoff drainage swales.

The contract construction cost for KRASR was $5,788,863. The cost of modification was $349,391 which brought the total cost to $6,138,254. The total cost for ASR and monitor well construction at KRASR was $1,741,171.

14.7.2 HASR Construction Cost Summary

The contract construction cost for the HASR surface facility was $2,240,000. The ASR and monitor wells were constructed under separate contracts from surface facility construction. The total construction cost for the ASR well, two storage zone monitor wells, an APPZ well, and a LFA well (all SFWMD lands) was $2,081,000.

14.8 Hydrogeological Setting and Hydraulic Characteristics Summary

Many of the stakeholder concerns about ASR operations focused on evaluating how far and how fast recharge water would be transported through the storage zone during cycle testing. Therefore, characterizing aquifer properties and development of site-specific groundwater flow and solute transport models was a significant effort during ASR system operational testing.

14.8.1 KRASR Hydrogeology, Hydraulics, and Rock Fracturing Potential

The storage zone occurs within the Ocala Limestone and uppermost Avon Park Formation at a depth range of -550 to -870 ft NGVD29. The storage zone is in the UFA, with overlying confinement by the ICU (Hawthorn Group, lower Arcadia Formation), and underlying confinement by the MC1 (upper Avon Park Formation). Permeability is not uniformly distributed with depth in the KRASR storage zone. An interval of preferential flow exists at the upper 20-ft of the storage zone, and this interval accounts for 63 percent of the natural groundwater flow in the upper FAS. During cycle test 2 recharge, the apparent linear flow rate at the 350-ft SZMW is 117 ft/day. During cycle tests 1 and 3 recharge, the apparent linear flow rates at the 1,100-ft SZMW are approximately 55 to 58 ft/day. Flow rate slows farther from the pumping stress.

Aquifer properties were estimated from aquifer performance testing during cycle testing. Transmissivity estimates using the Hantush-Jacob solution ranged between 20,100 ft^2/day and 36,500 ft^2/day, which are consistent with earlier transmissivity estimates obtained during ASR well construction. Storage coefficients estimates using the Hantush-Jacob solution are 0.00014, 0.00005 and 0.00007, which are lower than earlier estimates.

A local-scale groundwater flow and solute transport model was developed and calibrated using the SEAWAT v. 4 code. The preferential flow zone was incorporated into these simulations, and shows that recharge water flows faster and farther through this zone compared to permeable units lower in the storage zone. This model can be used to assess multiple aspects of an ASR system, including drawdown, recovery efficiency, freshwater “bubble” extent, well spacing, and well-to-well interactions.

Geotechnical evaluation of rock fracturing potential at KRASR indicates that the only possible failure mode is microfracturing, and that microfracturing is unlikely to be propagated into the overlying confining unit at typical operating pressures. The minimum wellhead pressure that would generate microfracturing at KRASR is 89 psi, which includes a 10 percent factor of safety. ASR wellhead pressures never exceeded 66 psi throughout the cycle testing program.

14.8.2 HASR Hydrogeology, Hydraulics, and Rock Fracturing Potential

The storage zone occurs within the lower Arcadia Formation and the Avon Park Formation, at depths of approximately -997 ft to -1,212 ft NGVD29. The storage zone includes the UFA, with overlying confinement by the ICU (Hawthorn Group, lower Arcadia Formation), and underlying confinement by the MC1 (upper Avon Park Formation). Permeability is not uniformly distributed with depth in the HASR storage zone. A flow zone was interpreted from geophysical flow log data at the top of the UFA (approximately -972 ft to -1,007 ft NGVD29. Detailed permeability and porosity characterization was interpreted from a unique geophysical study that incorporated NMR, sonic, and seismic reflectivity data through the storage zone. The storage zone consists of two high permeability units separated by a low permeability/high porosity unit.

Aquifer properties were estimated from aquifer performance testing during cycle test 1. The best estimate of transmissivity was obtained with the Hantush-Jacob solution using recharge phase data, at 20,600 ft^2/day. This value differs from that estimated during construction of the ASR well (8,104 ft^2/day), but is consistent with other estimates of transmissivity in the UFA in the region. Best estimates of storage coefficients were obtained with the Hantush-Jacob solution using recharge phase data, with values of 0.0001.

A local scale groundwater flow and solute model of the HASR system was developed and calibrated using the SEAWAT (v. 4) code. The calibrated model was able to reasonably reproduce head impacts observed during cycle testing, and was also used to evaluate different well spacings in an expanded HASR system.

Geotechnical evaluation of rock fracturing potential at HASR indicates that the only possible failure mode is microfracturing, and that microfracturing is unlikely to be propagated into the overlying confining unit at typical operating pressures. The minimum wellhead pressure that would generate microfracturing at HASR is 149 psi, which includes a 10 percent factor of safety. ASR wellhead pressures never exceeded 99 psi throughout the cycle testing program.

14.9 Cycle Testing Summary

14.9.1 KRASR Cycle Testing Results and Conclusions

The overall cycle testing goal for KRASR is to evaluate the feasibility of multi-year water storage. This ASR system is intended to have progressively longer recharge periods leading to large-volume storage, with subsequent distribution during periods of low water level. Cycle testing commenced in January 2009, and was completed in July 2013. Each successive cycle test had longer total duration, with longer recharge phase and therefore larger storage volume. Cycle test 4 was the longest (2 year duration), with the greatest volume in storage (nearly 1 billion gallons), and with the longest storage period (approximately 1 year). This cycle test was one of the largest single-well recharge events conducted to date in Florida. Cycle tests 2 through 4 at KRASR were completed with approximately 100 percent recovery. Native groundwater is fresh at this location, so recharge water quality is not degraded by mixing with brackish water in the storage zone.

The existing UV disinfection system provides inadequate attenuation of total and fecal coliforms in treated Kissimmee River recharge water. Inadequate attenuation occurs particularly at the onset of the wet season when surface water quality has high color values. Total coliforms and cyanobacteria are detected in the storage zone, primarily during the recharge phase. At KRASR, total coliforms were detected (4 CFU/100 mL) in 35 percent (60 of 171 samples) of all storage zone groundwater samples during recharge. Total coliform detections declined to 2 percent in storage phase samples, and to 3 percent in recovery phase samples. Total coliform detections during storage and recovery probably include wellhead sample contamination, as coliforms are expected to die off during long storage durations.

Mobilization and subsequent attenuation of arsenic was demonstrated during successive cycle tests at KRASR. Arsenic is mobilized during recharge phase of each cycle test by pyrite oxidation, resulting in concentrations that exceed the 10 μg/L regulatory standard during the recharge and early storage phases of each cycle test. Arsenic mobilization is a temporary condition at KRASR, due to the interaction of organic- and iron-rich surface water with sulfate-reducing conditions of the UFA. A published geochemical modeling study shows that arsenic is re-precipitated as a sulfide solid during storage and recovery in the storage zone. Arsenic concentrations measured in recovered water at the ASR well show concentrations less than 10 μg/L during cycle tests 2 through 4.

Molybdenum is mobilized during recharge of each phase most likely by pyrite oxidation, resulting in significant concentration increases in the storage zone. The maximum molybdenum concentration (approximately 500 μg/L) was measured during the recharge and storage phases of cycle test 1. Maximum concentrations declined in storage zone samples during cycle test 4 recharge and storage phase, to less than 180 μg/L. Storage zone concentrations sometimes exceed the 70 μg/L World Health Organization guideline for drinking water.

Phosphorus is attenuated during KRASR cycle tests 1 through 4. The mean phosphorus concentration in recharge water is 55 +/- 42 μg/L; the mean phosphorus concentration in recovered water is 7.9 +/- 10 μg/L. The mechanism for phosphorus attenuation is probably microbiological metabolism and/or calcium phosphate (apatite) precipitation.

Mercury and methyl mercury concentrations are attenuated at a statistically significant level in the aquifer during KRASR cycle tests 1 though 4. Mercury and methyl mercury concentrations in recovered water during all cycle tests at the ASR wellhead or point of discharge were nearly at their respective minimum detection limits. All mercury analyses are less than the 12 ng/L surface water quality criterion; there is no surface water quality criterion for methyl mercury. The mechanism for mercury attenuation has not yet been identified.

There is no statistically significant temporal change in surficial aquifer water quality during cycle tests 1 through 4. Variations over time in total dissolved solids and chloride concentrations probably respond to variations in infiltration and evapotranspiration in the surficial aquifer.

At completion of cycle test 4, most constituent concentrations were less than or within one standard deviation of the native concentration. Final iron concentrations were higher in the ASR well and 1,100-ft storage zone monitor well compared to the native condition, but all concentrations were below the 0.80 mg/L criterion for the water quality criterion exemption.

14.9.2 HASR Cycle Testing Results and Conclusions

Three cycle tests were completed at HASR system. Cycle testing commenced in January 2010, and was completed in June 2013. The ASR system was shut down for approximately 15 months between cycle tests 2 and 3. The primary cycle test objective was to evaluate the feasibility of annual recharge and recovery, with recharge during the wet season and recovery during the dry season. During cycle test 1 only, the discharge of recovered water was temporarily allowed to exceed surface water quality criteria for specific conductance and chloride. As a result, 85 percent of the recharged water was recovered. Percent recoveries were 21 percent (cycle test 2) and 41 percent (cycle test 3) owing to mixing of recharge water with brackish native groundwater quality at this site.

Total and fecal coliforms were detected infrequently in storage zone samples at HASR. The percent occurrence of total coliforms in the sum of samples during each phase was: recharge (10 percent; all cycle tests), storage (0 percent; all cycle tests), and recovery (4 percent; all cycle tests). Total coliform detections during recovery probably include wellhead sample contamination, as coliforms are expected to die off during long storage durations.

Arsenic is mobilized during recharge of each cycle test phase by pyrite oxidation, resulting in storage zone concentrations that exceed the 10 μg/L regulatory standard during the recharge and early storage phases. The maximum arsenic concentration (102 μg/L) was measured at the ASR wellhead during recovery phase of cycle test 1. Subsequent arsenic concentration maxima in storage zone samples were 19 μg/L (cycle test 2) and 5 μg/L (cycle test 3). Additional data are needed to quantify arsenic trends. However, generally speaking, arsenic concentrations are mostly below the 10 μg/L regulatory criterion throughout the cycle testing program.

Molybdenum mobilization occurs, as shown in the cycle test 3 dataset, but concentrations remain below 12 μg/L in storage zone monitor wells. A molybdenum concentration of 163 μg/L was measured in a single analysis during cycle test 1 recovery at the ASR well, which exceeds the World Health Organization guideline (70 μg/L) for drinking water.

Phosphorus attenuation cannot be confirmed at HASR due to the paucity of data. There is no statistically significant difference in mean phosphorus concentrations between recharge and recovered water samples at the ASR wellhead and point of discharge, respectively.

Mercury attenuation cannot be confirmed at HASR. There was no statistically significant difference in mercury and methyl mercury concentrations when HASR recharge water and recovered water samples are compared.

There is no statistically significant change in surficial aquifer water quality during cycle tests 1 through 3. Changes in total dissolved solids and chloride concentrations probably result from variations in recharge to the unconfined aquifer.

Final water quality condition of the storage zone is fresher than the native UFA, with regard to total dissolved solids and chloride concentrations based on mean concentrations measured during cycle test 3 recovery at the 1,010-ft SZMW.

14.10 Ecotoxicological and Ecological Studies at ASR Systems

An extensive ecotoxicological data collection effort was completed at KRASR to evaluate site-specific effects of recovered water quality on representative aquatic organisms. Four tests (7-day *Ceriodaphnia dubia* (water flea) static renewal chronic toxicity; 7-day *Pimephales promelas* (fathead minnow) embryo-larval static renewal chronic toxicity; 21-day *Daphnia magna* (water flea) life cycle toxicity; and Frog Embryo Teratogenesis – *Xenopus* assay; FETAX) showed no statistically significant difference in test results when surface (recharge) water was compared to controls. The No Observable Effect Concentration (NOEC) for these tests was 100 percent recharge water. These same four tests were conducted using recovered water during cycle tests 1 and 2. All tests except the 7-day *C. dubia* test showed NOEC equals 100 percent. The 7-day *C. dubia* test showed a minimal effect on reproduction during cycle test 1 recovery (IC_{25} of 95.52 percent recovered water). This same test showed an effect on reproduction (NOEC = 50 percent recovered water) with an IC_{25} of 76.41.

Two 96-hour chronic growth tests using *Selanstrum capricornutum* were conducted. One test showed reduced reproduction when exposed to 25 percent recharge water (NOEC = 25 percent recharge water), the other test showed NOEC = 100 percent recharge water.

Bioconcentration studies were performed during cycle test 1 recharge and recovery using *Lepomis machrochirus* (bluegill fish) and *Elliptio buckleyi* (Florida shiny spike mussel), in an onsite flow-through mobile bioconcentration laboratory. The primary objective was to evaluate changing metal concentrations in fish and mussel tissues before and after a 28-day exposure to recharge and recovered waters. Radium isotopes also were analyzed in mussel tissues during this test. At present, only results from the recharge water bioconcentration experiments in fish tissue have been interpreted. Comparison of fish tissues before and after exposure to recharge water shows that arsenic, chromium, mercury, and molybdenum are statistically greater at the end of the 28-day exposure. Additional interpretations will be presented in the ASR Regional Study technical data report.

Periphyton studies were conducted during cycle test 1 recharge and recovery, and cycle test 2 recovery. Cycle test 1 results were constrained by disruption of several stations during the 28-day recovery period, but these samples do provide good taxonomic data. During cycle test 2, periphyton samplers were placed in the Kissimmee River upstream from, adjacent to, and downstream of the POD during recovery. There was no apparent difference in diversity, density, or ash-free dry weights among these samples.

14.10.1 In-Stream Effects of Recovered Water at KRASR

Discharge of recovered water at a rate of 5 MGD (7.7 cfs) is less than one percent of the historical average Kissimmee River flow. The estimated effect of the recovered water plume is within 15-m of the POD. However, recovered water quality characteristics differ from Kissimmee River surface water characteristics, resulting in potential effects on aquatic ecosystems. Recovered water and surface water compositions differ with regard to dissolved gas concentrations, specific conductance, and temperature. Recovered water has greater dissolved oxygen, dissolved sulfide, and ammonia concentrations when POD samples are compared to average surface water concentrations. The co-existence of dissolved oxygen and dissolved sulfide is a disequilibrium condition because sulfide will eventually oxidize in the presence of oxygen. However, total sulfide concentrations at the POD exceed the EPA surface water guideline (2 μg/L), which may require re-evaluation of the cascade aerator design. Concentrations of un-ionized ammonia (the toxic species) are below the surface water criterion (0.02 mg/L) in all POD samples.

Temperature contrasts are most evident when warmer recovered water is discharged into cooler Kissimmee River water during winter months. Warm, oxygenated water could serve as a refugium for fish and potentially manatees in the immediate vicinity of the POD. The presence of warmer water during the winter could also affect spawning of black crappie and largemouth bass, and this potential effect requires further study.

14.10.2 First Flush Analysis at KRASR and HASR

"First flush" analyses characterize water quality of the initial volume of turbid recovered water. At KRASR, the concentrations for all constituents (including metals) in unfiltered samples were below surface water quality criteria. Comparison of metal concentrations (iron, arsenic, molybdenum) in filtered and unfiltered water samples suggests that metals tend to associate with the solid phase, which would be particulates in recovered water. Typical ASR system operation diverts turbid water to the backwash solids and equalization ponds until turbidity values are less than 29 NTU, so particulates are not discharged into the Kissimmee River.

The "first flush" of recovered water from HASR cycle testing was characterized by a single turbid sample (881 NTU) obtained on the first day of the cycle test 1 recovery phase. This water was diverted to an adjacent storage pond, not the Hillsboro Canal. This sample was not filtered, so data represent a bulk "water plus particulate" analysis. Of these metals, concentrations of the following exceeded drinking water and surface water quality criteria: iron, 2.42 mg/L; arsenic, 111 μg/L; beryllium, 0.23 μg/L; copper, 100 μg/L; and silver, 0.079 μg/L.

14.10.3 Fish Larvae Entrainment Investigation at KRASR

A qualitative fish fry entrainment study was inconclusive due to difficulty sampling the intake stream. Few larval fish but abundant zooplankton appeared in the few samples that were obtained through the intake screen into the wet well during recharge. More entrainment is likely during nighttime. A better sampling method is necessary to quantify fish fry entrainment.

14.11 ASR System Operational Costs

The operational cost information was subdivided into three phases of operation: recharge, storage, and recovery. Cost estimates were developed using average historical cost information from cycle tests 2, 3, and 4 at KRASR. An important metric of plant operational cost and efficiency is the cost normalized by the volume stored for a specific phase. This metric is only relevant to recharge and recovery phases since no water is transmitted during the storage phase.

14.11.1 KRASR Operational Cost Summary

The total monthly average cost per million gallons of water at KRASR was $401 during recharge and $256 during recovery. The cost of labor and power were the most significant portions of the operational costs during the recharge and recovery phases. Although power consumption was minimal during the storage phase, there were still labor costs and costs for additional services to be paid.

14.11.2 KRASR Water Quality Monitoring Costs Summary

Water quality monitoring costs are broken down by cycle test phase (recharge, storage, and recovery) at KRASR. Monitoring costs are further broken down to separate costs for regulatory compliance from costs for non-permit geochemical analyses. Monitoring costs consist of four components: analytical costs, labor costs, and miscellaneous (supplies and mileage) costs. The KRASR cycle test 3 monitoring plan was the most expensive ($292,500) because the wellfield was sampled weekly for one full year. Regulatory compliance costs (approximately $174,200) exceeded geochemical sampling costs ($118,270) in part because frequent total coliform detections during recharge triggered extended microbiological (including pathogens and phages) sampling once a month. Reduction of sampling frequency to biweekly and monthly during cycle test 4 resulted in a cost savings of approximately 30 percent.

14.11.3 HASR Operational Cost Summary

The total monthly average cost per million gallon of water stored at HASR was $147 during recharge and $104 during recovery. The cost of power was the most significant portion of the operational costs during the recharge and recovery phases. Maintenance costs were calculated in lieu of labor because the system was designed to operate with minimal labor. Again, although power consumption was minimal during the storage phase, there were still costs for maintenance and general services to be paid.

14.12 ASR Pilot Projects Address Stakeholder Concerns

The following summarizes how operational testing at KRASR and HASR addressed stakeholder concerns identified by the ASR Issue Team and in several National Research Council reports. Several of these concerns require consideration of ASR over larger basins, so those will be addressed in the technical data report of the ASR Regional Study.

14.12.1 Summary and Responses Stakeholder Concerns

Issue 1 focuses on the suitability of surface water as a source for ASR recharge. Specifically, is surface water quality sufficient for recharging the UFA with minimal pre-treatment, yet able to maintain regulatory compliance?

Response: Surface water quality was characterized at all proposed CERP ASR systems (five samples per site during 2002) prior to cycle testing for inorganic and organic constituents, including primary and secondary contaminants. These data indicated that water quality criteria exemptions were necessary for color and iron, as surface water concentrations exceeded regulatory criteria at KRASR. There were few detectable organic contaminants (mostly petroleum compounds), but their concentrations did not exceed regulatory criteria at KRASR and HASR. During cycle testing at KRASR and HASR, recharge water quality was analyzed weekly at the ASR wellhead primarily for major and trace inorganic constituents, nutrients, and other analytes required for regulatory compliance. Recharge water at both HASR and KRASR is characterized by high color values, and this reduces the performance of the UV disinfection system resulting in non-compliance at both systems with regard to total coliforms. High total organic carbon concentrations at KRASR and HASR led to formation of biofilms in the ASR well, but well performance was improved through periodic rehabilitation.

Issue 2 focuses on hydrogeologic data acquisition to refine the regional hydrogeologic framework, and define hydraulic properties and native water quality of the Upper Floridan Aquifer.

Response: This issue will have greater resolution in the ASR Regional Study, which includes a regional groundwater model, a revised hydrogeologic framework, and a native Floridan aquifer system characterization study for south Florida. Site-specific hydrogeologic characterization is complete at the KRASR and HASR systems. Samples acquired and data analyzed consist of: 1) core samples obtained during ASR and monitor well construction, which were analyzed for lithological and geotechnical characteristics; 2) borehole geophysical logs obtained during monitor well construction, which were analyzed for lithological and hydrological characteristics; 3) hydrologic parameters, which were estimated from aquifer performance tests; and 4) native groundwater quality characterization at KRASR and HASR, which consisted of major and trace dissolved inorganic constituents, nutrients, selected radionuclides, and water quality parameters.

Issue 3 focuses on the potential for hydraulic fracturing in representative storage zone lithologies at typical operating wellhead pressures, and the potential for upward migration of recharge or formation waters into shallower aquifers.

Response: Rock samples from representative storage zone and confining unit lithologies were tested to determine the most likely failure mode and pressure threshold that would induce rock failure. The most likely failure mode was microfracturing, and the pressure threshold to induce this type of failure is 89 psi at KRASR, and 149 psi at HASR. These pressure thresholds are above typical operational wellhead pressures during recharge. The results were published as a peer-reviewed journal paper (Appendix K).

No water-quality changes resulted from cycle testing in the overlying surficial aquifer (KRASR and HASR), or intermediate confining unit (KRASR).

Issue 4 focuses on potentially large sub-regional and regional hydraulic head increases from multiple ASR systems recharging into fresh and brackish aquifer systems.

Response: The development of a three-dimensional ground water flow and solute transport model is a major effort of the ASR Regional Study. The model will evaluate changes in head and water quality that result from regional-scale implementation of ASR in south Florida. However, hydrogeologic and hydraulic data collection at each pilot system (Issue 2) contributed to the ASR Regional Study model, and also enabled evaluation of storage zone hydraulics at KRASR and HASR.

Issue 5 focuses on quantifying the magnitude, duration, variety of water quality changes that occur during cycle testing.

Response: A robust water quality monitoring program was implemented at KRASR specifically to define the timing and magnitude of water quality changes during ASR cycle testing. A large dataset was developed based on weekly sampling of an expanded monitoring wellfield. Data acquired clearly defines the magnitude, extent, and duration of arsenic mobilization and attenuation, molybdenum mobilization and transport, phosphorus attenuation, and other significant water quality changes. Results indicate that water quality actually improves during storage with regard to nutrients. The water quality monitoring program implemented at HASR focused mainly on evaluation of regulatory compliance.

Issue 6 focuses specifically on mercury and methyl mercury transport and fate during cycle testing. The source of mercury and methyl mercury is surface water, but geochemical conditions in the UFA may or may not promote conversion of mercury to more toxic methyl mercury, thus increasing the toxicity of recovered water.

Response: The water quality data set acquired at KRASR clearly shows that mercury is not methylated during storage under the sulfate-reducing redox conditions of the storage zone. Comparison of recharge and recovered water concentrations of mercury and methyl mercury show statistically significant declines during storage during each KRASR cycle test.

Issue 7 focuses on optimizing operations to maximize the percent recovery at representative ASR pilot systems.

Response: The relationship between aquifer characteristics and recovery rates could not be evaluated at the CERP ASR pilot systems because recovery rate at both sites was by design at approximately 5 MGD. Percent recoveries were calculated at both KRASR and HASR. At KRASR, the percent recharge volume recovered ranged from 90 to 143 percent, the latter representing over-recovery during cycle test 1. Typically, approximately 100 percent of the water recharged at KRASR can be recovered due to fresh groundwater quality in the UFA at this location. At HASR, lower percent recoveries (21 percent, cycle test 2; 41 percent, cycle test 3) result from mixing with brackish groundwater. However, percent recoveries improved with successive cycles.

Value engineering studies were conducted throughout the cycle testing program to optimize cost-effective operation of various components of the KRASR system. Value engineering studies focus on 1) chemical addition for pre-treatment of recharge water; 2) filter media alternatives; and 3) recharge and recovery pump modifications and the use of artesian pressure for recovery.

14.13 Value Engineering Studies

Value engineering studies were performed to evaluate several operational options at KRASR. These include pumping with Variable Frequency Drive pumps, alternatives to minimize UV power consumption, filter media alternatives for color reduction, utilization of artesian pressure for the recovery phase, and onsite power generation.

14.13.1 Summary of Value Engineering Studies at KRASR

Power settings of the UV disinfection system were evaluated to determine whether power consumption could be reduced while still maintaining complete inactivation of total coliforms. The results showed that a change in the power setting from high to medium mode would cause an energy reduction of approximately 11 percent. UV disinfection system performance testing was conducted during the recharge phase of cycle test 2 (2009 and 2010). The performance test results were unsatisfactory, in that the disinfected recharge water did not meet the 3-$\log_{10}$ removal (required in specifications) or a consistent concentration of 4 CFU/100ml or less for total coliforms. Unfortunately, it was not possible to run the UV disinfection system at low or medium power settings during cycle testing at KRASR.

Modification of the pressure filter media was evaluated to reduce backwashing frequency and color in recharge water. To evaluate various media configurations, a four-filter column configuration was tested with influent solutions consisting of coagulant (aluminum chlorhydrate) and recharge water. Although some treatments improved water quality by reducing color, these alternatives were not pursued further. Modifications consisted of chemical treatment which is inconsistent with the operational goals of minimal oversight and reduced O&M costs required for CERP ASR systems.

The recovery pump design was evaluated for costs savings. New and expanded ASR systems can reduce operations costs through the use of a VFD recovery pump. At KRASR, the recovery pump operates at a single speed, and is oversized for this system. Removal of one stage of the 5-stage pump would reduce power consumption, yet still maintain a 5-MGD flow rate required during recovery. Additional costs savings can be realized by eliminating the recovery pump entirely, and utilize existing artesian pressure to recover through the ASR well. Water stored in the FAS can be recovered at KRASR through the ASR well at a flow rate of 5 MGD under natural artesian pressure without pumping. The removal of the recovery pump and reliance on artesian pressure would result in an estimated monthly savings of $8,320 during 24 hour-per-day recovery phase operation.

Alternative power supplies to KRASR were evaluated as a way to reduce power supply costs. Considering the location of the KRASR system, the most feasible options available are on-site power generation using a solar and/or hydro system that would either completely or partially reduce the load on the existing conventional system. Expansion of the KRASR system to include multiple wells will require a detailed evaluation of power supply constraints and alternatives.

The VE studies highlight several recommendations that can be incorporated into the design of future ASR facilities. Use of a VFD pump will control pumping costs associated with over-pumping to maintain pressure in the well during recharge. The use of artesian pressure in lieu of recovery pumps would save on operations costs.

14.13.2 Common Value Engineering Practices at Multiple ASR Facilities

The following list outlines various common VE considerations identified during cycle testing and optimization of the surface facilities that should be considered for future CERP ASR sites:

- **Increased Percent Recovery:** Recovery efficiency is defined as the percentage of the water volume stored during an operating cycle that is subsequently recovered while meeting a target water quality criterion. Additional considerations that would affect the recharge or recovered volume include well plugging (lack of cleaning and rehabilitation), specific site hydrogeology, native groundwater quality, and regulatory requirements.
- **Source Water Supply Planning**: Locate ASR sites to minimize pre-treatment and need for color and TDS reduction, thus minimizing UV dosage and energy demand for effective coliform inactivation.
- **Site Location Selection:** Selection criteria should include potential use of existing well, local economic health, proximity to other sites for efficient operation and maintenance, sludge storage availability, proximity of landfill and other critical resources, and proximity to existing wells for potential re-use for monitoring and/or recharge during ASR operations.

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