Aquifer Storage and Recovery Plan

SCIENCE PLAN

VERSION 2

FINAL - DECEMBER 2024

Ecological Studies: Periphytometer and Plate retrieved from C38S site

L63N Drilling Site

C59 Continuous Core Material, 1820-1830 feet below land surface

Aquifer Pump Test at C38S

USACE ERDC Membrane Pilot Test

C38S Drill Site for Test Wells

PREFACE

The South Florida Water Management District (SFWMD) and the United States Army Corps of Engineers (USACE) updated the Aquifer Storage and Recovery (ASR) Science Plan to address uncertainties identified in the 2015 National Research Council (NRC) review of the ASR Regional Study Final Technical Data Report and the 2021 and 2022 Independent ASR Science Plan Panel. This version of the Plan serves as an update to the inaugural 2021 and the Draft 2022 ASR Science Plan versions. Studies discussed herein will be conducted as ASR wells are constructed in a phased manner. A brief history of the Comprehensive Everglades Restoration Plan (CERP) ASR program is provided here for context.

The 1999 Central and Southern Florida Project Comprehensive Review Study (Restudy) identified the potential use of ASR technology as a means of storing water in aquifers for later use. Acknowledging this unprecedented scale of proposed use of ASR technology, the Restudy recommended construction of pilot projects and development of a regional evaluation of the effects of large-scale use of ASR in South Florida. The plans for these projects were developed and reviewed by the NRC during 2001 and 2002.

The results of the construction and testing of the ASR pilot projects along the Hillsboro Canal and C-38 Canal were published in 2013 (CERP ASR Pilot Project Technical Data Report) and 2015 (CERP ASR Regional Study Final Report). The investigations determined that up to 80 ASR wells could be constructed in the vicinity of Lake Okeechobee. The CERP ASR Regional Study Final Technical Data Report was reviewed by the NRC in 2015. The NRC concurred with the report findings but identified some uncertainties and topics that warranted further investigation.

In 2020, USACE and SFWMD released the Final Integrated Project Implementation Report and Environmental Impact Statement (PIR/EIS) for the Lake Okeechobee Watershed Restoration Project (LOWRP). The Recommended Plan identified in the LOWRP PIR/EIS included 80 ASR wells, a wetland attenuation feature (shallow impoundment), and two areas of wetland restoration. During public review of the PIR/EIS, stakeholder concerns were raised about the remaining ASR uncertainties highlighted by the NRC review. During the July 2019 Governing Board meeting, the SFWMD committed to developing a plan for scientific research, investigating the uncertainties as ASR wells are constructed in a phased manner. The 2021 ASR Science Plan was a result of that commitment.

Concerns related to acceptability and cost of the LOWRP Recommended Plan, received during state, agency, and tribal review of the Draft Report of the Chief of Engineers, resulted in direction to refine the Recommended Plan by removing the above-ground storage component (wetland attenuation feature) and its 25 associated ASR wells. In 2022, the SFWMD and USACE released the Third Revised Draft PIR/EIS for the LOWRP. The Revised Recommended Plan identified in the LOWRP PIR/EIS includes 55 ASR wells and two wetland restoration sites.

The ASR Science Plan is intended to be updated as needed as the ASR program is implemented, and as data and science become available. The previous updates to the ASR Science Plans were made based on the guidance from an independent ASR peer-review panel (PRP) of eminent Florida scholars and scientists. The document provides an update of the ongoing studies and future investigations that will take place as the ASR program moves forward.

Since the publication of the 2021 and 2022 ASR Science Plan and the release of the 2022 Third Revised Draft LOWRP PIR/EIS, the USACE has remaining uncertainties associated with ASR technology on a large-scale. The USACE has requested that their Engineering Research and Development Center (ERDC) conduct scientific studies that address water quality concerns, construction cost, Operation and Maintenance (O&M) cost, and well recovery performance. The results of these studies will be included in updates of the ASR Science Plan as they become available. The Final Revised LOWRP PIR/EIS is anticipated to be completed and submitted for Congressional authorization in 2028 or 2030 for the wetland and ASR components subsequent to completion of the ERDC studies which are anticipated to be completed in 2026. The updated versions of the ASR Science Plan will be reviewed by the ASR Science Plan PRP, to be kept apprised of the investigations' findings and to assist in developing future studies that ensure ASR technology is implemented in a science-led, phased approach. This publication continues the commitment of the SFWMD and USACE to communicate with the public as work progresses toward restoration of the South Florida ecosystem.

CONTRIBUTORS

The South Florida Water Management District gratefully acknowledges the many professionals who have contributed to this ASR Science Plan update. This document was updated collaboratively by a team of scientists, planners, and engineers with participation and valuable input from the South Florida Water Management District, United States Army Corps of Engineers, United States Geological Survey, and their technical consultants. The professionalism and dedication of the outstanding experts who prepared this complex and important document are sincerely recognized and appreciated.

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EXECUTIVE SUMMARY

Aquifer storage and recovery (ASR) is the storage of water in an aquifer using a dual-purpose well that is used for both recharge and recovery. ASR technology offers the potential to store and supply large volumes of water on a relatively small real estate footprint. As such, it is a vital component of the Comprehensive Everglades Restoration Plan (CERP) implemented by the South Florida Water Management District (SFWMD) and the United States Army Corps of Engineers (USACE). CERP is intended to capture, store, and redistribute fresh water and improve the quantity, quality, timing, and distribution of water for the natural system while providing for other water-related needs of the region, including water supply and flood protection. To achieve the intent of CERP, there is a critical need for new water storage due to extensive losses of natural storage in the system.

Despite the potential benefits of ASR, there are some technical uncertainties regarding the regional effects of large-scale ASR implementation. The technical uncertainties were identified in the National Research Council's (NRC's) 2015 review of the ASR Regional Study Final Technical Data Report. To reduce critical scientific uncertainties, the SFWMD and USACE developed the ASR Science Plan in 2021, describing potential studies to be conducted as ASR wells are implemented in a phased manner with review and input from an independent peer-review panel (PRP) of experts. The ASR Science Plan is intended to be a living document, updated and reviewed by the PRP on an as-needed basis. The proposed scope, schedule, and budget for ASR Science Plan studies are subject to change as the ASR program progresses and additional information becomes available.

The inaugural ASR Science Plan was published in 2021, and later updated and published online as a draft document in 2022. This updated 2024 (Version 2) of the Plan presents an overarching program of scientific studies that will support a phased ASR implementation schedule for the Lake Okeechobee Watershed Restoration Project (LOWRP). Although the studies proposed in this updated version of the ASR Science Plan are intended to be conducted at ASR locations identified in the 2022 LOWRP Integrated Project Implementation Report and Environmental Impact Statement (PIR/EIS), they have broad application beyond the LOWRP scope. These studies have value anywhere ASR wells are proposed within South Florida and can be used to address ASR uncertainties associated with other CERP and non-CERP projects.

The LOWRP Revised Recommended Plan includes 55 ASR wells and restoration of two wetland areas adjoining the lower reach of the C-38 Canal. The implementation schedule for the ASR component of LOWRP is the result of state legislative appropriations received for the design, engineering, and construction of ASR well clusters.

During development of the 2021 version of the ASR Science Plan, the PRP provided guidance and suggestions on how to evaluate stakeholder concerns about ASR implementation at the scale envisioned by LOWRP and how to address uncertainties regarding ASR technology as highlighted by the NRC in 2015. In June 2022, the PRP reviewed the progress of scientific investigations conducted since the 2020 review and provided comments on the ongoing studies and specific recommendations on the future directions of those studies. The draft 2022 ASR Science Plan was not finalized due to the USACE concerns with ASR technology. USACE requested that their Engineering Research and Development Center (ERDC) conduct scientific studies that address water quality concerns, construction cost, Operation and Maintenance (O&M) cost, and well recovery performance. A summary of the ongoing ERDC studies is provided in this version of the Plan and the results of these studies will be included in the next updates of the ASR Science Plan as they become available.

The studies included in this updated version of the ASR Science Plan are organized according to the main topics of the 2015 NRC report. Additionally, a summary of the proposed USACE ERDC studies were added to this version of the ASR Science Plan.

Project Sequencing, Schedule, Reporting, and Data Management (Chapter 2). The PRP suggested a robust program of scientific data collection, management, and dissemination as the ASR program moves forward. An annual schedule of formal project reporting and review is included herein, along with a "report card" process of evaluating the progress of the ASR Science Plan towards addressing the NRC uncertainties. A combination of data management tools — primarily Data Access Storage and Retrieval (DASR), Metacat, and DataOne— will preserve all information generated by the ASR program. ASR data are available to the public within an internet-accessible environment.

Future Construction and Testing (Chapter 3). The NRC recommended that additional local-scale information was needed on the Avon Park permeable zone (APPZ), which is one of LOWRP target aquifers for subsurface water storage. Recommendations included additional study of aquifer heterogeneity, anisotropy, and fracture potential to help determine orientation of ASR and monitoring wells and maximize recovery efficiency. Use of groundwater modeling, geophysical surveys, tracer studies, and injection tests were suggested to augment data from aquifer performance testing and continuous core acquisition.

Understanding Phosphorus Reduction Potential (Chapter 4). The NRC and PRP agreed that more research into the potential for ancillary benefits of nutrient reduction via ASR should be pursued. The SFWMD contracted with the United States Geological Survey (USGS) to perform column studies and flow-through experiments to document the effects of microorganisms within the aquifer and their impact on nutrients during storage when placed within deep, anoxic aquifer conditions.

Operations to Maximize Recovery (Chapter 5). There were several recommendations regarding the assessment of methods to increase the quantity and quality of water that is ultimately recovered from ASR systems. Establishment and maintenance of a buffer zone, operational sequencing of multi-well clusters, and location of well systems near surface water bodies were recommended.

The 2024 (Version 2) ASR Science Plan includes preparation of well-siting evaluations, design studies, and constructability analyses to locate well clusters near surface water bodies and to optimize recovery efficiency. A cycle testing program is proposed to develop a buffer zone within the aquifer where recovery efficiency is anticipated to be low.

Disinfection/Treatment Technology (Chapter 6). The NRC recommended that design evaluations be conducted to ensure recharge and recovery treatment technologies will be implemented to achieve regulatory compliance and minimize the potential for mobilization of undesirable constituents. Additionally, continuation of subsurface pathogen inactivation studies was recommended.

The ASR Science Plan contains an in-depth evaluation of available technologies for achieving regulatory compliance while minimizing operations and maintenance costs. USGS research on subsurface pathogen inactivation is ongoing.

Ecotoxicology and Ecological Risk Assessment (Chapter 7). The NRC recommended additional toxicity and bioconcentration tests on selected species during extended cycle periods. Design studies will be undertaken to minimize larval entrainment mortality and impingement at the ASR intakes, and potentially adverse thermal effects of recovered water on fish spawning once inflow and outflow point design is completed. Evaluation of community-level effects and conducting quantitative ecological risk assessment (ERA) using more refined, probabilistic methods was also recommended.

The ASR Science Plan includes description of the ERA Work Plan. This chapter also provides a description of the mobile lab design for future bench-scale bioaccumulation tests, and a summary of year 1 results from long-term pre-operational environmental monitoring along the C-38 Canal and northern part of Lake Okeechobee that began in August 2022, and future long-term ecological monitoring that will occur during cycle testing of new multi-well clusters along the C-38 Canal.

Water Quality (Chapter 8). Numerous recommendations were made regarding studies to understand reactions that occur within the storage zones of ASR wells in terms of mobilization of metals bound in the aquifer matrix and presence of undesirable constituents in recovered water. The use of the subsurface buffer zone concept to prevent degradation of water quality within the aquifer and in recovered water was suggested.

The use of monitoring plans, development of a subsurface buffer zone, and geochemical modeling and analysis during well construction and future cycle testing are described in the ASR Science Plan.

Planning-Level Cost Estimate and ASR Well Cost-Benefit Analysis (Chapter 9). Cost estimates were prepared for the research activities described within the ASR Science Plan. The estimates were prepared for planning purposes and are subject to change as the ASR program progresses. The ASR program costs are under development; as the program progresses and treatment technologies are determined, a cost-benefit analysis will be included in future updates to the ASR Science Plan.

United States Army Engineer Research Development Center Studies (Chapter 10). A Cooperative Research and Development Agreement was prepared and signed between the U.S. Army Engineer Research and Development Center (ERDC) and the SFWMD to address uncertainties with ASR technology for the Lake Okeechobee Watershed Restoration Project (LOWRP). These risks were grouped into three broad categories including water quality, construction cost and long-term O&M cost. To understand risks associated with these three categories, ERDC proposed modeling and lab-based investigations. Results of the studies will be provided in future ASR Science Plan versions.

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ACRONYMS, ABBREVIATIONS, AND UNITS OF MEASURE

2D	Two-Dimensional
3D	Three-Dimensional
APPZ	Avon Park Permeable Zone
APT	Aquifer Performance Test
ASR	Aquifer Storage and Recovery
ASTM	American Society of Testing Materials
CERP	Comprehensive Everglades Restoration Plan
CRADA	Cooperative Research and Development Agreement
DASR	Data Access Storage and Retrieval
DM	Data Management
DO	Dissolved Oxygen
DOC	Dissolved Organic Carbon
DZMW	Dual-Zone Monitoring Well
ECFM	East Coast Floridan Model
EML	Ecological Metadata Language
ERA	Ecological Risk Assessment
ERDC	United States Army Engineer Research and Development Center
F.A.C.	Florida Administrative Code
FAS	Floridan aquifer system
FDEP	Florida Department of Environmental Protection
FGCU	Florida Gulf Coast University
FSM	Field Sampling Manual
FWC	Florida Fish and Wildlife Conservation Commission
GPM	Gallons Per Minute
IAG	International Association of Geoanalysts
KRASR	Kissimmee River Aquifer Storage and Recovery (site)
LOWRP	Lake Okeechobee Watershed Restoration Project
MCL	Maximum Contaminant Level
MCLG	Maximum Contaminant Level Goal
MF/UF	Microfiltration/ultrafiltration
mg/L	Milligrams per Liter
MGD	Million Gallons per Day
MM	Mining Mode

NELAC	National Environmental Laboratory Accreditation Conference
NRC	National Research Council
O&M	Operation and Maintenance
OBI	Optical Borehole Imagery
ORP	Oxidation Reduction Potential
PFAS	Per- and Polyfluoroalkyl Substances
PIR/EIS	Project Implementation Report/Environmental Impact Statement
POC	Proof of Concept
PPM	Parts Per Million
pXRF	Portable X-Ray Fluorescence Analyzer
PRMRWSA	Peace River Manasota Regional Water Supply Authority
PRP	Peer-Review Panel
PQAP	Programmatic Quality Assurance Plan
QA	Quality Assurance
QASR	Quality Assurance Systems Requirements
QC	Quality Control
Restudy	Central and Southern Florida Project Comprehensive Review Study
SAMW	Surficial Aquifer Monitoring Well
SAS	Surficial Aquifer System
SAV	Submerged Aquatic Vegetation
SFWMD	South Florida Water Management District
SM	Soil Mode
SOP	Standard Operating Procedure
TDS	Total Dissolved Solids
UFA	Upper Floridan aquifer
UIC	Underground Injection Control
USACE	United States Army Corps of Engineers
USEPA	United States Environmental Protection Agency
USGS	United States Geological Survey
UV	Ultraviolet
VSP	Vertical Seismic Profile
WOE	Weight of Evidence

1 INTRODUCTION

1.1 ASR REGIONAL STUDY BACKGROUND

Aquifer storage and recovery (ASR) is the storage of water in an aquifer by means of a dual-purpose well that is used for both recharge and recovery. ASR technology has been employed successfully in Florida since 1983 (Pyne 2005). This technology offers the potential to store and supply vast quantities of water without the need for large tracts of land. As such, ASR is a vital component of the Comprehensive Everglades Restoration Plan (CERP), implemented by the South Florida Water Management District (SFWMD) and the United States Army Corps of Engineers (USACE). Of the many project components in CERP, seven include ASR wells. Of the original 333 ASR wells included in these seven CERP project components, as many as 200 wells were conceptualized to be integrated with Lake Okeechobee.

Despite the potential benefits of ASR, there are some technical uncertainties regarding regional-scale ASR implementation as envisioned in CERP. To address these uncertainties, the SFWMD and USACE conducted the 11-year ASR Regional Study, focusing on the hydrogeology of the Floridan aquifer system (FAS), possible ecological risks posed by recovered water, and the regional capacity for ASR implementation. Results of these scientific investigations were described in the ASR Regional Study Final Technical Data Report (SFWMD and USACE 2015). The project delivery team formulated plans to construct ASR pilot projects, then expanded the analyses to a more regional scope to address critical reviews of the project plans by the National Research Council (NRC) in 2001 and 2002.

Key findings from the 2015 ASR Regional Study Final Technical Data Report (SFWMD and USACE 2015) included the following:

- Large-capacity ASR systems can be built and operated in the interior of South Florida. To date, no "fatal flaws" have been uncovered that might hinder the implementation of CERP ASR.
- Variability in aquifer characteristics will result in variable well performances, making it prudent to conduct an exploratory program before constructing surface facilities.
- Groundwater modeling indicated the overall number of wells should be reduced from the originally proposed 333 wells to approximately 130 wells in the upper and middle portions of the FAS. Of those, 80 ASR systems could be constructed around Lake Okeechobee.
- Water recovered from the ASR pilot projects did not have any persistent acute or chronic toxicologic effects on test species. However, there were a few instances where reproduction was inhibited, warranting further investigation.
- Arsenic mobilization occurred during each cycle at the Kissimmee River ASR Pilot Project (KRASR). However, geochemical processes unique to this ASR system showed arsenic attenuation during storage of each cycle.
- Reduction in phosphorus concentrations was observed during ASR storage. This process was postulated to result from microbial uptake, adsorption, dilution, or mineral precipitation.
- Further implementation of CERP ASR should proceed in a phased manner, including expansion and continued construction and testing of demonstration facilities.

1.2 SUMMARY CONCLUSIONS OF THE 2015 NRC REVIEW

Upon completion of the ASR Regional Study Final Technical Data Report (SFWMD and USACE 2015), the USACE requested the NRC's Water Science and Technology Board convene a committee of experts to review the report and assess progress regarding uncertainties related to full-scale CERP ASR implementation. A critical review of the methodology, findings, and conclusions were provided by the NRC in the 2015 Review of the Everglades Aquifer Storage and Recovery Regional Study report (NRC 2015). Highest-priority NRC recommendations to address uncertainties included the following:

- Develop operations to maximize recovery and reduce surface and groundwater quality impacts.
- Conduct additional chronic ecotoxicological studies and develop a quantitative ecological risk assessment (ERA).
- Understand the mechanisms of phosphorus reduction.
- Evaluate treatment technologies for optimal water quality during recharge, storage and recovery.
- Compare ASR costs and benefits with other water storage alternatives.

The main objective of the ASR Science Plan is to develop potential study plans to address the remaining uncertainties from the NRC (2015) review as ASR wells are constructed in a phased manner. **Appendix A** includes a full list of the scientific milestones, reports, and technical publications generated for the ASR Program since 1986.

1.3 LAKE OKEECHOBEE WATERSHED RESTORATION PROJECT

As part of the CERP, the USACE and SFWMD initiated the Lake Okeechobee Watershed Restoration Project (LOWRP) planning effort in July 2016. LOWRP is intended to address water resource issues identified in the 1999 Central and Southern Florida Project Comprehensive Review Study (Restudy; USACE and SFWMD 1999) for the northern portion of the Lake Okeechobee watershed, Lake Okeechobee, and the Caloosahatchee and St. Lucie estuaries (northern estuaries). The project area covers a portion of the Lake Okeechobee watershed and includes four major drainage basins: Fisheating Creek, Indian Prairie, Taylor Creek/Nubbin Slough, and portions of the Lower Kissimmee (S-65D and S-65E), totaling approximately 920,000 acres. The LOWRP objectives are to: 1) improve the quantity, timing, and distribution of flows into Lake Okeechobee; 2) improve the timing and volume of freshwater flows from Lake Okeechobee to the northern estuaries; 3) increase the spatial extent and functionality of aquatic and wildlife habitat within Lake Okeechobee and the surrounding watershed; and 4) increase availability of water supply to existing legal water users of Lake Okeechobee.

The LOWRP planning effort evaluated combinations of aboveground water storage features, ASR wells, and wetland restoration sites to meet project objectives. The LOWRP Revised Recommended Plan (Alternative ASR) includes 55 ASR wells, and approximately 5,900 acres of wetland restoration in the Paradise Run and Kissimmee River Center areas (**Figure 1-1**). By increasing water storage capacity within the watershed, the LOWRP Revised Recommended Plan will improve the amount of time Lake Okeechobee is within the ecologically preferred stage envelope, benefitting native vegetation and wildlife. The LOWRP Revised Recommended Plan will reduce the return frequency, volume, and duration of freshwater flows from Lake Okeechobee to the northern estuaries, thus reducing turbidity, sedimentation, and unnatural changes in salinity that are detrimental to estuarine communities. The wetland restoration components will increase the spatial extent and functionality of aquatic and wildlife habitat within the Lake Okeechobee watershed. Additionally, the LOWRP Revised Recommended Plan will reduce water supply cutback volumes and frequencies to existing legal water users of Lake Okeechobee by increasing the lake stages in general within the ecologically preferred stage envelope, which is above water supply cutback trigger levels.

1.4 STATE APPROPRIATION 1642A AND SENATE BILL 2516

The Florida State Legislature appropriated funding to the SFWMD for LOWRP in 2019-2021 under State Appropriation 1642A. During the 2021 legislative session, the Florida Legislature also passed Senate Bill 2516 to further support the expeditious implementation of LOWRP. This funding was provided to the SFWMD for the design, engineering, and construction of specific LOWRP components designed to achieve the greatest reduction in harmful discharges to the Caloosahatchee and St. Lucie estuaries. The SFWMD and USACE determined the ASR well component would provide the greatest benefits to the estuaries. The ASR program is underway and the ASR project team has initiated or completed continuous cores, construction and testing of test/exploratory wells, treatment technology evaluation and proof-of-concept testing, permitting and design at multiple potential well cluster locations along the canals entering Lake Okeechobee, programmatic quality assurance project plan (PQAP), long-term pre-operational environmental monitoring along the C-38 Canal and northern Lake Okeechobee, design of mobile laboratory for bench-scale chronic toxicity and bioaccumulation studies, and quantitative ecological risk assessment work plan.

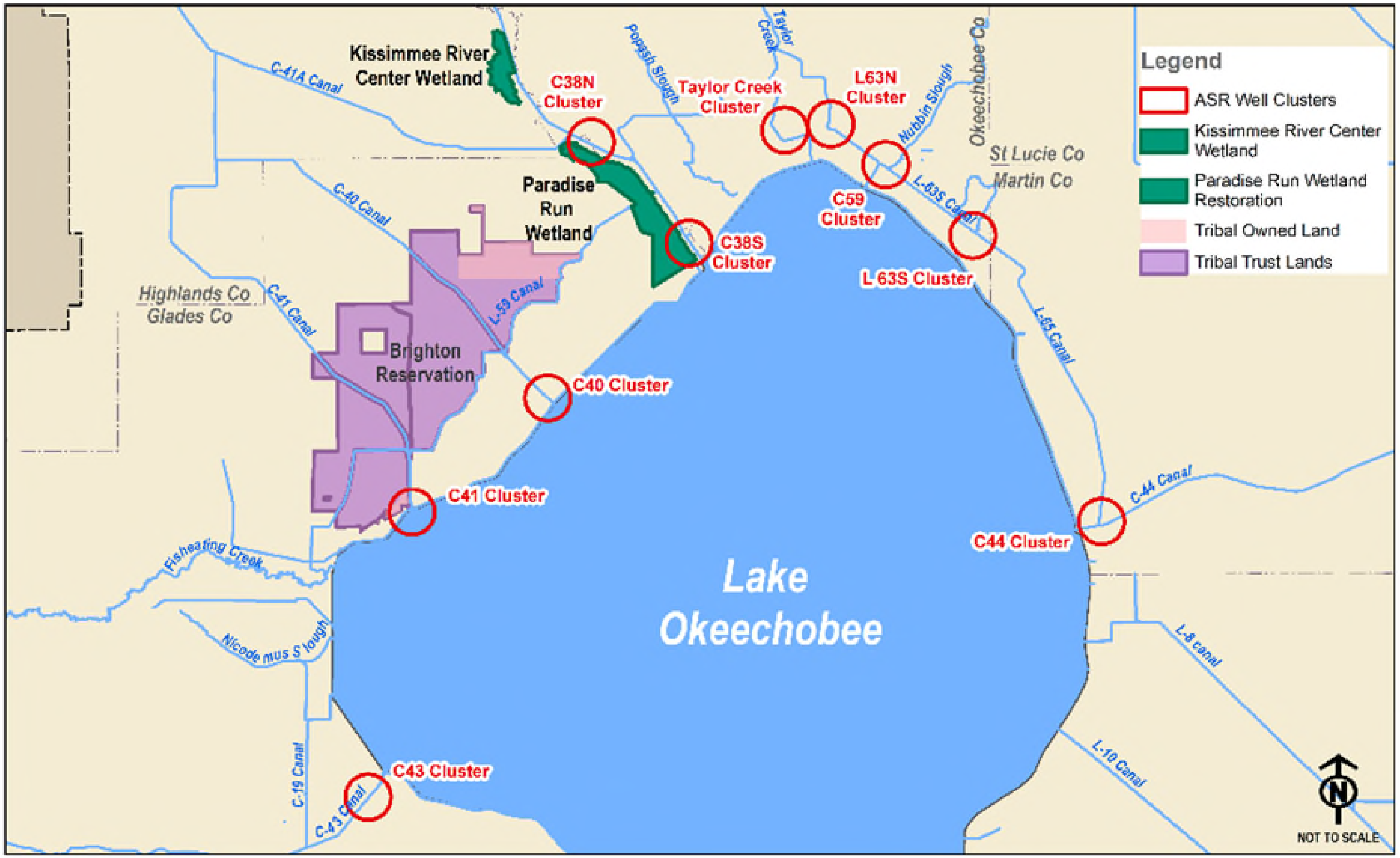

Figure 1-1. Lake Okeechobee Watershed Restoration Project Recommended Plan features.

1.5 2024 INDEPENDENT PEER-REVIEW SCIENCE PANEL

An independent panel of scientists was assembled to review the phased approach of ASR construction, development of water treatment facility, and review the progress of scientific investigations outlined in the updated 2024 Version 2 of the ASR Science Plan to address the technical uncertainties identified in the NRC (2015) review and previous years' PRP recommendations. The independent ASR peer-review panel (PRP) includes the following members:

Rene Price, Ph.D., P.G., Professor and Chair, Department of Earth and Environment, Florida International University (chair)
John Carriger, Ph.D., Research Scientist, National Risk Management Research Laboratory, United States Environmental Protection Agency
Mike Coates, P.G., Executive Director (retired), The Peace River Manasota Regional Water Supply Authority
Reid Hyle, Fish and Wildlife Research Institute, Florida Fish and Wildlife Conservation Commission
Thomas Missimer, Ph.D., P.G., Professor and Director of the Emergent Technologies Institute (retired), Florida Gulf Coast University

The PRP technical workshop was conducted on July 10, 2024 to review the progress of ASR studies conducted since the last technical workshop in June, 2022. The PRP subsequently published a final report of recommended future tasks based on the results of scientific investigations presented at the workshop (Price et al., 2024; **Appendix B**).

The PRP will convene as needed throughout implementation of the ASR program to review the progress of the scientific investigations summarized in this Version 2 ASR Science Plan.

1.6 ASR SCIENCE PLAN TO ADDRESS REMAINING UNCERTAINTIES

Although ASR technology has been used successfully in Florida since 1983 (Pyne 2005), concerns have been raised about regional-scale application of ASR as envisioned in CERP. The NRC's (2015) review of the ASR Regional Study Final Technical Data Report (SFWMD and USACE 2015) identified uncertainties that merit additional study before large-scale ASR can be implemented. To reduce critical scientific uncertainties, the SFWMD and USACE developed the 2021 ASR Science Plan, which outlined potential studies to be conducted as additional ASR wells are implemented in a phased manner. This inaugural version of the Plan was updated in 2022 (SFWMD and USACE, 2022a), and included summary of progress of scientific investigations conducted between 2020 and 2022. The 2024 Version 2 of the ASR Science Plan describes the scientific progress made since June 2022 and future tasks. The ASR Science Plan was developed with review and input from the PRP as well as subsequent reviews and comments from the public, interested stakeholders, and subject matter experts from the USACE, Florida Fish and Wildlife Conservation Commission (FWC), and the Florida Department of Environmental Protection (FDEP). The ASR Science Plan is intended to be a living document, updated as needed based on the newest information available at the time of update. The proposed scope, schedule, and budget for ASR Science Plan studies are subject to change as the ASR program progresses and additional information becomes available.

While continuous cores are collected and exploratory wells are constructed and tested, there is benefit from reactivating the existing ASR systems along the C-38 Canal (KRASR) and L-63N Canal. Both systems provided information about ASR performance in the Upper Floridan aquifer (UFA) and the APPZ. When the design studies are complete, permits will be applied for and obtained to construct new multi-well clusters. Upon completion of construction, the new ASR systems will begin operation with a series of cycle tests. A subsurface buffer zone will be established prior to the beginning of cycle testing. The duration of recharge, storage, and recovery will progressively increase over time. During the first few years, an intensive water quality monitoring program will be implemented to assess the operational efficiency of the system, assess water quality interactions, and ensure regulatory compliance. The water recovered from the ASR systems will provide important information on the potential adverse impacts to biota within the Lake Okeechobee and downstream ecosystems. Ultimately, as additional essential ecological data are obtained from the operational clusters to complement data collected from the earlier pilot system studies, a comprehensive quantitative ERA will be conducted. The subsequent chapters of this updated ASR Science Plan describe progress on the scientific investigations that have been initiated during 2021-2023, outline future tasks to address each of the recommendations and remaining uncertainties elucidated in the NRC (2015) review, and establish an anticipated schedule of future construction activities. The schedule will be updated annually and included in the next ASR Science Plan updates.

1.7 REPORT ORGANIZATION

The following chapters are organized into broad topics that were addressed in the NRC (2015) report. The anticipated project sequencing, schedule, reporting, and data management are presented in Chapter 2. Within each subsequent chapter are specific areas of remaining uncertainty identified by the NRC. For each NRC comment, there is a summary of the 2020 and 2022 PRP recommendations (Arthur et al. 2020; Missimer et al. 2022), followed by the progress on work completed since the last technical review in June 2022, and a summary of ongoing and future work that is performed or will be performed to address the NRC uncertainties. The chapters end with a summary of the 2024 PRP recommendations (Price et al. 2024; **Appendix B**) on the ongoing and future studies.

2 PROJECT SEQUENCING, SCHEDULE, REPORTING, AND DATA MANAGEMENT

This chapter presents a summary of activities to support the advancement of the ASR Science Plan, including a discussion of project sequencing, a schedule of near-term activities, project reporting, and the data management plan.

2.1 PROJECT SEQUENCING

As recommended by the NRC, implementation of LOWRP ASR wells will proceed in a phased approach and will include continued monitoring and research activities as design and construction proceeds. **Table 2-1** and **Table 2-2** show phases of project progression for a specific cluster of ASR wells and highlight studies that will occur during the various phases, as currently planned. The dates indicate time frames associated with building out the first ASR well cluster at C-38S. Subsequent clusters will have different time frames but will follow a similar pattern of development. Numerous studies are anticipated to occur during each project phase, and multiple project phases will occur concurrently. The studies and phases are subject to change as the ASR program is implemented and more data are available.

2.2 PROJECT SCHEDULE

Near-term project activities for the initial ASR well clusters and an estimated schedule for their initiation are presented below. Factors that could influence the project sequencing and schedule include funding availability, regulatory requirements and approvals, annual PRP reviews and input, and integration of projects constructed by other agencies or entities. Many of the near-term activities can be described with some certainty, while activities in more distant years are less clearly defined and will be formulated based on the findings of earlier studies through adaptive management. Details of future studies beyond 2026 or related to subsequent ASR clusters will be provided in subsequent updates of the ASR Science Plan as the ASR program progresses and additional information becomes available.

2021

- Collected continuous core at L-63N
- Initiated continuous core at C-38S
- Submitted core samples for mineralogic and geotechnical analyses
- Completed initial pre-treatment technology evaluation
- Initiated development of the ASR Programmatic Quality Assurance Plan
- Developed an ERA scope of work
- Completed quantitative ERA based on the historic toxicological and bioaccumulation data at the KRASR location
- Designed a mobile laboratory for conducting toxicological and bioaccumulation studies
- Completed mesocosm studies literature review
- Developed preliminary work plans for toxicological, bioaccumulation and ecological studies
- Initiated USGS column studies of nutrient reduction/plugging potential
- Permitted/procured exploratory well construction at C-38S and C-38N
- Continued repair and refurbishment of the KRASR facility
- Evaluated the existing L-63N ASR system for potential reactivation
- Initiated construction of exploratory ASR and monitoring wells at C-38S and C-38N

2022-2023

- Performed treatment technology – 30% design of a 10 MGD demonstration facility at C-38S

- Continue assessing, repair, refurbishment, and evaluation for reactivation of the KRASR facility
- Collected continuous cores at C-38S and L-63S locations
- Continued core analysis for mineralogic and geotechnical properties
- Initiated continuous core and monitoring well construction at C-40/C-41
- Completed a hydraulic model for C-40/C-41 preliminary design
- Continued construction of exploratory ASR and monitoring wells at C-38S and C-38N
- Designed and obtained permits for exploratory ASR and monitoring wells at L-63N
- Initiated construction of exploratory ASR and monitoring wells at L-63N
- Initiated the design and permitting of surface facilities/treatment systems at C-38N and C-38S
- Performed exploratory geochemical modeling
- Completed development of the Programmatic ASR Quality Assurance Plan
- Developed ERA Work Plan for completing ERA
- Initiated long-term ecological monitoring along the C-38 Canal and northern Lake Okeechobee
- Initiated mixing zone geochemical modeling
- Completed a survey of radium isotopes in UFA and APPZ in south Florida from existing data
- Conducted seismic geophysical surveys at C-44
- Completed aquifer performance tests at C-38S and C-38N
- Developed a sub-regional groundwater flow and solute transport model for the C-38S and C-38N ASR systems

2023-2024

- Review of intermediate design submittal for the surface facilities/treatment systems at C-38S
- Continued construction of ASR and monitoring wells at C-38S and C-38N
- Completed construction of a new ASR well pair (UFA and APPZ) at C-38S. Initiated bid process for new ASR well pair at C-38N
- Completed Aquifer Performance Testing (APT) at C-38S
- Continued construction of ASR and monitoring wells at L-63N
- Initiated subregional groundwater flow and solute transport modeling at new ASR cluster sites
- Initiated a focused geochemical modeling effort to quantify arsenic mobilization in deoxygenated recharge water
- Initiated Phase 2 USGS study of pathogen inactivation and nutrient reduction/well clogging using columns and field mesocosms
- Completed acquisition of continuous cores at C-38S, L-63N and C-59, reports completed or are in preparation
- Continued borehole fracture analysis with USGS using continuous cores. Initiated a new fracture analysis task to inform anisotropy in the groundwater flow model
- Continued long-term ecological monitoring along the C-38 Canal and northern Lake Okeechobee
- Completed ERA Work Plan
- Completed design of mobile laboratory for conducting chronic toxicity and bioaccumulation studies at multiple ASR locations
- Initiated ERDC studies to complement the groundwater modeling effort and also geochemical studies in columns to quantify arsenic mobilization

2024-2029

- Complete final design and permitting of the surface facilities/treatment systems at C-38N and C-38S
- Initiate construction of surface facilities and treatment systems at C-38S
- Initiate cycle testing of multi-well clusters at C-38S
- Conduct recovered water mesocosm tests at C-38S and C-38N cluster locations
- Perform a local-scale solute transport model evaluation at C-38 N and S ASR locations

- Continue long-term ecological and bioaccumulation monitoring studies along the C-38 Canal and northern Lake Okeechobee
- Initiate acute and chronic toxicity and bioaccumulation experiments at different ASR cluster locations
- Conduct quantitative ERA
- Conduct Cost-Benefit Analysis

Table 2-1. Phases of ASR project progression and proposed studies to address National Research Council comments.

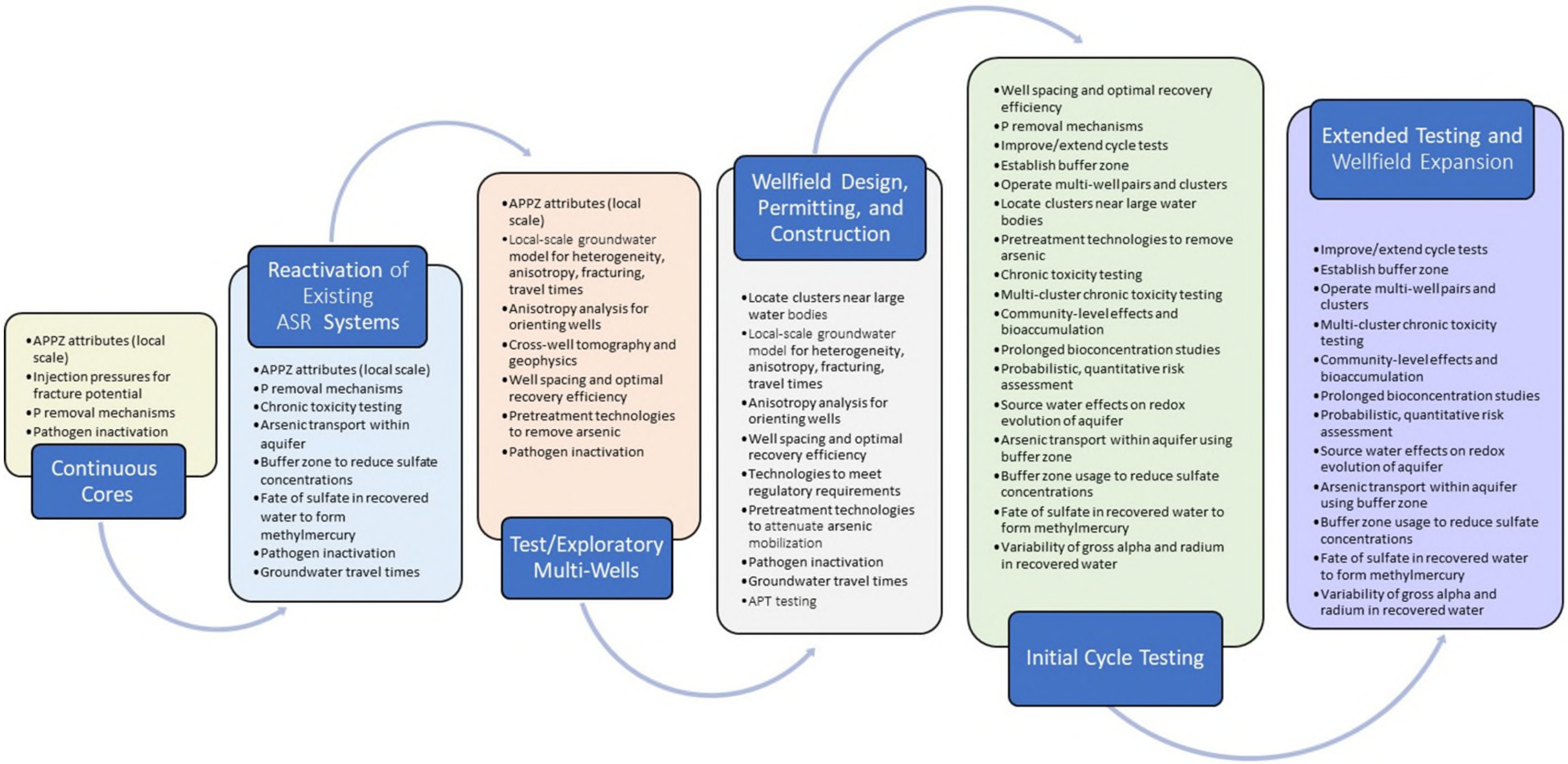

Table 2-2. Proposed studies to address National Research Council comments during various phases of ASR implementation.

Uncertainties Identified by the National Research Council	Continuous Cores	Reactivation of Existing Wells	Exploratory Test Wells	Design, Permitting, and Construction of Demonstration Facility at C-38S	Initial Cycle Testing at C-38S	Extended Testing and Wellfield Expansion at C-38S	Design, Permitting, and Construction of Additional Wellfields and Treatment Facilities
Local scale information on APPZ attributes	■	■	■		■	■	■
P removal mechanisms	■	■			■	■	■
Pathogen inactivation in the aquifer	■	■		■	■	■	■
Chronic toxicity testing and bioaccumulation studies		■			■	■	■
Arsenic transport within aquifer using buffer zone		■			■	■	■
Buffer zone usage to reduce sulfate concentrations		■			■	■	■
Fate of sulfate in recovered water to form methylmercury		■			■	■	■
Groundwater travel times		■	■	■	■	■	■
Local scale model for heterogeneity, anisotropy, fracturing, travel times		■	■	■	■	■	■
Pretreatment technologies to attenuate arsenic mobilization		■		■	■		■
Well spacing and optimal recovery efficiency			■	■	■		■
Anisotropy analysis used for orienting wells			■	■	■		■
Cross-well tomography and geophysics			■	■			■
Locate clusters near large water bodies			■	■			■
Technologies to meet regulatory requirements				■			■
Multi-cluster chronic toxicity testing					■	■	■
Long-term community-level effects and bioaccumulation					■	■	■
Bioconcentration studies					■	■	■
Probabilistic, quantitative risk assessment					■	■	■
Variability of gross alpha and radium in recovered water					■	■	■
Source water effects on redox evolution of aquifer					■	■	■
Improve/extend cycle tests					■	■	■
Establish buffer zone					■	■	■
Operate multi-well pairs and clusters					■	■	■

2.3 PROJECT REPORTING: ASR PROGRESS REPORT CARD

The ASR Science Plan report card **Table 2-3** was updated to show stakeholders the progress made towards addressing the NRC and PRP recommendations since 2022.

Table 2-3. 2024 ASR Science Plan progress report card.

National Research Council Uncertainties and ASR Peer Review Panel Recommendations	% Progress Towards Adressing the Topic									
	10	20	30	40	50	60	70	80	90	100
2015 National Research Council Uncertainties										
Local scale information on attributes of APPZ										
Research phosphorus removal mechanisms										
Research pathogen inactivation in the aquifer										
Couple pathogen inactivation with groundwater travel times	*									
Establish buffer zone										
Arsenic transport within aquifer using buffer zone										
Buffer zone usage to reduce sulfate concentrations										
Fate of sulftate in recovered water to form methylmercury										
Local scale model for heterogeneity/anisotropy/fracturing/travel times										
Pretreatment technologies to attenuate arsenic mobilization										
Analysis of wellfield cluster for spacing and optimal recovery efficiency										
Anisotropy analysis used for orienting wells										
Cross-well tomography and geophysics										
Locate clusters near large water bodies										
Examine technologies to meet regulatory requirements										
Variability of gross alpha and radium in recovered water										
Examine source water effects on redox evolution of aquifer										
Improve/extend cycle tests										
Operate multi-well pairs and clusters										
Continue chronic toxicity testing at multiple ASR locations										
Long-term ecological monitoring and bioconcentration studies, community-level effects										
Probabilistic, quantitative ecological risk assessment										
2021 ASR Peer Review Panel Recommendations										
Develop ASR Programmatic Quality Assurance Plan										
Data Storage, Management, and Public Access										
2022 ASR Peer Review Panel Recommendations										
Spacers in core storage										
Core geochemical analysis										
Local-scale groundwater model layers development										
Hydrologic modeling to include fracture and faulting patterns to determine optimal well spacing										
Add new Panel member with strong background in water treatment and economics of water treatment										
Revisit point-of-compliance and reduced pretreatment options with regulatory agencies										
Implement incremental approach to design, construction, and operation of the pretreatment of water to be stored										
Test other coagulants (e.g. ferrate) with media filtration as a potential pretreatment method										
Develop detailed plan of arsenic monitoring during all portions of the ASR operations										
Develop detailed water quality monitoring plan for cycle testing										
Develop recovered water monitoring including arsenic, molybdenum and other ions that may be leached from the aquifers during storage										
Expand ichthyoplankton monitoring to the early dry season; characterize ichthyoplankton risk when impingment and entrainment most possible										
Establish a system to implement and update the ERA; use Bayesian networks in a risk assessment framework; use separate but interconnected conceptual models; develop tiered assessments for focusing data collection efforts and needs from conservative to more realistic assumptions										

Note: Yellow-colored cells indicate work progress between 2020-2022, green-colored cells indicate work progress since 2022, and blank cells indicate no work progress. Asterisk (*) indicates preliminary work progress (e.g., scopes of work have been developed but work has not begun) towards addressing the 2015 NRC, and 2021 and 2022 PRP recommendations. Work progress is directly linked to the progress on well construction, and operational and permitting status (some of the studies and tests cannot begin until ASR wells are constructed and operational).

2.4 PROJECT DATA MANAGEMENT

2020 Peer-Review Panel Guidance

The following guidance was provided by the PRP in its 2020 report (Arthur et al. 2020; SFWMD and USACE 2021b, **Appendix B**).

Research activities related to ASR and groundwater modeling are data intensive, including hydrologic, meteorologic, chemical, and biological data collected at a variety of spatial and temporal frequencies and extents. Users and providers of the data may include a diverse set of individuals and groups from academia, nongovernmental organizations, commercial institutions, and municipal, state, and federal agencies. Rich sets of legacy data on multiple aspects of the FAS have been collected by numerous groups. Ongoing data collection as part of specific short-term studies or long-term monitoring is planned or under way. The hydrologic and ecological modeling that is a core part of CERP will produce large amounts of model output.

The data emanating from these various activities will need to be organized, validated to meet quality assurance objectives, maintained, and curated. Furthermore, the data must be accessible, discoverable, reviewable, and usable by individuals or groups, ideally within and beyond the CERP set of stakeholders. The PRP strongly recommends the SFWMD ASR team develop a comprehensive data management plan. Such a plan would ensure internal and external access to relevant data over the short and long term, facilitate data analyses and syntheses across multiple data types and sources, buffer against the potential turnover of key personnel, and increase transparency and communication to stakeholders as CERP is implemented and evaluated. In short, a well-planned and implemented information management system will make all aspects of CERP, including ASR, more likely to succeed.

Developing and implementing a comprehensive data management plan likely will require full-time information managers throughout the life of the project. Other complex, data-intensive projects such as the Long-Term Ecological Research Network, the Consortium of Universities for the Advancement of Hydrological Sciences, Inc., and the Ecological Society of America have developed functional information management and data registry systems that might serve as models. The plan should include multiple aspects of information management, including the following:

- Definition of data types; standardization of analytes (e.g., consistent reporting of dissolved nitrogen) and formats, ranging from raw data to metadata; and details of what data types are available and how they are characterized and organized
- An explicit data management plan, from the method of collecting and initially transferring data from the field into digital form to follow-up data flow, including quality control (QC), analysis, synthesis, and dissemination
- Agreements about which data and types will be centrally housed and which will be distributed among individual stakeholders
- Maintenance of database integrity, including quality assurance (QA), short- and long-term curation, archival, and data backup plans
- Description of the data access and sharing policy
- Description of limitations and disclaimers on data use
- Creation of an accessible environment for the retrieval of information
- Facilitation of linkages among diverse data sets
- Documentation of metadata for data interpretation and analysis
- Analysis of information management staffing needs

The Plan for Data Storage, Management, and Public Access

ASR project environmental metadata and data will be managed within the hosted internet accessible member repository (SFWMD-CERP), DataOne, Content contributors will use an ORCID sign-in and a combination of data management (DM) tools; MetacatUI and Metacat, uniquely preserving all information generated by the implementation of each project component. This DM system creates digital information packages encompassing the entire data lifecycle. Packages are composed of metadata, as well as any file-type of digital data deliverable in native format. The packages conform to Ecological Metadata Language (EML) standards and render the information keyword searchable. Once a package is generated and stored in a DataOne hosted Metacat member repository, the information becomes accessible via a web browser.

In addition to using the hosted member repository at DataOne for ecological monitoring and research data, the SFWMD will store ASR well data in the DBHYDRO database. DBHYDRO is the SFWMD corporate environmental database that stores hydrologic, meteorologic, hydrogeologic, and water quality data. The DBHYDRO browser allows users to search DBHYDRO, using one or more criteria, and to generate a summary of the data from the available period of record. DBHYDRO users can select data sets of interest and have the time series data dynamically displayed in tables or graphs. ASR data stored in the DBHYDRO database will also be referenced within the relevant Metacat packages accessible through DataOne (**Figure 2-2**).

- DataOne/MetacatUI is a metadata generation application, conforming to the Ecological Metadata Language specification. Information about people, sites, research methods, and data attributes are among the metadata created. Data are packaged with metadata in the same container. Both user interfaces allow the user to create a catalog of data and metadata that can be queried, edited, and viewed.
- Metacat is a flexible, open-source metadata catalog and data repository that targets scientific data, particularly from ecology and environmental science. Metacat is a generic XML database that allows storage, query, and retrieval of arbitrary XML documents without prior knowledge of the XML schema. Metacat is designed and implemented as a Java servlet application that uses a relational database management system to store XML and associated meta-level information.

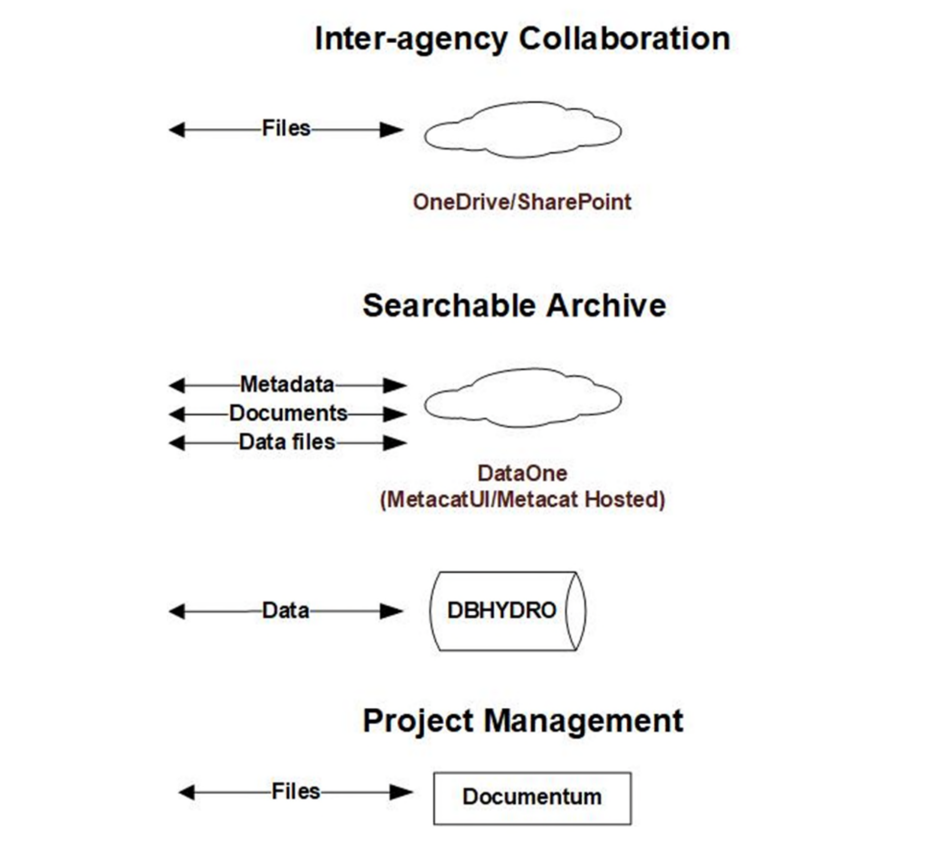

Figure 2-1. Data management tools to be used for ASR project data

2.5 ASR SCIENCE PLAN QUALITY ASSURANCE

Activities conducted under the ASR Science Plan are required to meet the applicable requirements of Chapter 62-160, Florida Administrative Code (F.A.C.), known as the Quality Assurance (QA) Rule. The QA Rule, overseen by the FDEP, applies to many aspects of the ASR Science Plan studies: field activities, sample documentation, sample handling, storage, shipment, laboratory activities and other applicable activities that may affect data quality.

Additionally, the ASR Science Plan is being implemented as a component of CERP, which requires strict adherence to data collection and validation methods as well as QC verification and coordination. These procedures are documented in CERP Guidance Memorandums and a Quality Assurance Systems Requirements (QASR) manual (USACE and SFWMD 2018) that are maintained by the CERP Quality Assurance Oversight Team.

Furthermore, as recommended by the PRP (**Appendix B** in SFWMD and USACE 2021b) a separate Aquifer Storage and Recovery Programmatic Quality Assurance Plan (ASR PQAP) (SFWMD and USACE 2022b, **Appendix C**) has been developed to specify the QA requirements for the specific sample and/or data types that will be produced for the ASR Science Plan. PQAP has been developed based on the current understanding of the activities and studies associated with the LOWRP ASR program and it covers the following aspects of the ASR: water quality sampling, analysis, and assessment; well construction and testing; engineering and design services; hydrogeologic evaluations; ecological evaluations; construction observations; cycle testing; ASR system operation; and data management. The PQAP has been prepared using the most recent standard operating procedures (SOPs), standards, rules, guidelines, and procedures. In instances when SOPs did not exist, a general approach or standard industry practices were summarized to ensure activities follow consistent procedures and the results yield their intended quality objectives.

The PQAP was developed based on the following documents:

- U.S. Environmental Protection Agency (USEPA) Requirements for Quality Assurance Project Plans, Final, EPA QA/R-5
- USEPA Guidance for Quality Assurance Project Plans, Final, EPA QA/G-5
- FDEP Chapter 62-160.600, F.A.C.

The Plan also incorporates specific QA/QC requirements from several other documents including, but not limited to, the following:

- FDEP Chapter 62-160, F.A.C.
- 40 CFR Chapter 1, Subchapter D, Part 136 and Part 141
- The 2003 National Environmental Laboratory Accreditation Conference (NELAC)
- Standard, EPA/600/R-04/003, June 2003 or the NELAP standard 2016 revision, as applicable
- USEPA Test Methods for Evaluating Solid Waste, Physical/Chemical Methods (USEPA SW-846, most recent updates)
- USEPA Methods for Chemical Analysis of Water and Wastes, revised March 1983 EPA600/4-79-020
- Standard Methods for the Examination of Water and Wastewater methods
- American Society of Testing Materials (ASTM) Methods
- QASR manual and CERP Guidance Memorandums
- FDEP regulatory requirements included in DEP-QA-002/02 Requirements for Field and Analytical Work and DEP-EA 001/07 Process for Assessing Data Usability, and the SOPs included in DEP-SOP-001/01 (FDEP SOPs)
- SFWMD requirements, including SFWMD Water Quality Monitoring Section’s Field Sampling Manual (FSM) (SFWMD-FIELD-FSM-001) and associated SOPs
- USEPA Contract Laboratory Program National Functional Guidelines for Organic and Inorganic Data Review (USEPA, latest versions)

The PQAP is a living document and will be updated as specific needs of the ASR program and new tasks are refined or identified. Applicable SOPs will be developed for processes not specified in the aforementioned documents. All contractors and subcontractors conducting work for the ASR program will be required to comply with the applicable procedures documented in the PQAP and the individual Work Plans and applicable SOPs to assure that comparability and representativeness of the data produced is maintained, quality of work produced meets the specified data quality objectives, and constructed systems meet appropriate standards and their intended purposes.

3 FUTURE CONSTRUCTION AND TESTING

3.1 NRC comment: More local-scale information is needed on the attributes of the APPZ, including a groundwater model to assess storage effects on the APPZ.

2020 Peer-Review Panel Guidance

The following guidance was provided by the PRP in its 2020 report (Arthur et al. 2020; SFWMD and USACE 2021b, **Appendix B**).

Page 5, PRP report: The rock fracturing analysis indicates that it should not be a problem in the normal operation of the regional ASR system. Results of this analysis seem conservative, especially above the Upper Floridan aquifer (UFA). There are improvements that could be realized in the analysis that would likely assist in evaluating the risk of unexpected movement of injected water. First, the principal stress produced in a horizonal-bed aquifer in the horizontal plane would produce horizontal fractures with high apertures at the borehole interface, not vertical fractures. Second, to keep the fractures open a proppant (e.g., quartz sand) would have to be injected under high pressure. When the applied stress is terminated (pumps are shut down), the vertical load is likely to cause annealing of the fractures both at the large scale and the micro-scale. The only way to induce significant vertical fracturing would be to drill a horizontal offset well, common in petroleum and natural gas development. In addition, the relatively finer-grained and less consolidated sediments overlying the UFA are likely to resist fracturing. The physical response would be minor compaction along the boundary with the UFA (see also Wellfield Scale – Seismic Monitoring).

Page 6, PRP report: Extensive permeable zones commonly occur along unconformities and epikarst horizons. An experienced karst geoscientist should be included in the research team as the wells are cored and logged (e.g., borehole geophysics and downhole imaging). This will assist in understanding the injection zones and mineral phases coating sediment and rock surfaces, the latter which may inform understanding of geochemical interactions.

Page 6, PRP report: Elsewhere in this report, the PRP recommends re-evaluation of the application of sequence stratigraphic analysis at the regional and wellfield scales. Understanding transgressive and regressive cycles of sea level is interesting from a historical geology perspective; however, we view the relevance of this aspect of sequence stratigraphy to be nominal for ASR operations. The design of a seismic stratigraphic study should be to identify erosion/epikarst zones, karst features, faulting and folding of target strata because of their effects on porosity and hydraulic conductivity and integrity of an ASR injectate "bubble."

Page 10, PRP report: The SFWMD ASR team understands that aquifer hydrogeology is site specific, as are water-rock interactions within the Floridan aquifer system in both the UFA and APPZ during ASR operations. As such, it is imperative that the ASR plan going forward include a detailed description of water quality monitoring at each and every ASR location during all phases of the ASR operation, including time-series monitoring. The PRP recommends that serial samples of the injected water be collected with time to identify any temporal water-quality variations that might offer insight as to optimal times or conditions for water injection.

We also suggest aquifer performance tests (APTs) for anisotropy, flow zone analysis (maybe with packer testing), as well as cross-well tomography to depict permeability away from the injection wells. Testing should be done in a way to understand aquifer heterogeneity and anisotropy and potential for fractures. Also, we suggest the SFWMD ASR team explore various resistivity testing techniques (e.g., time domain) to characterize fluid movement in storage zones (with salinity contrast between native and injected water) before, during and after cycle testing as these results can be useful in defining the extent of the freshwater buffer zone during operations.

2022 Peer-Review Panel Guidance

The following guidance was provided by the PRP in its 2022 report (Missimer et al. 2022, SFWMD and USACE 2022b, **Appendix B)**

Page 7, PRP report: A very important part of the ASR scientific research is the collection of 5 continuous cores from approximately 500 to 2100 feet below surface at five future ASR well cluster sites. Knowledge on the geology and hydrogeology at these sites was deemed to be insufficient to answer many of the questions related to the design of the ASR wells and how to predict future performance. The Panel believes that this information is very useful in terms of characterizing the geology, groundwater hydraulics, and water quality of the specific sites. The Panel recommends that all five sites be completed and the cores should be archived for future scientific studies by researchers.

It was observed by the Panel that there were gaps in the cores caused by inability to recover core material related to the presence of cavities or fractures and the removal of core for other studies (e.g., fracture testing, construction of thin sections, etc.). It is recommended that markers should be placed in the core boxes to note the gaps, the reason for the gaps, and the proper vertical location of remaining pieces of core within marked intervals. This can be accomplished using wooden blocks that contain depth notations similar to the system used by the Florida Geological Survey (2 x 2 x ¾ inch wooden blocks).

The Panel strongly recommends that thin sections constructed from the cores by third party consultants should be archived at the South Florida Water Management District or by the Florida Geological Survey. This refers specifically to the glass slides which should be placed in appropriate special boxes. These thin sections could be used in the future for further research on the geology of southern Florida.

The Panel applauds the drilling crew on their high recovery of rock core during the most recent drilling operations. The trace metal and fracture analysis has produced some interesting results which should be incorporated into future well construction design, the water quality monitoring plan, and hydrologic modeling. In particular, the observance of high concentrations of metals (e.g. arsenic, mercury, nickel, molybdenum) in rock core retrieved from 1300 ft in core L-63N, suggests that well casing should be placed to a depth beneath that unit (at least 25 ft or as determined by the aquifer thickness and distribution of hydraulic conductivity) to minimize the contact of recharge and discharge water with the upper portion of the APPZ. The occurrence of the “ash-layer” within the APPZ is also interesting and should be investigated further as it seems to be a unit of low permeability which divides the APPZ into two permeable units. The unit also has unusual mineral and organic matter content which may result in previously unknown water quality conditions. Additionally, molybdenum was detected in the UFA and should be investigated during cycle testing and possibly geochemical modeling.

Page 8. PRP report: The Panel believes that the geochemical properties of the core material measured using a hand-held XRF unit at Florida Gulf Coast University (FGCU) has provided very useful information that has significant bearing on the design of the ASR wells. The Panel recommends that this scientific investigation be continued with the other cores to further characterize the two or three aquifers that will be used for ASR at sites north of Lake Okeechobee and at other in the future.

Progress Since 2022

The APPZ within the FAS was identified by the LOWRP as a high-potential zone for water storage. An extensive hydrogeologic data collection program is in progress at the L-63N, L-63S, and C-38S sites to investigate the aquifer properties of the UFA and APPZ. Data collected included continuous cores, native groundwater quality, and discrete interval packer testing data (groundwater quality and specific capacity). A detailed aquifer performance test was completed at the C-38S location. Hydrologic characteristics obtained at C-38S will inform the SEAWAT steady state groundwater flow model. The standard suite of geophysical logs (gamma-ray, caliper, resistivity, sonic, and temperature) and Optical Borehole Imagery (OBI) logs were run as each portion of the borehole was completed prior to casing installation.

During continuous coring process, packer testing and groundwater quality sampling was performed at 30-ft intervals (below a depth of 500 ft bls) to characterize groundwater quality and relative groundwater production characteristics with depth. Packer test samples are analyzed for the following constituents:

- total alkalinity
- arsenic
- calcium
- potassium
- magnesium
- sodium
- silica
- sulfate
- chloride
- total dissolved solids (TDS)
- strontium

As each well is completed and developed, an expanded list of groundwater quality constituents will be analyzed from UFA and APPZ open intervals. These data will characterize the native groundwater end-members for subsequent geochemical modeling efforts and will define pre-operational (native) groundwater quality prior to ASR cycle testing. Groundwater samples are analyzed for the following constituents:

- Field Parameters: pH, dissolved oxygen, specific conductance, temperature, turbidity, odor
- Major inorganic anions and cations: calcium, magnesium, sodium, potassium, barium, strontium, sulfate, silica, chloride, bromide, fluoride, carbonate alkalinity
- Trace inorganic constituents: aluminum, antimony, arsenic, beryllium, cadmium, chromium, copper, iron, lead, manganese, mercury and methyl mercury, molybdenum, nickel, radium, selenium, silver, thallium, uranium, vanadium, zinc
- Other inorganic and organic analytes: total dissolved solids, total suspended solids, total hardness (calculated) non-carbonate hardness, total organic carbon, total dissolved sulfide, corrosivity, cyanide
- Nutrients: total phosphorus, ortho-phosphate, total nitrogen (calculated), nitrate + nitrite, ammonia, total Kjeldahl nitrogen
- Stable and Radioactive Isotopes: delta deuterium (δH-2), delta oxygen-18 (δO-18), U-234 and U-238, iodine-131, strontium 89, strontium-90, radium 226, radium 228, gross alpha, gross beta
- Primary Organic Constituents: volatile organic compounds, semi-volatile organic compounds, herbicides, pesticides
- Municipal Water Treatment Analytes: haloacetic acids, bromate, chlorine, total trihalomethanes, foaming agents
- Microbiologicals: *Cryptosporidium*, *Giardia lamblia*, *Escherichia coli*, enteric viruses, fecal coliform, total coliforms, heterotrophic plate count

The continuous corehole reports for C-38S, L-63N, and L-63S are included as **Appendix C**, **D**, and **E**.

Mineralogic Characterization: Discrete core samples from the UFA and APPZ were sent to a specialty laboratory for the following analyses:

- Porosity
- Vertical and horizontal hydraulic conductivity
- X-ray diffraction
- X-ray fluorescence
- Cation exchange capacity
- Acid insoluble residue
- Thin-section petrography
- Scanning electron microscope analysis

These analyses characterize porosity and permeability, bulk mineralogy, and mineral composition and fabric in selected samples from the Ocala Limestone and Avon Park Formation. Samples from the C-38S continuous core were selected and submitted for analysis in June 2022. The mineralogic report from the C-38S continuous cores are included in **Appendix F.**

Cores collected from the C-38S and L-63S locations were analyzed by FGCU for selected trace element concentrations using a hand-held portable X-ray fluorescence (pXRF) analyzer in 2023. The C-38S core was unpacked, and every 10-foot section/box of core was inspected. Half of the L-63S core was acid treated by the USGS and used for the ASR fracture study and the second untreated half of the core was used by FGCU for the pXRF geochemical analysis.

The pXRF data collection effort was focused on the proposed ASR storage zones while also collecting data at one-foot depth intervals along the entire length of the collected cores. The X-550 pXRF has multiple analyzing settings. Based on the recommendations from SciAps, the Soil mode (SM) and Mining mode (MM) were utilized. The SM mode is best used to measure elements with low concentrations in the sample in parts per million (ppm or µg/g), while the MM mode is better to measure elements that have higher concentrations (from hundreds to thousands of parts per million or µg/g). The SM mode has three beams that operate at different voltages and amperages to minimize element overlap during analysis. Beam one operates at 50 kilovolts (kV) and 60 microamps (µA); beam two operates at 40 kV and 30 µA; and beam three operates at 115 kV and 30 µA. Based on recommendations from SciAps, each SM beam was operated for fifteen (15) seconds (45 seconds total). The MM mode has two beams – also with the intent of limiting elemental overlap of peaks during analysis. Beam one of MM mode operates at 40 kV and 35.5 µA; and beam two operates at 10 kV and 200 µA. Based on the recommendations from SciAps, each MM beam was operated for 25 seconds (50 seconds total).

These pXRF data complement the mineralogical analyses of discrete samples and provide information on the occurrence and concentrations of major inorganic cations and anions, and metals within the Floridan aquifer. The elements measured by the pXRF included the following 33 elements: Ca, Mg, Si, Al, Fe, S, K, Mn, P, Na, Hg, As, Mo, Cd, Cu, Sr, Zn, V, Ti, Cr, Ni, Ag, Se, Co, Rb, Ba, Pb, Sn, Sb, Ra, U, Zr, and Sr. During 2023, FGCU completed the following hand-held XRF analyses of the C-38S and L-63S cores:

C-38S summary:

- 908.66 feet of core was analyzed between February and July 2023
- A total of 1,712 analyses were completed (856 in mining mode and 856 in soil mode)
- 82 of the total analyses were deleted due to the elemental totals being above 100% or under 29%

L-63S summary:

- 648.92 feet of core was analyzed between October and December 2023
- A total of 1,140 analyses were completed (570 in mining mode and 570 in soil mode)
- Data quality checks are still in progress for these results

FGCU used eight reference standards to calculate the pXRF instrument elemental calibrations. The following reference standards were used:

- CGL 020 ML-3: limestone from the International Association of Geoanalysts (IAG)
- COQ-1: carbonatite from the USGS
- OPC-1: ordinary Portland cement from IAG
- DBC-1: ball clay from IAG
- SdAR-M2: metal-rich sediment from IAG and USGS
- CRM2: serpentinite from IAG
- OU-5: Leaton dolerite from IAG, and
- JSd-2: stream sediment from the Geological Survey of Japan

These reference standards were selected because they cover a wide range of metals of interest such as As and Mo, and carbonate standards. Eight replicates were obtained for the two pXRF analysis modes (soil and mining) for each reference standard. The pXRF analysis results can be viewed via this interactive website: http://mewstat.hopto.org/limestone/

The raw data collected by the pXRF were corrected by multiplying the measurements by the estimated correction factor. To assess the precision of the pXRF, the C-38S core was analyzed at the 20 depths listed in **Table 3-1.** Each depth was analyzed eight times using pXRF soil mode, and eight times using pXRF mining mode. These depths were selected because they provide the largest number of elements that could be analyzed, based on the geochemical data obtained during the C-38S core initial analyses.

Table 3-1. C-38S core sections used for pXRF geochemical precision analyses.

C-38S Precision Analysis Depths (depth of core in ft below land surface)
507.83
529.00
531.17
551.50
848.82
866.17
966.25
1,007.00
1,082.08
1,098.58
1,099.08
1,113.67
1,133.00
1,177.67
1,204.67
1,241.83
1,256.58

1,322.50
1,362.08
1,405.25

In addition, the pXRF analyses, a sample of a presumed volcanic ash layer identified in the L-63N core was also analyzed. This ash layer could allow the age of deposition for the Avon Park Formation to be more accurately determined. The following two standard size (27 by 46 mm) thin sections from the same billet (blank) were produced: 1) a polished thin section, and 2) thin section with a cover slip. The polished thin section was produced in case the sample needed to be studied on an electron microscope. The thin sections were used for the analysis. Volcanic lithic clasts, bipyramidal and faceted quartz, and trace amounts of plagioclase feldspar were identified petrographically.

Additionally, a sample of the ash layer was submitted for mineral separation and zircon U-Pb age dating at the University of Arizona's LaserChron Center. Results of the dating are expected in 2024.

Upon completion of continuous coring and testing in the corehole, the C-59 exploratory corehole was converted to a UFA monitoring well completed to a total depth of 847 feet bls.

Regional Fracture Analysis

This work includes a borehole fracture interpretation and analysis of the UFA and the APPZ flow zones associated with the ASR test well program. Drill cutting, cores, geophysical logs, and OBI logs were collected during borehole and well construction. These data will be used to identify fractures within the boreholes, determine aquifer anisotropy, fracture flow direction, and secondary permeability within the UFA and the APPZ flow zones associated with the ASR test well program. High resolution 2D, 2D swath and 3D seismic reflection data around the northern half of the lake was also collected during 2018 and 2022. These data will be reviewed as part of this evaluation. In addition to the data collected as part of the ASR Program and seismic surveys, historical borehole data and previous fracture trend analyses will be reviewed and incorporated into this study.

Summary of Fracture Porosity Analysis

Characterization and assessment of the distribution of fractures within specific aquifer intervals of the Floridan Aquifer system were performed as part of the Lake Okeechobee Watershed Restoration Project (LOWRP) efforts. The overall progress to date includes completion of the identification and description of fractures in the recovered cores from L-63N, L-63S and C-38S. Analysis of core from the C-59 test well will begin immediately upon receipt of the continuous core samples. Fracture assessment is conducted on OBI logs using the WellCAD Image and Structure Interpretation Workspace image module. In addition, visual examination of slabbed core is included in the fracture assessment. The strike and dip of the fractures are dependent on the quality of the borehole OBI and caliper logs. High-quality photographs of the slabbed core are provided for each well.

Ongoing and Future Studies

Continuous Core Analyses (2024-2025)

A Phase I site investigation and constructability investigation is being performed at the C-40 and C-41 sites. A comprehensive data collection program is expected to be conducted in the future.

Mineralogic characterization, as described above, will continue by the USGS on discrete core samples from the C-59, L-63N, and C-38S sites. The XRF geochemical analyses, chemistry data, thin section data, and age for the ash layer results from these sites will be included in the next version of the ASR Science Plan.

Utilization of the L-63N ASR Well (2024-2030)

The existing L-63N ASR well completed in the brackish APPZ will be utilized during the future Aquifer Performance Test (APT) on the L-63N ASR Wells 1 and 2. The mechanical integrity of the existing well constructed in the 1980s was found to be acceptable and the permit renewal for the existing well is under evaluation by the FDEP. The APT results of the newly constructed UFA Test Well and APPZ ASR Test Well at L-63N will inform the future buildout of the site and how the existing well can be utilized to improve the recoverability of stored water.

2024 Peer-Review Panel Guidance

The following guidance was provided by the PRP in its 2024 report (Price et al. 2024; **Appendix B**).

The removal of cores before geochemical analyses resulted in gaps in geochemical record; cores should not have been removed for other studies before completing the analyses. The use of a hand-held X-ray fluorescence unit provided very consistent and useful geochemical data on the cores and the statistical analyses provided a higher degree of accuracy. The results particularly on arsenic, molybdenum, and mercury have some impact on the design of the primary ASR wells. Exposure of the high concentrations of metals to the stored water in the lithologic units within the APPZ and UFA is a concern. All boreholes should be logged using advanced borehole techniques as described in Maliva et al. (2009).

3.2 NRC comment: Local-scale groundwater modeling should be undertaken to refine uncertainties about aquifer heterogeneity and anisotropy, travel times, and analysis of potential fracturing.

2020 Peer-Review Panel Guidance

The following guidance was provided by the PRP in its 2020 report (Arthur et al. 2020; SFWMD and USACE 2021b, **Appendix B**).

Page 5, PRP Report. The SFWMD ASR team appears aware of the challenges of working with multi-scale groundwater models. Model scales are both spatial and temporal and may include large fluxes in water volumes over short periods. Bracketing extreme conditions in context of climate change (e.g., extreme drought or rainfall over extended periods) at all scales in all aquifers will be important as these possible future conditions will impact regional groundwater withdrawals and managed recharge activities. Equally important, tracking model uncertainty at all scales should be routine to inform the planning and adaptive management process.

A more specific modeling observation relates to impacts of surficial aquifer system heads on deeper aquifers. FAS modeling did not include the surficial aquifer system, which in most cases is not a major issue. However, the surficial aquifer system head is important because it impacts the heads in all underlying aquifers. In several USGS coastal plain MODFLOW models (e.g., the 17-layer model in North Carolina), the model sensitivity showed that the head in the uppermost aquifer (surficial or unconfined) was a dominant force in controlled heads in the deeper aquifers (Guo et al. 2015). Therefore, including surficial aquifer system heads under extreme drought or rainfall conditions is recommended while modeling the FAS.

The PRP suggests APTs for anisotropy, flow zone analysis (maybe with packer testing), and cross-well seismic tomography to depict permeability away from the injection wells. Testing should be done in a way to understand aquifer heterogeneity and anisotropy and potential for fractures. Also, the PRP suggests the SFWMD ASR team explore various resistivity testing techniques (e.g., time domain) to characterize fluid movement in storage zones (with salinity contrast between native and injected water) before, during, and after cycle testing as these results can be useful in defining the extent of the freshwater buffer zone during operations.

2022 Peer-Review Panel Guidance

The following guidance was provided by the PRP in its 2022 report (Missimer et al. 2022; SFWMD and USACE 2022b, **Appendix B**).

The Panel agrees with the Hydrologic Modeling team on its use of SEAWAT to model the groundwater flow conditions before and during ASR operations. More explanation of the model layers would be appreciated, specifically a more detailed description of the "Flow Zone" indicated between the ICU and UFA layers on **Table 3-2**. Also, the Panel suggests that regional fracture and faulting patterns should be included in the hydrologic modeling, as higher permeable zones from fractures, faulting or karst layers can influence water storage, migration and recovery. A combination of identification of preferential flow paths with hydrological modeling should inform future monitoring well placement.

Progress Since 2022

Aquifer Performance Testing at the C-38S and C-38N Sites

Upon completion of the construction of the UFA and APPZ ASR test wells, a series of aquifer performance tests (APTs) including step-drawdown tests and constant-rate tests were conducted at C-38S between September and October 2023, and at C-38N between November and December 2023 (**Figure 3-1**). The purpose of the APTs was to determine the hydraulic properties of the Upper Floridan aquifer (UFA) and the Avon Park Permeable zone (APPZ) under pumping conditions.

The APT consisted of the following tests at C-38N and C-38S:

- One Step-drawdown test on each UFA ASR test well
- One Step-drawdown test on each APPZ ASR test well 30-day observation period during static (non-pumping) conditions
- One 5-day artesian flow test of each UFA and APPZ ASR test wells, simultaneously
- One 5-day constant-rate pumping test at each UFA ASR test well
- One 5-day constant-rate pumping test at each APPZ ASR test well
- One 5-day constant-rate pumping test on the UFA and APPZ ASR test wells, simultaneously
- 48-hour observation period during recovery at each UFA and APPZ ASR test well, following each artesian or pumping test

The APT was designed to create a controlled condition by pumping one well in the producing aquifer, and precisely measuring water level changes in non-pumping wells and monitoring wells (both zones if the well was a dual-zone monitoring well [DZMW]) having similar completion intervals to evaluate site-specific aquifer hydraulic characteristics including the evaluation of leakance between the pumping and non-pumping intervals, and horizontal anisotropy in the pumping intervals. A total of 27 monitoring wells; 13 completed in the UFA, 10 completed in the APPZ, 1 completed in the Hawthorn Group sediments, and 3 completed in the surficial aquifer system (SAS) were monitored during the APT. Each well was equipped with continuous recording transducers to monitor water levels and barometric pressure. Field water quality parameters such as temperature, pH, specific conductance, TDS, and turbidity, sand production, silt density index were monitored in the pumping well discharge. Field samples were obtained for laboratory analyses for primary and secondary water quality standards.

The step-drawdown test performed at each ASR well included four, 2-hour steps at rates between 1,300 gallons per minute (gpm) and 5,200 gpm. At the UFA test wells, artesian flow rates varied between 40 gpm and 1,528 gpm and pumping flow rates varied between 318 gpm and 4,524 gpm. At the APPZ test wells, artesian flow rates varied between 2,522 gpm and 2,637 gpm and pumping flow rates varied between 5,180 gpm and 5,331 gpm. **Table 3-2** presents the flow rates measured during each phase of the APT.

Table 3-2. APT Flow Rates.

Test Type	C-38S		C-38N	
	APPZ	UFA	APPZ	UFA
Artesian	2,522	1,528	2,637	40
Pumping	5,180	4,524	5,331	318
Combined	5,199	4,524	5,331	318

Flow rates as gpm; calculated from orifice plates and manometer.

The APT results are being incorporated in the local-scale groundwater model transient calibration to aid in predictive scenarios associated with the impacts of drawdown in the aquifer and other water users in the area injection of the freshwater “bubble” geometry, recovery efficiency of each aquifer, identify potential upconing of saltwater from deeper aquifers, and spacing between proposed ASR wells completed in the UFA and APPZ at each wellfield.

Local-scale Groundwater Flow and Solute Transport Model Development for C-38N and C-38S

A local-scale groundwater flow model is being developed to evaluate the potential effects of implementing a 50 million gallon per day (MGD) wellfield at the C-38N and C-38S sites on hydrogeologic conditions such as, aquifer heterogeneity, anisotropy, travel times, and the potential influence of natural fracture systems. The local-scale model is being developed using a similar methodology as the USACE KRASR local-scale model and incorporating the United States Geological Survey (USGS) groundwater modeling code, MODLOW 2005 and mass transport and density-dependent flow code, SEAWAT, with TDS of 35,000 mg/L normalized to seawater. TDS data is normalized by dividing each measured value by 35,000 mg/L, a commonly accepted TDS value for seawater, resulting in a unitless value of 1.0 for seawater and 0.0 for freshwater. Model outputs are then multiplied by 35,000 to convert back to actual concentrations for display and reporting purposes.

To evaluate and select a domain large enough to minimize the interaction of simulated C-38N and C-38S ASR operations with the model boundaries, Stantec Consulting Services Inc. developed a pair of 1-layer models representing the two ASR storage zones, the UFA and the APPZ. The maximum operational scenario is five ASR wells, completed in the UFA and APPZ, with each well storing and recovering 5 MGD. This was simulated in the 1-layer models as one cycle of injection, storage, and recovery at a single ASR well in each aquifer. The extent of the modeled head and concentration changes were then used to select the area of the model domain that extended outside the simulated freshwater bubble extent or would limit the interaction between simulated ASR injection and the model boundaries. ASR operations within the UFA and APPZ were simulated using a similar hydrogeologic framework and boundary conditions to that established in the KRASR local scale model (USACE, 2012). Two, 1-layer models representing the UFA and APPZ were created by vertically clipping the existing KRASR model to isolate select layers. The lateral extent determined from the C-38S single layer model domain resulted in a grid refinement to encompass ASR sites along the northern shore of the Lake such as, C-40, C-41, C-59, L-63N, and L-63S.

Results from the single-layer C-38S operational simulations and the multi-layer simulation for operations show an increase in hydrostatic head in the UFA and APPZ during the recharge phase and drawdown in groundwater levels during recovery. Simulation results, particularly in the UFA, indicate that the originally proposed model domain, equivalent to the KRASR model domain (48,000 ft by 48,000 ft), would not be sufficient to reduce interactions between the anticipated ASR pumping impacts and the model boundary; therefore, the model extent was recommended to be approximately 40 by 40 miles (210,000 ft by 210,000 ft). The increase in model domain will accommodate the local modeling effort for C-38N and C-38S and future modeling efforts at other proposed ASR sites along the northern extent of the Lake.

Unlike the KRASR model, a total of 22 model layers were chosen to represent hydrostratigraphic units from the SAS to the Boulder Zone. The model layers were reduced to efficiently run the model within the domain, which may be used in future modeling scenarios at other ASR locations. Grid discretization will remain the same as the KRASR model at the ASR well locations and will increase outwards with gradually increasing cell sizes, up to a maximum cell dimensions of 2,400 by 2,400 ft. Specified head and constant concentration boundary conditions will be established at the local scale model boundaries based on the SFWMD East Coast Floridan Model (ECFM) (Giddings, et.al, 2014).

Following a similar methodology used in the creation of the USACE's KRASR model (USACE, 2012), the initial conditions and boundary conditions for the local-scale C-38N and C-38S model were created by running the existing USACE Regional and ECFM models to simulate regional heads, TDS concentrations, and temperature in the aquifers. Density- and viscosity-dependent SEAWAT simulations of the two regional models were run in long-term transient mode to emulate equilibrium conditions. The quasi-steady state model aquifer and solute transport parameters, including hydraulic conductivity, porosity, dispersity, and storage, were assumed to be homogeneous within each hydrogeologic layer.

During the development of the models, Stantec prepared two interim technical memoranda (TM), Model Framework and Domain Assessment and Model Construction and Steady-state Calibration. The Domain Assessment TM provides an overview of the model setup, model results, a discussion on the outcomes of the assessment for the single-layer models, and a recommendation for the domain extent for the local-scale groundwater flow and solute transport model. Model Construction and Steady-state Calibration TM presented the model calibration to quasi-steady-state conditions using data collected from SFWMD regional databases. The calibration was effectively performed by preparing a steady-state model representing static aquifer conditions including hydraulic head and TDS concentrations for a period of 10 years.

ONGOING AND FUTURE STUDIES

Aquifer Performance Test Analysis (2024)

The analyses of the APT data will include calculating the specific capacity (gpm/ft), transmissivity (gallons per day per foot [gpd/ft] and square feet per day [ft^2/day], storage parameters, and well efficiency using the following methods: Cooper-Jacob, Theis, Hantush-Jacob. APPZ data was corrected for tidal and barometric effects using the USGS SeriesSEE Water Level Modeling Excel Add-in. These data provide the ability to evaluate the local versus regional heterogeneity and boundary effects as well as the hydrogeological conditions in the vicinity of the ASR and monitoring wells. Therefore, investigating how parameters change dynamically during an APT provides additional hydrogeological information about the ASR wells, monitoring wells, and targeted UFA and APPZ aquifers.

Upon preliminary review of APT results and incorporation of aquifer properties into the local-scale groundwater model, it was determined that 1,000 feet of spacing between well pairs is sufficient for future construction of well pairs to maximize well efficiency during recovery.

The APT data and results will be included in the final well completion report for C-38N and C-38S that is expected to be completed by mid-2024 and will be included in the next version of the ASR Science Plan.

Local-scale Groundwater Flow and Solute Transport Model Development for C-38N and C-38S (2024)

Additional calibration of the local-scale model, with spatially varying aquifer parameters, will be performed as part of the transient calibration to the C-38N and C-38S APT results.

Upon completion of the model, a final report will be developed to include the two aforementioned TMs as attachments and information regarding the development, calibration approach, calibration statistics achieved, model verification, and sensitivity analysis. The report will include maps and figures displaying model parameters and the locations of model boundary conditions, model grid, calibration statistics, graphics of observed vs. simulated water levels, TDS concentrations, and other elements of a standard model documentation report. Groundwater elevations, aquifer flow directions and the results of the predictive simulations will also be included. A complete model and final report are expected to be completed in 2025 and will be included in the next version of the ASR Science Plan.

Borehole Fracture Interpretation and Analysis Investigation (2024-2025)

Borehole fracture interpretation and analysis of the FAS will be performed by compiling geophysical logs, seismic logs, cores, lithologic interpretation, and other data collected for the ASR program.

OBI was performed by the USGS in each exploratory corehole at C-38S, C-38N, L-63S, L-63N, and C-59 and the water well drilling contractor completed OBIs in the ASR test wells and dual-zone monitoring wells. Geophysical logs collected during the advancement of the boreholes, including video survey logs, will be visually compared to OBI logs to validate fracture and bedding planes.

This data, along with regionally accepted publications, will be imported into WellCAD software to aid in identifying fractures and bedding planes within each borehole. Azimuth, dip angle, frequency, and dip orientation will be recorded and analyzed in each hydrogeologic unit encountered. An image and structure interpretation module will be utilized to identify and analyze structural features, such as bedding planes or fractures from acoustic borehole imager, OBI, 3D CoreScan, and formation micro-imager. APT data collected at the C-38N and C-38S sites will be incorporated into the interpretation of the fracture flow directions.

Upon completion of the borehole fracture analysis, a final report will be prepared to include the input and output files from WellCAD, maps, and graphical representations of the fracture trends in the local area. The report will describe the process of analysis and identify primary and secondary flow directions or anisotropy, along with aperture, if present, at all sites. Figures will include 3D representations of fractures identified in OBI logs. Maps of the area will depict the primary and secondary fracture trends as identified in the study.

The borehole fracture interpretation and analysis report is expected to be completed in early 2025.

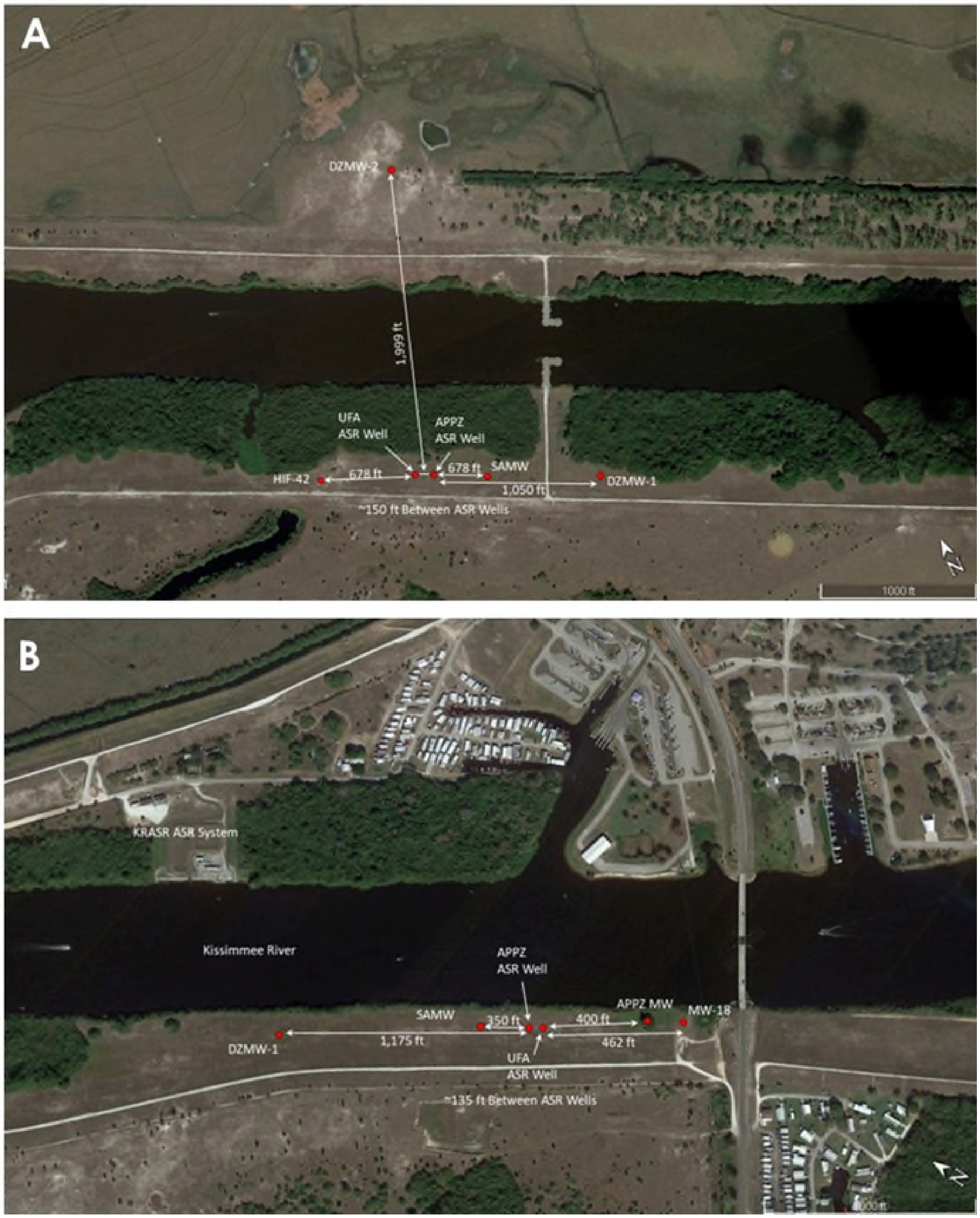

Figure 3-1. C-38N (A) and C-38S (B) ASR test wells and monitoring well layouts.

2024 Peer-Review Panel Guidance

The following guidance was provided by the PRP in its 2024 report (Price et al. 2024; **Appendix B**).

The PRP noted that the aquifer testing procedures conducted at C-38N and C-38S were technically correct and produced data with the ability to be analyzed with a reasonable degree of accuracy. The standard curve comparisons and the use of the Jacob straight line method tends to overestimate the transmissivity and underestimate the storativity and does not calculate leakance therefore, the degree of accuracy may not be true for the APPZ. The PRP recommended using the Hantush-Jacob log-log method which includes the leakance calculation.

The hydraulic analysis of the data from the APPZ cannot be considered to have a high degree of accuracy based on the very small amount of drawdown achieved in the monitoring well (about 0.3 ft). However, it is clear from the analyses that the transmissivity is over 1,000,000 gpd/ft. The PRP recommended the analysis of transmissivity data include the removal of the tidal water level fluctuations, using a harmonic analysis and compare the tidal fluctuations with those at the nearest surface tide gage station using standard equations. This analysis may be used to calculate the aquifer diffusivity, which would be useful.

In regard to the value of transmissivity calculated for the APPZ, the PRP noted that the District must be aware that the very high aquifer transmissivity makes it a very poor choice for ASR use. There is no successful ASR system in the world that uses an aquifer with a transmissivity this high. The recovery of freshwater will be low, perhaps in single digits. If a change in plans for the ASR goals would be to dispose of water in the Lower APPZ, then the project could be successful. Over decades, the freshwater injected would tend to move upward, therefore freshening the entire aquifer system. However, treating this water to drinking water standards makes this option financially infeasible.

Analysis of Groundwater Quality Data

The review panel recognizes that groundwater water quality sampling and hydraulically testing the aquifer during drilling and packer testing is useful and should continue. The data collected provides a better understanding of the aquifer system.

Interpretation of the groundwater chemistry results were not presented in 2024 ASR Science Plan. The PRP recommends a more detailed interpretation of the overall groundwater chemistry data once the construction and testing of the ASR test wells are complete. Additional recommendations include plotting groundwater temperature with depth on the same plot as the oxygen and hydrogen isotopes.

2024 Peer-Review Panel Guidance

The following guidance was provided by the PRP in its 2024 report (Price et al. 2024; **Appendix B**).

During well construction, the well is acidized using 32 % hydrochloric acid. The use of low molarity concentrated hydrochloric acid for borehole enhancement is not recommended for use in carbonate aquifers. It tends to have effects than penetrate to small distances from the inner borehole, can damage the cement grout seal at the base of the casing, and creates potential site safety hazards. It can also assist in removing some trace metals incorporated in the aquifer surrounding the near vicinity of the open borehole out to perhaps three or four feet.

Usage of sulfamic acid is recommended because it has a slow reaction time and penetrates deeper into the aquifer surrounding the borehole. It also presents a lower risk of damaging the grout that seal the base of the casing.

Use of acidification on the Avon Park High Permeability Zone was perhaps not useful in terms of hydraulic conductivity enhancement. The aquifer already has a very high transmissivity, so the elimination of aquifer skin effects surrounding the borehole was not an issue. In addition, the use of acid tends to expose fresh surfaces on the many organic layers that contain very high concentrations of trace metals of concern. The first injection and recovery cycle could produce high concentrations of these metals, particularly during the first test, and over repeated tested until the metals supply is reduced.

Perhaps doing the initial injection and recovery cycle using water from a nearby UFA ASR well at 5 MGD would reduce the concentration of trace metals and would allow a recovery rate to be determined without pretreatment. This method would require cooperation from the FDEP and the USEPA for the test period but would not require drinking water standards to be met. In this case there would be no issue with PFAS compounds.

3.3 NRC comment: The effects of aquifer anisotropy should be assessed, including the consideration of orienting recovery wells along the direction of preferential groundwater flow.

2020 Peer-Review Panel Guidance

The following guidance was provided by the PRP in its 2020 report (Arthur et al. 2020; SFWMD and USACE 2021b, **Appendix B**).

Page 7, PRP Report. The geometry of ASR well clusters has a significant impact on the potential recovery of stored water. One of the more effective geometries is the alignment of ASR in a linear mode in the down-gradient direction. This orientation may diverge from patterns of surface water bodies. In a gradient-oriented wellfield configuration, injected water commonly is captured at the terminus of the line before it can escape the effective capture radius of the system. This issue becomes more important as the natural flow gradient becomes greater. This alignment is particularly attractive in the case of continued injection during multiple or consecutive years of high-water conditions without annual recovery when some of the injected water could escape recapture as it moves with regional flow.

Progress Since 2022

This evaluation is pending the results of the aquifer performance tests and groundwater flow and solute transport modeling at the C-38N and C-38S locations. It is anticipated that the effects of aquifer anisotropy will be evaluated by use of the APTs, fracture analysis (by the USGS), and results of the local-scale groundwater model.

Ongoing and Future Studies

Local-scale Groundwater Flow and Solute Transport Model for C-38N and C-38S (2022-2024)

Characterization of aquifer anisotropy at the C-38N and C-38S sites will be developed as the USGS fracture analysis project results become available. This effort will develop similarly as the L-63N and L-63S cores are analyzed. These analyses will encompass the UFA and the APPZ. Fracture presence, orientation, and dip results will be incorporated into refined local-scale groundwater flow and transport models at the C-38N/C-38S and L-63N/L-63S sites as they become available. Model simulations can then inform future wellfield designs, including well spacing and orientations. It is anticipated that modeling results will be available by early 2025, subject to performance of aquifer testing and exploratory well completions.

3.4 NRC comment: Consider the use of tracer studies to determine hydraulic flow directions to properly orient/locate monitoring wells.

2020 Peer-Review Panel Guidance

The following guidance was provided by the PRP in its 2020 report (Arthur et al. 2020; SFWMD and USACE 2021b, **Appendix B**).

Page 6, PRP Report. As noted in **Section 3.2**, the PRP suggests APTs for anisotropy, flow zone analysis (maybe with packer testing), and cross-well seismic tomography to depict permeability away from the injection wells. Testing should be done in a way to understand aquifer heterogeneity and anisotropy and potential for fractures. Also, the PRP suggests the SFWMD ASR team explore various resistivity testing techniques (e.g., time domain) to characterize fluid movement in storage zones (with salinity contrast between native and injected) before, during, and after cycle testing as these results can be useful in defining the extent of the freshwater buffer zone during operations.

Progress Since 2022

To date, no tracer studies have been conducted at the existing and newly constructed SFWMD ASR facilities.

Ongoing and Future Studies

Reactive Transport Modeling for C-38N and C-38S (2024-2026)

As described under NRC comment 3.2, a local-scale groundwater model is being developed and calibrated by Stantec. ERDC will use the calibrated local-scale flow model and prepare a numerical model to quantify uncertainty in strategies to prevent arsenic (or other constituents of concern) mobilization. The model will focus on arsenic fate and transport and will allow for recommendation for future simulation efforts for the design of well-operation and monitoring schemes for ASR sites.

Geochemical and geohydrologic model parameterization from laboratory experimentation and field sampling and onsite aquifer testing, including detailed characterization of potential ASR sites from geophysical investigations and analysis of the rock cores, will be used to inform the groundwater reactive transport model.

The model effort is expected to begin in mid-2024 and be completed by mid-2026.

The reactive transport model will provide details for the planning efforts for tracer testing.

Tracer Studies at Exploratory Wells at C-38S and C-38N (2028-2029)

Tracer studies may be conducted at the C-38S and C-38N sites upon completion of the groundwater flow and solute transport modeling. Tracer studies may include pumping out of the test wells or injecting non-radioactive tracer into the wells for a brief period of time. Prior regulatory approval is required before tracer studies may proceed. Detailed scoping of the tracer testing methodology has not yet been undertaken.

3.5 NRC comment: Consider the use of cross-well seismic tomography and regional seismic evaluation to assess the effects of tectonic faults on well location and performance.

2020 Peer-Review Panel Guidance

The following guidance was provided by the PRP in its 2020 report (Arthur et al. 2020; SFWMD and USACE 2021b, **Appendix B**).

Page 6, PRP Report. There is a significant potential role for applied geophysics regarding aquifer property characterization, especially at the wellfield scale. For example, 2D and 3D seismic surveys can provide information on storage zone integrity through identification of collapse zones that may be pathways for injectate to migrate vertically. These potential pathways, if present, could jeopardize the effectiveness of the ASR wells. Borehole geophysics such as vertical seismic profiles (VSPs), porosity-type logs, and ground-truthing through acquisition and hydrogeologic study of cores would inform seismic surveys and allow for improved post-processing to characterize subsurface properties in relation to ASR. APT data could be used to validate interpretive seismic results. Changes in water temperature could be used to ascertain whether these interpreted collapse zones are allowing upward fluid movement.

Progress Since 2022

Collier Geophysics LLC., (Collier) conducted high-resolution 2-D seismic reconnaissance data acquisition, processing, and integrated during between 2022-2023. A total of 9.06 miles of seismic data was collected from the C-38N, L-63N, L-63S, C-59, C-40, C-41, Port Mayaca, and C-44 locations (**Figure 3-2)**. The primary objective of this seismic reconnaissance data acquisition was delineation and hydrogeological characterization of the Intermediate aquifer system (Hawthorn Group) and the underlying FAS. The secondary objective was to evaluate the integrity of the storage zone, especially where the hydrogeological structure between aquifers and confining units of the FAS was not fully understood. The seismic study collected 2-D high-resolution seismic data and tied these data back to the available hydrogeologic, lithologic, and well log geophysical data. Such an integrated approach facilitated a more comprehensive characterization of the aquifer systems. Synthetic seismograms were created using the downhole geophysical logs collected during the ASR drilling. Synthetic seismograms tie the seismic data collected from the surface to the downhole geophysical logs collected from the ASR coreholes. Synthetic seismograms convert the seismic data from time to depth and can be used to pull out more petrographic information from the seismic data. Collier used these synthetic seismograms to create seismic cross sections at each ASR site. The seismic data collected for this study provided details about the structure and stratigraphy of the FAS and overlying formations. Significant differences in the continuity of reflectors were noted within formations along seismic lines and between ASR sites. As noted in the Collier report, dipping to sub-vertical features were observed on several lines that appear to divide blocks with differing reflector properties. Well HIF-42 is located in a block with coherent horizontal reflectors on seismic line C-38N to a depth of about 800 feet below ground surface. The rock in the HIF-42 corehole was noted as having an unusually tight formation through the Suwanee, Ocala, and Upper Avon Park section but was very permeable in the lower Avon Park Formation. It is possible that further examination of the seismic response of additional wells will lead to stratigraphic interpretations that will help identify favorable and unfavorable locations for wells. The collected seismic data and interpretations of each seismic line was included in the Collier final report attached as **Appendix G**.

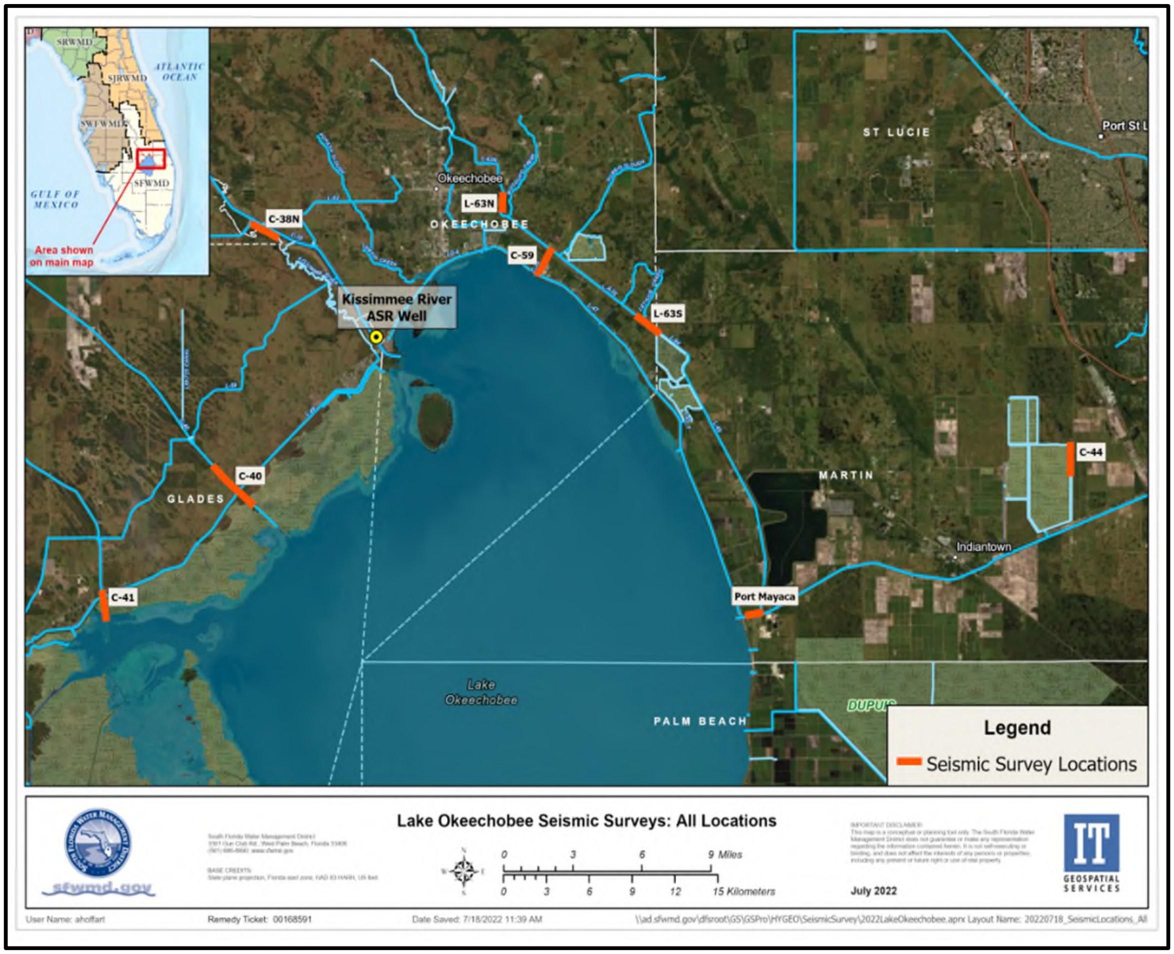

Figure 3-2. Locations of Completed Seismic Surveys.

2024 Peer-Review Panel Guidance

The following guidance was provided by the PRP in its 2024 report (Price et al. 2024; **Appendix B**).

The District should continue to analyze the data collected to date and pursue the measurement of extensive east-west oriented lines to better understand facies changes and continuity of various aquifers in the ASR project area and other regions of southern Florida.

3.6 NRC comment: Analysis of optimal wellfield cluster configurations and well spacing should be conducted to promote maximum recovery efficiency.

2020 Peer-Review Panel Guidance

The following guidance was provided by the PRP in its 2020 report (Arthur et al. 2020; SFWMD and USACE 2021b, **Appendix B**).

Page 8, PRP Report: Geometric ASR well arrangements that use triangles, double lines, or grids tend to trap native water between wells, thereby inducing mixing within the ASR storage zone. When operating a complex multi-well ASR system, it may be necessary to fully flush the ASR aquifer or zone between the first two wells, in the case of a triangle, before injection in the third well begins to avoid the mixing issue. This concept expands on typical buffer zone maintenance practices to improve recovery efficiency. The trapped water issue becomes more complex when using double lines or a grid. If the ASR storage zone has low TDS concentrations, there is no problem; however, as salinity in the ASR aquifer increases, the geometry problem becomes more acute. The trapped water issue can greatly reduce recovery efficiency.

In addition to well configurations, as new ASR wellfields are conceptualized, the PRP encourages consideration of hybrid approaches, including one or more of the following: bank filtration; aquifer storage, transfer, and recovery (i.e., recharge and recovery not using the same well); inter-aquifer transfer; wetland pre-treatment; or surface reservoirs. Hybrid approaches are advancing worldwide. A technical workshop focusing on emerging wellfield configurations and operational strategies would inform future decisions.

Progress Since 2022

The existing ASR pilot facilities (L-63N ASR and KRASR) constructed to date are single well systems. Newly constructed and proposed well clusters consist of an APPZ ASR test well, UFA ASR test well, a dual-zone monitoring (DZMW) well, and a surficial aquifer monitoring well (SAMW). Two sets of well clusters were substantially completed at the C-38N and C-38S sites in August 2023. Construction of one well cluster at L-63N began March 2023.

The constructed well spacing between each ASR test well at C-38N and C-38S sites is provided in **Table 3-3**.

Table 3-3. Well Spacing Between ASR Test Wells.

Site Well ID		C-38S APPZ	C-38S UFA	C-38N APPZ	C-38N UFA
C-38S	APPZ		135	35,002[1]	
	UFA	135		35,152[1]	
C-38N	APPZ	35,774[1]			151
	UFA	35,925[1]		151	

[1]Measured from distance (feet) between midpoint of UFA and APPZ ASR wells.

Upon evaluation of the APT results and the development of the local-scale groundwater model (described in response to NRC comment 3.2), preliminary minimum well spacing recommendations are approximately 1,000 feet. The siting of future well clusters at C-38S will be minimally spaced 1,000 feet from the newly constructed ASR test wells.

Ongoing and Future Studies

Construction of Second ASR Well Pair at C-38S (2024-2025)

Construction of a second well pair at C-38S is expected in late 2024. This well pair will be constructed within 1,000 feet of the existing ASR test wells in a linear alignment due to real estate constraints along the levee and the C-38 Canal. Additional well pairs alignment and spacing will be reevaluated upon completion of testing and incorporation into the local-scale groundwater model.

Design and Construction of ASR Clusters at Future Wellfields (2025)

Analysis of ASR wellfield configurations at L-63S, C-59, and C-40/C-41 locations will be evaluated upon completion of the local-scale groundwater flow and transport model simulations.

3.7 NRC comment: Additional analysis of injection pressures on the propagation of fractures should be conducted, perhaps using step-rate tests that assess injectivity as a function of injection pressure.

2020 Peer-Review Panel Guidance

The following guidance was provided by the PRP in its 2020 report (Arthur et al. 2020; SFWMD and USACE 2021b, **Appendix B**).

Page 5, PRP Report. Analysis indicated rock fracturing should not be a problem during normal operation of the regional ASR system. Results of the analysis seem conservative, especially above the UFA. There are improvements that could be realized in the analysis that likely would help evaluate the risk of unexpected movement of injected water.

Page 7, PRP Report. Following the regional characterization of rock fracturing, minimal concern exists regarding fracturing through the overlying strata due to their modulus of elasticity; however, fracturing of the more brittle carbonate strata below the formation is a greater concern. Fracturing could increase the efficiency of injection or develop pathways for injectate migration and reduce recovery efficiency. To evaluate local fracturing during ASR, and as validation of previous fracture modeling, installation of a few high-sensitivity seismic geophones could provide a fracture monitoring strategy. The geophones also would provide data if collapse events occur.

Progress Since 2022

During construction of the ASR wells, the final 26-inch FRP casings were pressure tested for mechanical integrity. Each casing was tested at 150 psi; therefore, in accordance with 62-528.410 F.A.C., the well may not operate (inject) at a pressure greater than 100 psi. Regionally, ASR wells completed in the UFA do not exceed operational (recharge phase) pressures of 50 psi. Based on the transmissivity and hydraulic properties of the APPZ, it is expected the APPZ ASR wells will operate (recharge phase) at a lower pressure than the UFA.

During the APT at C-38N and C-38S, transducers deployed in each ASR and monitoring well monitored and recorded hydraulic pressure within the aquifer. The APT did not include injection of water into the aquifer; therefore, the monitoring of injection pressures on fractures in the stratum was not conducted.

Ongoing and Future Studies

Cycle Testing at C-38S (2027)

During the recharge phase of cycle testing, well pressures will be monitored, as required by the FDEP permit and cycle testing plan. Monitoring and analysis of injection on the propagation of fractures will not be conducted in the near future.

4 UNDERSTANDING PHOSPHORUS REDUCTION POTENTIAL

4.1 NRC comment: More research into long-term nutrient removal mechanisms and rates under varying aquifer conditions should be undertaken.

2020 Peer-Review Panel Guidance

The following guidance was provided by the PRP in its 2020 report (Arthur et al. 2020; SFWMD and USACE 2021b, **Appendix B**).

Page 11, PRP Report. The PRP agrees that phosphorus removal during storage likely is caused by advective dilution, bacterial consumption, and most likely adsorption. The high potential for phosphorus to adsorb onto limestone has been demonstrated in laboratory tests (Price et al. 2010) and in shallow injection wells in the Florida Keys (Corbett et al. 2000). The precipitation of apatite ($Ca_{10}(PO_4)_6(OH,F,Cl)_2$) is not anticipated to be a significant process based on the kinetics in the aquifer environment. Also, dissolved inorganic phosphorus can easily desorb from the bedrock with even small increases of chloride associated with saltwater intrusion (Flower et al. 2017), so monitoring of phosphorus with chloride concentrations during recovery is recommended.

Page 11, PRP Report. The bioclogging column studies proposed by the USGS are a good step towards addressing the potential for phosphorus reduction. The PRP recommends geochemical modeling to assess the potential for phosphorus reduction and calcium carbonate dissolution/precipitation. The PRP understands the proposed testing is to be completed on cores and columns of FAS material collected from the exploratory borings in the UFA and APPZ. The PRP suggests similar testing be conducted for the water quality and microbial analyses during the injection, storage, and recovery phases of all ASR operations.

Progress Since 2022

The bioclogging flow-through column experiments conducted by the USGS are in progress. This should further refine the rates and capacity for nutrient reduction and potential aquifer plugging from microbial biofilms during subsurface storage. The characterization may help estimate the maximum amount and duration of nutrient reduction if a “biomass plateau” is created within the aquifer during storage of nutrient-laden water.

These flow-through column experiments use columns of sterilized borosilicate glass beads, solid core with a native population of biota set in a triaxial cell, crushed core material on which native biofilms have colonized, and crushed core material without biofilm colonization. The core materials used in the column experiments were collected from the UFA and APPZ during the drilling of C-38S, L-63S, and C-59 coreholes. Solid cores suitable to be set in a triaxial cell were not able to be collected from the APPZ at C-38S. Core fragments suitable for crushed core material was able to be collected for all aquifers in all coreholes.

Microbial activity and biofilm growth will be quantified through microscope imaging of biofilm development, a suite of microbiology assays, and analysis of biogenic gases produced within the columns. Biogeochemical modelling will be completed using data collected through hydrogeological and mineralogical analyses of the cores, and geochemical analyses of source water and discharge from test columns. Clogging can come from biomass growth, calcium carbonate precipitation, and particulates in the source water. The data collected from these analyses and modelling will be used to evaluate the microbiological, chemical, and physical factors that contribute to clogging the aquifer in ASR storage zones.

It is anticipated that the bioclogging flow-through column experiments will be complete by early 2025. The first of four experiments have been completed for the crushed core material from the UFA storage zone at well C-38S. Preliminary data indicate effects of bioclogging can be detected and quantified in the laboratory column systems during a three-week charge period. Additionally, there are significant reductions in dissolved oxygen, dissolved organic carbon (DOC), nitrates and phosphorus during the recharge and storage phases.

Ongoing and Future Studies

US Geological Survey Bioclogging Experiments (2024-2025)

The results of the USGS flow-through column study can be used to conduct research related to the following:

- Determination of nutrient-holding capacities for specific storage zones at ASR facilities using established native biofilm communities grown on core material extracted from the same storage zones under study.
- Characterization of geochemical processes (e.g., changes in salinity between the recharged surface water and native groundwater) that influence bioclogging and nutrient adsorption/desorption rates from core materials.
- Characterization of biogeochemical processes (e.g., dissolved oxygen, oxidation-reduction potential, changes in salinity, carbonate dissolution) that influence rates of immobilization/mobilization of metals from core materials.
- Generation of biogeochemical data sets that will be used to refine existing models (e.g., Phosphorus Load Simulation Model) and develop new geochemical/reactive transport models for the fate and transport of nutrients, metals, and microorganisms.

Phosphorus Loading Spreadsheet Model (2025)

In 2019, the SFWMD used the Phosphorus Loading Spreadsheet Model (a simple spreadsheet model) to estimate the reduction in phosphorus load to Lake Okeechobee due to implementation of LOWRP. The model indicated the ASR component would result in an annual phosphorus load reduction of approximately 4.1 metric tons. This estimate was conservatively computed based on the assumed volumetric recovery efficiency of the ASR, without recognition of a subsurface microbial or mineralogic uptake effect. Upon completion of the USGS flow-through column study (described above), the Phosphorus Loading Spreadsheet Model can be rerun to include documented rates and capacities of microbial phosphorus uptake.

5 OPERATIONS TO MAXIMIZE RECOVERY

5.1 NRC comment: Improve/understand cycle tests to increase recovery efficiency.

2020 Peer-Review Panel Guidance

The following guidance was provided by the PRP in its 2020 report (Arthur et al. 2020; SFWMD and USACE 2021b, **Appendix B**).

Page 8, PRP Report. As noted in **Section 3.6**, geometric ASR well arrangements that use triangles, double lines, or grids tend to trap native water between wells, thereby inducing mixing within the ASR storage zone. When operating a complex multi-well ASR system, it may be necessary to fully flush the ASR aquifer or zone between the first two wells, in the case of a triangle, before injection in the third well begins to avoid the mixing issue. This concept expands on typical buffer zone maintenance practices to improve recovery efficiency. The trapped water issue becomes more complex when using double lines or a grid. If the ASR storage zone has low TDS concentrations, there is no problem; however, as salinity in the ASR aquifer increases, the geometry problem becomes more acute. The trapped water issue can greatly reduce recovery efficiency.

Page 9, PRP Report. There are concerns about water loss during recovery. Past studies of possible water recovery from long-term operating boulder zone injection wells showed poor results. Design modifications could be made to allow higher recoveries from these wells. The SFWMD ASR team should evaluate pros and cons of deep ASR wells based on surface water hydrologic modeling of extreme events.

Progress Since 2022

This uncertainty will be addressed when the initial well clusters **Figures 5-1 and 5-2** are placed into operation. When developed, the local-scale groundwater model will be useful in simulation of alternatives for cycle testing and operation of the wellfields to maximize recovery efficiencies.

Ongoing and Future Studies

The SFWMD will continue to develop the local-scale groundwater model and a solute-transport model to aid in evaluating hydraulic impacts of ASR. Calibration to static conditions is important as a first step and valuable for evaluating hydraulic impacts, but there will still be large uncertainties with respect to simulated recovery efficiencies (unless system is freshwater into freshwater and chemistry is irrelevant). Solute-transfer models need to be calibrated to actual ASR cycle testing results, which for the near future the only adequate available data is from the KRASR tests. Chloride, sodium, sulfate, or some other parameters in which there is a difference between recharged and native groundwater should be used as a tracer. The local model layering should capture as much of the aquifer heterogeneity as possible (discrete major flow zones) and the local-scale groundwater model with its 22 model layers accomplishes this goal. A cycle- test-calibrated model could then be used to evaluate design and operational options for increasing recovery efficiency, such as the size of the buffer zone and configurations of multiple well systems.

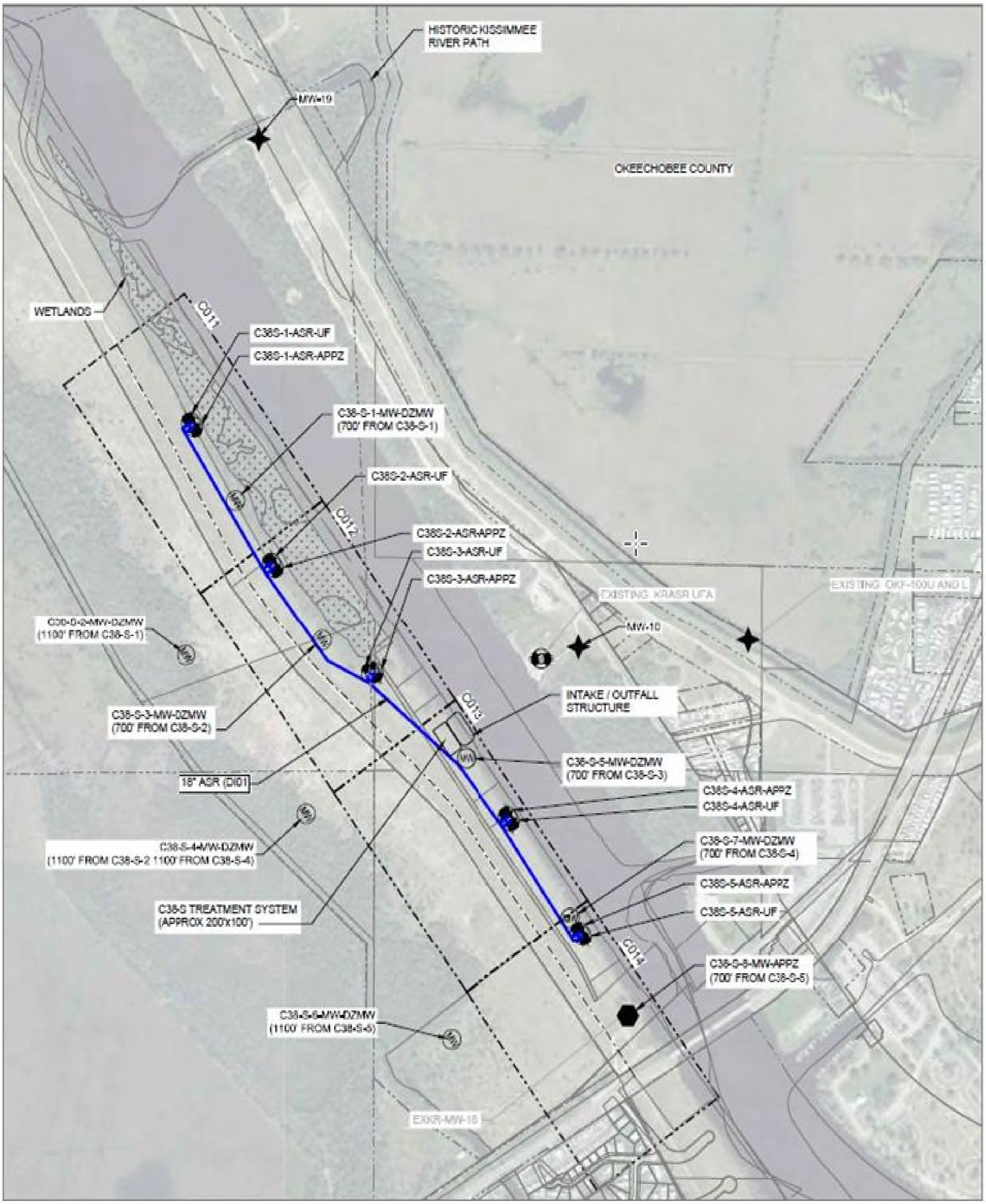

Figure 5-1. Conceptual layout of the C-38S ASR wellfield.

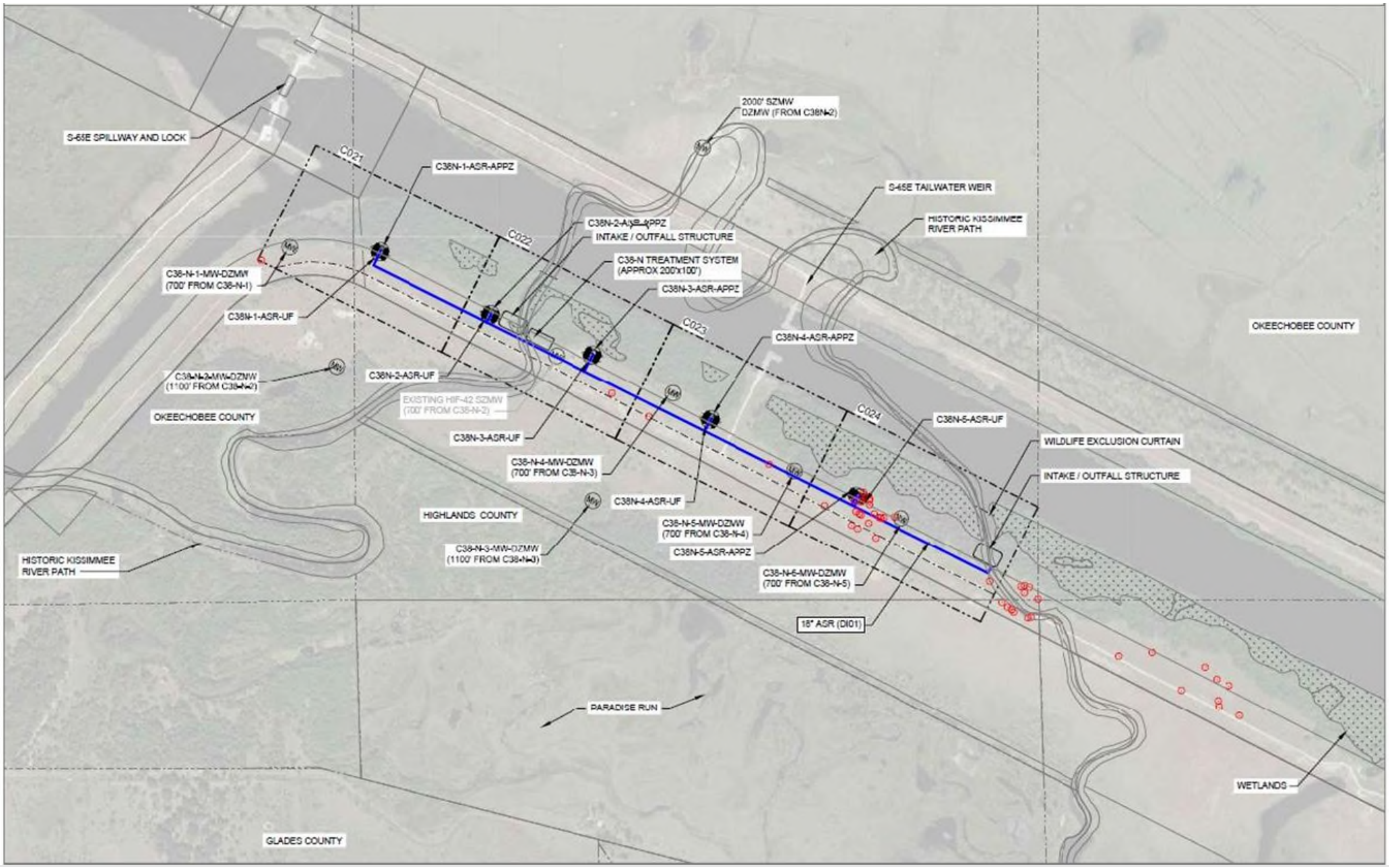

Figure 5-2. Conceptual layout of the C-38N ASR wellfield.

Conceptualizing ASR Cycle Testing in the UFA and APPZ (2022-2024)

ASR cycle testing operations in the “stacked” UFA and APPZ aquifers of the FAS have not been implemented anywhere in south Florida. Thus, there are many uncertainties that require further evaluation during the Planning and Engineering Design (PED) phase. The hydraulic characteristics and native groundwater quality of the UFA differ from those of the APPZ. Hydraulic characteristics will be quantified during APTs at each location, as described in the comment 3.2 response. Native UFA and APPZ groundwater composition will be characterized at every site after each ASR and monitoring well is completed.

Conceptualizing operational scenarios for ASR cycle testing is needed at each ASR system location. For ASR systems that may operate in tandem (C-38S, C-38N and L-63N, L-63S), site-specific hydraulic and groundwater quality data will inform the local-scale models currently under development. Groundwater flow and solute transport models will be calibrated using static conditions (pre-development potentiometric surfaces of the UFA and APPZ). Once calibrated, the models will simulate the effects of different operational scenarios in the UFA and APPZ. Further refinement of the models is anticipated once preliminary cycle tests are completed, which can assist in optimizing the recovery efficiency of future cycles.

Cycle Testing (2027)

5.2 NRC comment: Establish and maintain a freshwater buffer zone during cycle testing.

2020 Peer-Review Panel Guidance

The following guidance was provided by the PRP in its 2020 report (Arthur et al. 2020; SFWMD and USACE 2021b, **Appendix B**).

Page 9, PRP Report. The concept of a buffer zone is most applicable to ASR systems that operate on an annual schedule to meet peak demand in public utility systems. Also, the buffer zone is a key factor in storage aquifers that contain brackish water because it increases the annual operational efficiency. Operational efficiency is commonly defined to include all water injected with a comparison of the water recovered to the goal TDS, including the water used to create the buffer zone. As it applies to ASR well systems, if the target aquifer is essentially fresh water, the use of a buffer zone is not essential. The wells will always have a high recovery efficiency because they exhibit the blended storage concept. In ASR wells located where brackish water occurs in the aquifer storage zone, a buffer zone is important, particularly if annual cycles of injection and recovery are anticipated (one injection and recovery period each year). A buffer zone is only effective if the storage aquifer rock has predominantly intergranular porosity. Where the transmissivity is very high and associated with channel pores (e.g., dual porosity), a buffer zone does not provide a clear operational advantage. The recovery efficiency will tend to remain low. In addition, as the salinity in the storage aquifer increases, the necessary buffer zone rises because more water needs to be displaced to prevent upward migration during rest/storage cycles. In the case of moderate- to high-salinity native groundwater, injection of more water than recovered is a common practice in order to create a buffer zone between the low- and high-quality water. Management of the volume and growth rate of the buffer zone could improve fouling issues, nitrogen and arsenic mobilization and transformation, and recovery efficiency.

Progress Since 2022

This uncertainty will be addressed when the first few well clusters are placed into operation. Buffer zones typically are defined as a mixed zone between native groundwater and recharge water, with the proportional mixing of the two end-members based on conservative tracers such as chloride. Four test cycles conducted at the KRASR well from 2009 to 2013 resulted in recovery of a volume of water equal to or greater than the volume of water recharged because the UFA at this location is fresh. Thus, there was no development of a residual "bubble" of water left in the aquifer to create a buffer zone for subsequent cycles. Development of a buffer zone has been shown to improve recovery efficiencies in brackish aquifers, and also to retain native groundwater constituents of concern (chloride, sulfate, radium) in the aquifer during recovery. Buffer zone development in the APPZ storage zones will be particularly important because native groundwater is brackish in the project area.

Ongoing and Future Studies

Local-scale Groundwater Flow and Solute Transport Model Simulations

An important consideration of ASR operations in a "stacked aquifer" hydrogeologic setting is that a freshwater buffer zone may be required *below* the UFA (in the APPZ), not just as a zone between native and recharged water within a single aquifer. The concept of upconing during recovery will be an important scenario to be tested during actual ASR operations as well as by using local-scale groundwater flow and solute transport models.

Characterize a Buffer Zone Based on Sulfate Concentrations

Increased sulfate concentrations in recovered water may stimulate mercury methylation in nearby sediments in receiving surface water bodies. Sulfate in native UFA and APPZ groundwater may limit recovery efficiency so that mercury methylation risk is minimized. Native UFA groundwater at C-38S and KRASR is fresh (chloride concentration approximately 300 mg/L) but native groundwater sulfate concentrations far exceed sulfate concentrations in the C-38 Canal or L-63 Canal. Native sulfate concentrations in the APPZ also exceed surface water sulfate concentrations. Transient SEAWAT solute transport simulations using TDS will serve as a proxy for preliminary estimates of sulfate concentrations during mixing. These simulations will define the sulfate threshold in recovered water that will reduce mercury methylation risk.

5.3 NRC comment: Operate multi-well pairs and clusters to improve performance.

2020 Peer-Review Panel Guidance

The following guidance was provided by the PRP in its 2020 report (Arthur et al. 2020; SFWMD and USACE 2021b, **Appendix B**).

The operation of well clusters is a good concept but requires special operational management. If a three-well cluster is used, only two wells can be used during the first injection cycle because if all three are used, a column of saline water (if present) may be trapped between the wells and cause extensive mixing and very poor recovery. The third well should be pumped only after the injection zone in that well is flushed of native water. This is not an issue where the UFA groundwater is fresh (for example, C-38S); however, in brackish water systems such as other UFA and APPZ aquifers, it is a major issue.

Progress Since 2022

This uncertainty will be best be addressed when the first few ASR multi-well clusters are placed into operation. To date, the ASR projects constructed at the KRASR, Hillsboro Canal, and L-63N Canal are single-well systems.

Ongoing and Future Studies

Exploratory Wells at C-38S and C-38N (2022-2023)

Extensive hydrogeologic and aquifer testing was conducted at the UFA and APPZ at C-38S and C-38N following completion of ASR test and monitoring wells. Groundwater quality was characterized with data obtained from packer tests at 30-ft intervals in the exploratory borehole. Specific capacity tests were conducted at appropriate permeable intervals. Aquifer parameters derived from these tests were incorporated into the local-scale groundwater flow and solute transport model simulations. These simulations will provide insight on many operational scenarios such as well-to-well interactions and interactions between the UFA and APPZ during pumping.

Cycle Testing (2025-2026)

A local-scale groundwater flow and solute transport model will be developed to simulate proposed cycle testing scenarios and support Underground Injection Control (UIC) permitting for the C-38N and C-38S ASR systems.

6 DISINFECTION/TREATMENT TECHNOLOGY

6.1 NRC comment: Examine treatment technologies to consistently meet regulatory requirements.

2020 Peer-Review Panel Guidance

The following guidance was provided by the PRP in its 2020 report (Arthur et al. 2020; SFWMD and USACE 2021b, **Appendix B**).

Pages 14-15, PRP Report. ASR wells are classified as Class V injection wells under the FDEP and United States Environmental Protection Agency underground injection control rules. The definition of an underground source of drinking water is any groundwater with a TDS concentration of 10,000 mg/L or less. Under the underground injection control rules, any water injected into an underground source of drinking water must meet all drinking water standards. This includes bacteria levels and many other parameters.

There are two potential strategies to meet these rules. The first is to treat the recharge water to meet all primary drinking standards and request exemptions for any secondary standard exceedances. This is the current direction the SFWMD and USACE are taking. Another approach would be to reclassify parts of the FAS (with buffers) to sole use as an ASR aquifer (with an aquifer exemption, as defined by the United States Environmental Protection Agency) and set appropriate standards that may exceed certain drinking water quality standards. Because the bacteria injected into the aquifer tend to die off rapidly and most arsenic and other regulated substances remain in the aquifer, the only water quality standards that would have to be met are those at the point of discharge back into the natural system. The “sole use” designation could save large amounts of capital and operating expenditures over the long term and would not pose any environmental risks.

2022 Peer-Review Panel Guidance

The following guidance was provided by the PRP in its 2022 report (Missimer et al. 2022; SFWMD and USACE 2022, **Appendix B**).

The Panel recommends the addition of a new Panel member that has a strong background in water treatment and economics of water treatment.

The Panel has serious concerns with the cost of operating a more complex pretreatment system in future large-scale ASR implementation. The Panel recommends revisiting the point-of-compliance issues with the regulatory agencies to both maintain high degrees of water quality in the storage aquifer, but to also save capital costs of building a large number of water treatment facilities with the associated costs of operation. Potential solutions include using a 300-foot distant monitoring well as a point of compliance or trickle chlorination below the wellhead to kill remaining bacteria. The Panel also recommends investigation of possible different pretreatment system design wherein the storage aquifer where it contains saline water which would require desalination before it could be used for drinking water.

The Panel suggests using an incremental approach to the design, construction, and operation of the pretreatment of the water to be stored. It is suggested that a single water treatment facility be constructed and operated at some chosen capacity from 5 to 20 MGD to acquire real data on both construction and operating costs. The capacity of this test facility should be matched with a specific ASR multi-well site. If the costs are found to produce an unreasonable financial burden on the South Florida Water Management District and the U. S. Army Corps of Engineers, the pretreatment issue should be revisited with consideration of reduced water treatment based on a new point of compliance and a number of aquifer exemptions (see section above). Additional solute transport modeling could be conducted to determine if any private or public wells would have impacts that would be detrimental to their operation based on operation of a reduced degree of water treatment.

Membrane filtration methods were evaluated which have a very high operating cost. The Panel recommends that other coagulants be tested before media filtration is abandoned as a potential treatment method. One rather effective coagulant is ferrate which was recently found to be more effective that ferric chloride to remove organic matter and suspended sediment in seawater reverse osmosis desalination systems (see Alshahri et al., 2022). It should be noted that there are other coagulants that could also be more effective than aluminum chlorohydrate.

Progress Since 2022

In 2020, the SFWMD initiated a water treatment technology review to evaluate processes that could be used to meet regulatory requirements during ASR operation. The processes reviewed included pressure and mechanical filtration, screens, exclusion barriers, membranes, cartridge filters, ion exchange, coagulation, chemical disinfection, pasteurization, oxidation, ultraviolet disinfection, ultrafiltration, and nanofiltration. Various combinations of those processes were systematically evaluated to determine the most optimal, efficient, and cost-effective configurations. In concert, SFWMD executive management remains committed to meeting the Florida drinking water standards prior to ASR well injection and storage, per 62-528 F.A.C. and UIC permit requirements. Based on the results of the Water Treatment Technology Evaluation, the SFWMD proceeded with proof of concept (POC) testing of treatment systems.

From 2021-2022, POC testing was conducted for two technologies: (1) Membrane Filtration Systems (MFS), and (2) Granular Media Filtration (GMF) followed by Ultraviolet (UV) disinfection. The intent of testing was to challenge treatment systems with poor quality (high color) surface water. In response to a request for statement of qualifications, four MFS respondents were selected to demonstrate systems that can produce water suitable for aquifer recharge. POC testing of these systems was conducted in parallel with GMF and UV treatment at the existing KRASR facility.

Microfiltration/ultrafiltration (MF/UF) membrane treatment technology demonstrated the ability to remove coliform bacteria by size exclusion and to remove significant amounts of DOC. While granular media filtration helped remove solids and reduce turbidity, it was unable to effectively reduce color to meet secondary drinking water standards. Residual color following GMF inhibited performance of UV disinfection.

The SFWMD LOWRP ASR POC Testing Report was finalized in July 2022, which provided the basis for the treatment process selection for the future treatment facility. This report is included herein as **Appendix H**.

Upon completion of the POC testing and review of the consultant analysis, SFWMD selected membrane treatment using straining, coagulation, and MF/UF as the preferred treatment technology for the basis of design. A generalized schematic of the selected membrane treatment process is illustrated in **Figure 6-1**.

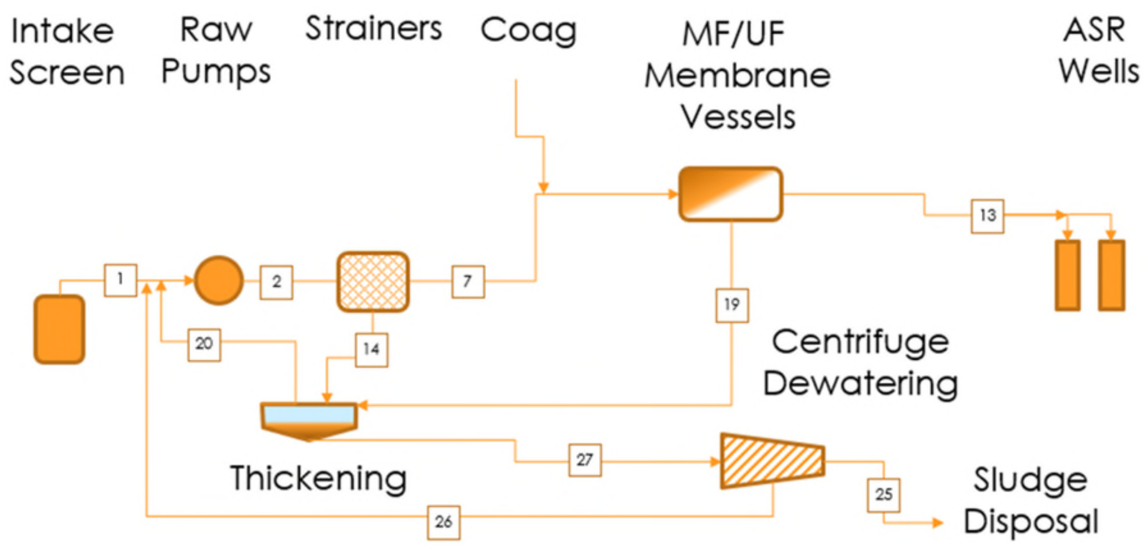

Figure 6-1. Schematic of Selected Treatment Process: Coagulant with MF/UF Membranes.

(Source: SFWMD LOWRP ASR Proof of Concept (POC) Testing Report, July 2022)

Preliminary design of the ASR treatment facility using the selected treatment process is currently underway and employs an incremental and phased approach to design, construction, and operation at the proposed C-38S ASR well location. The initial phase (Phase 1) of the project includes design and construction of pretreatment facilities for demonstration scale testing, sized at 10 MGD to facilitate cycle testing of the first two ASR wells at C-38S.

Ongoing and Future Studies

Desktop Evaluation of Ferrate Coagulant for Media Filtration

The alternative coagulant suggested, ferrate, is represented by Ferrate Treatment Technologies (FTT). Stantec looked at ferrate for the City of West Palm Beach in 2017, but never made it past the scoping stage of a pre-oxidizer study. FTT representatives emphasized benefits as an oxidizer and coagulant. However, this chemical carried additional risks which eliminated it from further consideration:

- Ferrate is a strong oxidizer (for ASR, it would need to be quenched with another chemical before recharge to avoid arsenic liberation).
- Ferrate must be synthesized on-site. This is a chemical engineering process, which requires tightly controlled mixing of feedstocks.
- Additional tankage for clarification and removal of sludge would be necessary.
- The “ferrator” is a proprietary piece of equipment. Very few operators have experience with it.
- All studies provided were for lab or field demonstration tests.
- Stantec could not find references for full-scale treatment facilities using this.

Media filtration was eliminated from consideration due to the inability to capture the small particle size ranges produced through coagulation. Under direct filtration evaluation, coagulated DOC particles passed through the comparatively large media pore sizes. Remaining color decreased UV Transmittance for disinfection downstream.

Preliminary Design of ASR Treatment Facility for Demonstration Testing

The planned ASR wells will utilize excess surface water during the wet season to recharge the UFA and APPZ. This stored water will be recovered to the same water bodies during extended dry periods. Prior to storage, the water must be treated to meet regulatory requirements for UIC ASR facilities.

Preliminary design of a proposed ASR Treatment Facility at C-38S is ongoing. Design of the C-38S treatment facility has been developed with a phased approach. Initial construction (Phase 1) includes construction of facilities necessary to enable demonstration-scale testing of membrane filtration technology and cycle testing of one well pair at a capacity of 10 MGD.

Membrane filtrate production capacity will be split evenly between 3 suppliers (3.3 MGD, each). Where feasible, process equipment and facilities common to all Membrane Filtration System Suppliers (MFSS) has been designed to be compatible with future full-scale facility expansion to a capacity of 50 MGD (Phase 2). This approach to facility design was favored to make greatest use of capital investment and minimize stranding of assets which may not fit with facility expansion in a 2 – 4-year horizon.

Treatment systems for demonstration-scale testing generally consist of the following elements at the following scales:

- Common treatment facilities including intake structure and screens, wetwell, pumps, and strainers, electrical room and operations room. (full-scale, 50 MGD)
- Membrane filtration systems procured from suppliers (both polymeric and ceramic). (Demonstration-scale, 10 MGD total [approximately 3.3 MGD, ea.]).
- Membrane backwash treatment and solids thickening systems, suitable for and dedicated to each MFSS (Demonstration-scale).
- Solids dewatering systems (Demonstration-scale, [expandable to 50 MGD]).

Solids from the membrane backwash treatment process will be thickened by sedimentation or flotation, stored for batch dewatering, and mechanically dewatered. Dewatered cake of approximately 18-20% solids will be conveyed and loaded into trucks and hauled offsite for landfill disposal.

Facilities are being designed to deliver recovered water from ASR wells to the C-38 Canal. The design will also include process interconnections with the flexibility, if needed, to convey recovered water back to the treatment facility for re-treatment to remove arsenic prior to discharge. Re-treatment will consist of sodium hypochlorite addition to oxidize Arsenite (As-III) to Arsenate (As-V), precipitate and coagulate prior to removal by membrane filtration. It is anticipated that this re-treatment step may be necessary during early cycle testing for “first-flush” recovered water, rather than long-term treatment of recovered water. However, this will be developed as part of the draft operations plan and evaluated during demonstration testing.

Demonstration testing facilities are intended to allow for operation of treatment systems for a 1-2-year period. The results of demonstration scale testing will be used to evaluate long-term operational performance and optimize capital and operating cost projections. The SFWMD intends to use the results and experiences of demonstration scale testing to establish design criteria for the balance of plant facilities needed for full-scale facility expansion to 50 MGD. The design criteria will allow competitive selection of the membrane supplier on the basis of net present value. A net present value evaluation will allow for economic evaluation of treatment systems proposed, ancillary related systems, and the operational costs of the overall facility for a true apples-to-apples comparison.

The subsequent phase (Phase 2) of this project will include design of remaining full-scale (50 MGD) treatment facilities, including buildings, permanent membrane systems, chemical storage, backwash, and dewatering processes.

Background Source Water Sampling for Contaminants of Emerging Concern

Perfluoroalkyl and polyfluoroalkyl substances, collectively referred to as (PFAS), are a group of synthetic chemicals that have been used in industry and consumer products since the 1940s. They occur in a variety of manmade products and manufacturing processes, such as nonstick cookware, waterproof clothing, and firefighting foam. PFAS are chemicals that are persistent in the environment and have been recognized as contaminants of emerging concern by the USEPA due to their environmental and human health impact.

On March 14, 2023, the EPA announced their proposed National Primary Drinking Water Regulation (NPDWR) to limit the presence of six per- and polyfluoroalkyl substances (PFAS) in drinking water, including:

- perfluorooctanoic acid (PFOA),
- perfluorooctane sulfonic acid (PFOS),
- perfluorononanoic acid (PFNA),
- hexafluoropropylene oxide dimer acid (HFPO-DA, commonly known as GenX Chemicals),
- perfluorohexane sulfonic acid (PFHxS), and
- perfluorobutane sulfonic acid (PFBS).

On April 10, 2024, EPA announced the final PFAS NPDWR, establishing legally enforceable Maximum Contaminant Levels (MCLs) and health-based non-enforceable Maximum Contaminant Level Goals (MCLGs) for these PFAS. **Table 6-1** presents the final drinking water regulation for select PFAS. The Hazard Index (HI) addresses additive health risk from co-occurrence of these compounds and is calculated as a summation of the individual concentrations divided by the health-based water concentrations, or the levels below which adverse health effects are unlikely to occur.

Table 6-1. USEPA Final PFAS National Primary Drinking Water Regulation (April 2024).

Compound	Final MCLG	Final MCL (enforceable levels)
PFOA	Zero	4.0 parts per trillion (ppt) (also expressed as ng/L)
PFOS	Zero	4.0 ppt
PFHxS	10 ppt	10 ppt
PFNA	10 ppt	10 ppt
HFPO-DA (commonly known as GenX Chemicals)	10 ppt	10 ppt
Mixtures containing two or more of PFHxS, PFNA, HFPO-DA, and PFBS	1 (unitless) Hazard Index	1 (unitless) Hazard Index

(https://www.epa.gov/sdwa/and-polyfluoroalkyl-substances-pfas; April 10, 2024)

Regulated public water systems have three years to perform initial monitoring for these PFAS in their drinking water (by 2027), followed by regular compliance monitoring. Public water systems that detect

PFAS above the new standards will have five years (by 2029) to implement solutions that reduce PFAS in their drinking water. Enforceable MCL compliance for public water systems will begin in 2029.

As part of the LOWRP ASR program, SFWMD initiated background source water sampling and testing for PFAS in May 2023. The background sampling program is ongoing and includes testing the C-38 Canal surface water near the proposed C-38S ASR location for the presence of PFAS. The SFWMD continues to perform background sampling for PFAS on a biweekly basis to better understand its seasonal presence in the source water and potential impact to the LOWRP ASR program. Additionally, the USEPA continues to develop, validate, and publish recommended analytical methods to test for PFAS compounds in different matrices, including non-potable water. At the present time, analytical Method 1633 is the recommended method to be used for PFAS analyses in surface waters. EPA published Method 1633 in January 2024 as final to support testing for 40 PFAS compounds in wastewater, surface water, groundwater, soil, biosolids, sediment, landfill leachate, and fish tissue.

Peer Review Panel Member Addition

As recommended in the 2022 PRP report (Missimer et al. 2022; SFWMD and USACE 2022, **Appendix B)**, an expert with a strong background in water treatment and economics of water treatment was added to the 2024 ASR Science Plan Panel. Mr. Coates has 35+ years of experience working in Florida in utility operations and management, water resources evaluation, and water supply planning and development for Peace River Manasota Regional Water Supply Authority (Authority), Tampa Bay Water, and the South Florida and Southwest Florida Water Management Districts. He is a member of the American Water Works Association (AWWA) and the Association of Metropolitan Water Agencies (AMWA).

Mr. Coates currently serves as Executive Director of the Peace River Manasota Regional Water Supply Authority (Authority), responsible for providing drinking water sourced from Peace River to customers in Charlotte, Desoto, and Sarasota counties, as well as the city of North Port. To do this, the Authority operates an interconnected regional water supply system consisting of raw water reservoirs, a surface water treatment facility, and an aquifer storage and recovery (ASR) system.

2024 Peer-Review Panel Guidance

The following guidance was provided by the PRP in its 2024 report (Price et al. 2024; **Appendix B**).

Underground Injection Control (UIC) Permitting Considerations

The 2022 ASR Treatment Proof of Concept Testing Report identifies the coliform limit of 4 cfu/100 mL as the applicable standard for ASR recharge. The FDEP has recently employed a non-rule standard requiring recharge to ASR wells in a USDW to meet all primary drinking water standards, including those for coliform. The project team should confirm the standards that the FDEP will apply for water recharged to ASR. The inability to meet certain secondary drinking water standards would necessitate the issuance of a Water Quality Criteria Exemption (WQCE). The Project team should confirm that the FDEP continues to issue WQCEs for secondary drinking water standards.

Treatment Technology Considerations

The proposed coagulation process without a following step to settle the water before it contacts the filters should receive considerable attention in the 10 MGD pilot test. Increased membrane fouling resulting in shorter run-times between filter backwash cycles, and the potential to impact membrane longevity at scale-up could be an issue. As part of the 10 MGD pilot testing, the project team should identify other water treatment facilities in the U.S. that employ similar final-scale (~50 MGD) facilities using ceramic membrane filter capacity and visit/interview operators of such facilities to support design criteria, operational decisions and costing for the proposed facilities. The panel also recommended that the project team confirm market capacity to supply a preferred membrane prior to a decision to move ahead with a selected membrane. The proposed treatment process diagram presented in the ASR Science Plan Workshop (July 10, 2024) indicated that decant water from the sludge thickening will be reintroduced upstream of the ceramic membranes. Presumably, a polymer will be utilized to enhance the sludge thickening/dewatering. Information about the tests on the effect of the polymer laden water on the ceramic membranes needs to be provided.

If PFAS concentrations in source water for the ASR Project exceed the proposed MCLs, an alternative primary treatment to that which is being tested (the 10 MGD pilot), or a treatment process that is supplemental to the current tested process will be required. Treatment options will depend on PFAS concentrations and which PFAS compounds are present. The panel recommends that a sampling program for PFAS in the source water be undertaken, followed by consideration of treatment methods to ensure compliance with new regulations. If treatment to reduce PFAS is needed in addition to the ASR treatment program already proposed, the possibility of an aquifer exemption should be seriously considered.

Cost of Current Proposed Pretreatment System

Based on the latest preliminary design of the pretreatment system to meet potable water standards for injection, including secondary standards, there are a number of several design elements that may affect the financial viability of the North Lake Okeechobee Aquifer Storage and Recovery Project, such as reduction of oxidation levels in the injected water, post-recovery treatment of the water after storage, disposal of residuals, and the potential removal of PFAS compounds in the water from the Kissimmee River. There are several other issues with using membrane treatment for the process to achieve primary and secondary drinking water standards. The high energy consumption for the final total capacity will create the need for extensive electrical power infrastructure to be constructed and maintained. In addition, the non-continuous operation of the ASR system creates the need to place the treatment membranes in a rest condition for extensive periods when unused, causing the necessity to “pickle” the membranes with a chemical compound, such as sodium bisulfate. The episodic use of electrical energy also is a factor in determining the cost and tends to increase based on the power company's necessity to recover the cost for providing it. There is an alternative to the pretreatment of the ASR system water to meet both primary and secondary water quality standards. An aquifer exemption could be sought by applying to the FDEP and the USEPA. The decision to meet both primary and secondary water quality standards should be carefully reviewed. Development of these estimates, particularly operational costs, should include collaboration with public water utilities in Florida.

The District should employ an independent reviewer of the economics of the ASR pretreatment plan and the design of the 10 MGD test facility before it is constructed and operated. This review should be conducted before the proposed 10 MGD membrane plant and other water treatment infrastructure is bid, constructed and operated. A viable option would be to retain the National Water Resources Institute to conduct this review.

6.2 NRC comment: Develop appropriate pre-treatment strategies to attenuate arsenic mobilization.

2020 Peer-Review Panel Guidance

The following guidance was provided by the PRP in its 2020 report (Arthur et al. 2020; SFWMD and USACE 2021b, **Appendix B**).

Page 10, PRP Report. In hydrogeologic settings where arsenic is mobilized during ASR activities, the mechanisms of mobilization are understood well enough to employ pre-treatment mitigation measures. The PRP recommends the SFWMD ASR team consider pre-treatment redox control of injected waters as it has been found effective in reducing arsenic concentrations. Redox control alternatives include use of reducing agents, membranes, catalytic oxygen removal, and degasification. The cost of such measures should be carefully analyzed to ascertain feasibility.

Investigations of water-rock interactions during ASR have focused on processes controlling a limited number of mobilized constituents. However, several metals besides arsenic, are mobilized during ASR, and while the concentrations do not exceed drinking water standards, their environmental effects are largely unknown. For all water quality analyses, the PRP suggests broad-spectrum hydrogeochemical analytical packages be used. These are cost-efficient, multi-method, multi-element analytical packages that provide robust information about constituents that may not be known concerns today. As scientific understanding continues, especially in ecotoxicology, data within an expanded analyzed parameter list may become useful.

Based on results of ASR monitoring plans at each well and wellfield, a post-treatment action plan should be developed if the recovered water has high concentrations of arsenic, gross alpha activity, uranium, radium, or other constituents of concern.

2022 Peer-Review Panel Guidance

The following guidance was provided by the PRP in its 2022 report (Missimer et al. 2022; SFWMD and USACE 2022, **Appendix B**).

Even though previous ASR testing has indicated arsenic retention after multiple cycle testing, a detailed plan of arsenic monitoring during all portions of the ASR operations, in particular during the early periods of recovery, needs to be developed.

The Panel recommends the Science Plan include water quality sample collection during the recovery phases of the cycle testing in a logarithmic-type manner such that many water samples are collected from the recovered water during the beginning of the phase, and then fewer samples can be collected at later times. The Panel looks forward to reading a more detailed plan for water quality monitoring during cycle testing.

Progress Since 2022

The SFWMD completed a Water Treatment Technology Evaluation which recommended Proof-of-Concept testing of treatment systems for removal of natural organic matter and exclusion of coliform bacteria prior to aquifer recharge. POC Testing was conducted from November 2021 – January 2022. The SFWMD LOWRP ASR Treatment POC Testing Report was finalized in July 2022, which detailed results of the POC testing of treatment systems and provided the basis for determining a selected treatment process for the first few well clusters that are constructed under this program. The final POC Testing Report is included herein as **Appendix H**.

The treatment technologies evaluated during POC testing do not have the ability to remove dissolved oxygen (DO) from water. Results of the POC testing suggest that the resultant recharge water will be undersaturated with regard to most carbonate minerals and oxidizing (by dissolved oxygen) to sedimentary sulfide minerals. These conditions suggest that arsenic mobilization will occur, but the magnitude of arsenic (and other metals) mobilization is difficult to predict.

The SFWMD initiated an evaluation of DO removal technologies to minimize the risk presented by potential arsenic mobilization. Results of the evaluation and the selected DO removal technology will be incorporated in design of the ASR Treatment Facility for demonstration-scale testing at C-38S.

Ongoing and Future Studies

Dissolved Oxygen (DO) Removal Technology Evaluation

SFWMD is currently evaluating scientific and engineering application of alternatives to minimize risk presented by potential arsenic mobilization. As part of this endeavor, SFWMD is conducting a DO removal technology evaluation. The evaluation includes:

- Bench-scale testing of DO reduction through chemical addition using Sodium Hydrosulfide (NaHS)
- Geochemical modeling using PHREEQC to demonstrate if dissolution or precipitation of arsenic bearing minerals in the aquifer is occurring due to the injection of surface water and to determine if DO removal from surface water is anticipated to have a significant impact on the magnitude of these reactions
- Technology survey and evaluation, including review of technical literature, outreach to utilities currently using DO reduction technologies with ASR wells, and evaluation of capital and operational costs for near-term demonstration scale testing and future full-scale facilities

The technology evaluation will examine membrane degasification, vacuum stripping, chemical addition using sodium bisulfite, chemical addition using sodium hydrosulfide (NaHS), Minox deoxygenation, and gas displacement technology (GDT) as potential deoxygenation technologies for incorporation in pre-treatment facility design. Design criteria, DO removal effectiveness, potential process chemistry impacts, capital cost, operational costs, and maintenance considerations for these technologies will be analyzed and summarized in a technical memorandum. The selected DO removal technology will be incorporated in design of the ASR Treatment Facility for demonstration-scale testing at C-38S.

Characterization of Radium in Native Groundwater

Additional effort is ongoing to characterize the range of radium, radium isotope, gross alpha, and uranium concentrations in the native groundwaters of UFA and APPZ. Results of this evaluation will characterize the magnitude and hydrogeologic occurrence of these constituents (Mirecki, in prep).

Cooperative Research and Development Agreement with US Army Engineer Research and Development Center

In addition to SFWMD/USACE evaluations, the U.S. Army Engineer Research and Development Center (ERDC) is conducting ex-situ (i.e., modeling and lab-based) investigations through a Cooperative Research and Development Agreement (CRADA) with the SFWMD. ERDC’s work will be a multi-year effort to examine:

- Mobilization and release of pollutants, contaminants, or hazardous substances, and hazardous, toxic, and radioactive wastes (HTRW) constituents
- First-cost construction
- Long-term O&M cost

To address concerns related to mobilization of arsenic and other metals in groundwater, ERDC and the SFWMD are collaborating through modeling and lab-based investigations to characterize and quantify geochemical and microbial reactions, reaction kinetics, and groundwater flow parameters under conditions representative of the FAS during ASR. This information will then be used to parameterize a reactive-transport groundwater model suitable for simulating key processes for water quality and the evolution of groundwater system conditions over time during ASR cycling.

Five main efforts are outlined under the CRADA and in various stages of development:

- Task A: Collection of core material for laboratory investigations
- Task B: Batch and small-scale column studies to characterize arsenic speciation and distribution within FAS solids and geochemical reactions that occur when FAS aquifer material is exposed to representative surface water
- Task C: Intermediate-scale reactive transport studies for quantifying arsenic speciation and distribution reactions within FAS aquifer material under ASR-representative conditions
- Task D: Development of a calibrated and validated reactive transport groundwater model capable of simulating field-scale ASR injections and associated changes in groundwater quality over time
- Task E: Surface water treatment characterization

As part of Task E, ERDC began field testing of their ASR Source Water Treatment Pilot System in February 2024 at the KRASR site. The pilot treatment system will be optimized and run onsite to generate representative ASR injection water samples to support batch and column arsenic mobilization studies (Tasks B and C). ERDC's pilot operation will also assess deoxygenation and stabilization approaches for reducing arsenic mobilization potential during injection, storage, and recovery. ERDC currently plans to examine/test deoxygenation using a chemical reductant and physical oxygen removal through membrane systems.

The ERDC core testing and geochemical modeling programs will provide valuable insight on arsenic mobilization.

Preliminary Design of ASR Treatment Facility for Demonstration Testing at C-38S

As discussed in Section 6.1, preliminary design of a proposed ASR Treatment Facility for demonstration-scale testing at C-38S is ongoing. Facilities will be designed to treat raw water, convey treated water to ASR wells for storage, and deliver recovered water from ASR wells to the C-38 Canal. The design will also include process interconnections with flexibility, if needed, to convey recovered water back to the treatment facility for re-treatment to remove arsenic prior to discharge. Re-treatment will consist of sodium hypochlorite addition to oxidize Arsenite (As-III) to Arsenate (As-V), precipitate and coagulate prior to removal by membrane filtration. It is anticipated that this re-treatment step may be necessary during early cycle testing for "first-flush" recovered water, rather than long-term treatment of recovered water. However, this will be developed as part of the draft Operations Plan and evaluated during demonstration testing. The draft Operations Plan is currently being developed under the preliminary design phase of the pretreatment facility.

Cycle Testing (2027-2029)

In addition to water treatment processes, the effects of using a buffer zone to minimize detrimental water quality effects (including constituents suggested by the PRP) in the aquifer will be evaluated during cycle testing. Details of future studies will be provided in subsequent updates of the ASR Science Plan as the ASR program progresses and additional information becomes available.

2024 Peer-Review Panel Guidance

The following guidance was provided by the PRP in its 2024 report (Price et al. 2024; **Appendix B**).

Arsenic Mobilization Considerations

The mobilization of arsenic at ASR facilities serving public water systems is addressed by a September 27, 2013, letter from the USEPA to the FDEP. The letter addresses the permitting of these ASR facilities when increases in arsenic concentration greater than the drinking water MCL in the USDW result from geochemical reactions in the aquifer. The ability to re-treat all recovered water before distribution, as well as having institutional controls in place in the form of land ownership (or easements) is also considered. The project team should consider the applicability of this USEPA relief mechanism on arsenic mobilization, which may be preferable to the implementation of chemical or membrane processes to reduce DO in recharge water.

Post-treatment of Recovered Water

The collection and analysis of surface water data have been well done and should be useful in performing a variety of environmental impact assessments. Once the various data are collected and processed, the review panel recommends that the necessity to post-treat the recovered water from the ASR wells be carefully assessed. Once the treatment standards are set for TDS, dissolved chloride, hardness, and pH, an analysis of the cost to do post-treatment to minimize the environmental impacts needs to be added to the project's operational costs.

6.3 NRC comment: Continue research on subsurface pathogen inactivation using a wider array of pathogens.

2020 Peer-Review Panel Guidance

The following guidance was provided by the PRP in its 2020 report (Arthur et al. 2020; SFWMD and USACE 2021b, **Appendix B**).

Research by the USGS on microorganism die-off and fate of nutrients (e.g., Lisle 2014, 2020) should be continued with the purpose of addressing the NRC (2015) uncertainties related to water quality, nutrient reduction potential, and pathogens.

Progress Since 2022

Extending the studies on the inactivation of *E. coli* in ASR storage zones (Lisle, 2016) the USGS examined the inactivation (i.e., loss of infectivity) of MS2 bacteriophage, poliovirus type 1 (PV1), and *Cryptosporidium parvum* in an anaerobic and reduced groundwater system that has been identified as storage zones for ASR facilities (Lisle and Lukasik, 2022). Anaerobic and reduced (Oxidation Reduction Potential (ORP) < -250 mV) groundwater from an artesian well was diverted to an above-ground, flow-through mesocosm that contained diffusion chambers filled with MS2, PV1, or *Cryptosporidium parvum*. The respective infectivity assays were performed on microorganisms recovered from the diffusion chambers during 30-day to 58-day experiments. The study revealed that the groundwater geochemical conditions in the aquifer enhanced the inactivation of MS2, PV1, and *C. parvum* at rates approximately 2.0–5.3-fold, 1.2–17.0-fold, and 4.5–5.6-fold greater, respectively, than those from published studies that used diffusion chambers in aerobic-to-anoxic groundwater systems, with positive redox potentials.

Additionally, the USGS published the performance of a quantitative microbial risk assessment (Gitter et al., 2023) to evaluate the potential health effects of recharging partially treated water into the Floridan aquifer. This study revealed the risks of developing a GI infection from drinking recovered recharge water no longer exceeded the EPA's annual human risk threshold ($1 \times 10-4$) for *E. coli*, *Pseudomonas aeruginosa*, poliovirus type 1 and *Cryptosporodium parvum* by days 31, 1, 52 and 80 of storage in the aquifer zone for each pathogen, respectively. The disability-adjusted life years (DALYs) per person per year no longer exceeded the World Health Organization threshold ($1 \times 10-6$) by for these same microorganisms after 27, <1, 43 and 72 days of storage in the aquifer zone, respectively. In summary, the study found that the ASR storage phase in these types of aquifers yield a significant reduction in health risk.

Ongoing and Future Studies

During May 2021 the USGS initiated a project titled Characterization of Microbiological and Geochemical Processes That Contribute to Nutrient Reduction and Potential Clogging of ASR Facilities in the Lake Okeechobee Watershed (SFWMD Agreement #4600004412). Due to well drilling issues and delays in the field and restrictive access to USGS facilities and resources during COVID the effective start date for this project was moved forward to late 2022 with an extension of the period of performance to the end of January 2025. Using crushed core material from two ASR storage zones (i.e., UFA and APPZ) to pack separate laboratory columns, through which surface waters identified as source water for ASR recharge is pumped, data are being collected to characterize rates of bioclogging and nutrient reduction and changes in geochemistry during the recharge and storage phases of an ASR cycle. At the time of this update, the first of four experiments have been completed for the crushed core material from the UFA storage zone at well C-38S. Preliminary data indicate effects of bioclogging can be detected and quantified in the laboratory column systems during a three-week recharge period. Additionally, there are significant reductions in dissolved oxygen, dissolved organic carbon, nitrates and phosphorus during the recharge and storage phases.

6.4 NRC comment: Couple pathogen inactivation studies to groundwater travel times and distances using local-scale groundwater modeling.

2020 Peer-Review Panel Guidance

The following guidance was provided by the PRP in its 2020 report (Arthur et al. 2020; SFWMD and USACE 2021b, **Appendix B**).

USGS work should continue as planned to address the NRC (2015) uncertainties related to water quality, nutrient reduction potential, and pathogens.

Progress Since 2022

Extending the studies on the inactivation of *E. coli* in ASR storage zones (Lisle, 2016) the USGS examined the inactivation (i.e., loss of infectivity) of MS2 bacteriophage, poliovirus type 1 (PV1), and *Cryptosporidium parvum* in an anaerobic and reduced groundwater system that has been identified as storage zones for ASR facilities (Lisle and Lukasik, 2022). Anaerobic and reduced (Oxidation Reduction Potential (ORP) < -250 mV) groundwater from an artesian well was diverted to an above-ground, flow-through mesocosm that contained diffusion chambers filled with MS2, PV1, or *Cryptosporidium parvum*. The respective infectivity assays were performed on microorganisms recovered from the diffusion chambers during 30-day to 58-day experiments. The study revealed that the groundwater geochemical conditions in the aquifer enhanced the inactivation of MS2, PV1, and *C. parvum* at rates approximately 2.0–5.3-fold, 1.2–17.0-fold, and 4.5–5.6-fold greater, respectively, than those from published studies that used diffusion chambers in aerobic-to-anoxic groundwater systems, with positive redox potentials (See Section 6.3: Progress Since Last Year).

The inactivation rates of the microorganisms (Lisle, 2016; Lisle and Lukasic, 2022) and the nutrient removal rates by native planktonic and biofilm microbial communities (Lisle, 2020) were derived so they could be easily incorporated into hydrologic and, if determined to be of importance to the SFWMD, biogeochemical reactive transport models.

Ongoing and Future Studies

Presently, the District is evaluating the necessity to incorporate the microbial inactivation and nutrient removal rates into a groundwater flow model. Detailed scoping has not been undertaken.

7 ECOTOXICOLOGY AND ECOLOGICAL RISK ASSESSMENT

7.1 NRC comment: Locate ASR systems adjacent to large water bodies to allow for adequate mixing zones.

2020 Peer-Review Panel Guidance

The following guidance was provided by the PRP in its 2020 report (Arthur et al. 2020; SFWMD and USACE 2021b, **Appendix B**).

The primary avenues for impacts to fish at operational ASR facilities are thermal alterations to receiving waters and impingement/entrainment of early life stages of various species. A warm plume in winter and/or a cool plume in summer may alter the spawning timing of some species in the vicinity of recovered water discharge. ASR review should explore quantified risks and mitigation strategies, which need to be considered when discharge of recovered water is likely. ASR recovery probably would occur during low flows throughout the spring spawning period. Warm, highly oxygenated water being released in the winter is likely to attract species such as blue tilapia into the area and displace some cool season spawners such as largemouth bass and black crappie. Quantifying likely outcomes based on possible plume sizes and relative impact on system-level recruitment may be warranted. Tempering recovered water for temperature in addition to ensuring good oxygenation may be a desirable mitigation strategy if thermal effects are deemed detrimental.

As noted in Section 10.6 of the CERP Final Technical Data Report for the KRASR pilot project (SFWMD and USACE 2013), impingement and entrainment can be mitigated by intake design as well as the timing and diffusion of withdrawals during recovery. The testing of these alternatives offers an opportunity for adaptive management by monitoring for the presence of vulnerable organisms during recharge and recovery operations and considering altered withdrawal regimes if needed. The SFWMD and USACE (2015) noted that oxygenated recovery water could attract fish during low ambient oxygen conditions and pose a kill risk if there was a sudden withdrawal of the oxygenated recovery water. This risk should be low at sites like KRASR if the recovery water is discharged during low-flow augmentation. Low oxygen concentrations in the lower C-38 Canal typically occur during high stages when recharge/withdrawal activities most likely would be occurring, as opposed to discharge of recovered water. The PRP recommends having a site-specific monitoring protocol in place for this possibility.

Progress Since 2022

To date, the ASR systems that are being constructed or may be reactivated by the SFWMD are located along the C-38 Canal (KRASR, C-38N, and C-38S) and the L-63N Canal. The systems were constructed along canals that convey large quantities of water during wet periods and offer substantial capacity for mixing with receiving water in the canal.

In 2023, the Environmental Consulting & Technology, Inc. (ECT) and Intertek-Professional Service Industries, Inc. (Intertek-PSI) contractors initiated CORMIX modeling study to evaluate the potential for a mixing zone for the C-38S ASR site's discharge of recovered water to the C-38 Canal. The CORMIX modeling focused on the discharge of a single recovery well at a rate of 10 MGD. The goals were to identify potential constraints on securing a mixing zone, including those associated with the configuration of the outfall, the relative flows of the recovered water and the receiving water, and the quality of the recovered water. Recovered water quality was considered as it affects the potential mixing of the recovered water with the receiving water, as well as the ability to achieve the relevant Water Quality Standards within the regulatory limits of the mixing zone. Preliminary recommendation on the outfall configuration for the recovered water to increase the speed and orientation of the discharge to increase initial mixing and facilitate transport of the plume downstream was also provided by the contractors to the ASR construction team.

Additionally, as recommended by 2020 PRP (Arthur et al. 2020; SFWMD and USACE 2021b, **Appendix B)**, the ECT contractor-initiated monitoring of fish and ichthyoplankton in 2022 as part of the long-term ecological monitoring along the C-38 Canal and northern Lake Okeechobee. This data will be used to evaluate the possible impacts for spawning season disruptions due to temperature alterations during ASR recovery periods. Black crappie was identified by PRP as an important commercial species that spawns in Lake Okeechobee that should be a subject of long-term monitoring.

The long-term ecological monitoring efforts include electrofishing during spawning at upstream and downstream C-38 Canal locations adjacent to the ASR clusters and northern Lake Okeechobee. The surveys include both fish community surveys and collection of fish tissue for metal analyses. Voucher specimens for all species encountered are also collected and preserved. During the first year of the study, fish community surveys were conducted twice in the wet season (September 2022 and June 2023) and twice in the dry season (December 2022 and February 2023). At each station and during each event, electrofishing was conducted for 30 minutes. During these timed surveys, stunned fish were collected, identified to the lowest practical taxonomic level, weighed, measured (total length) and photographed. Physical anomalies and evidence of disease were noted on field forms. Fish not retained for tissue analysis (described below) or voucher collections were released. Fish tissue sample collection targeted three species: black crappie (*Pomoxis nigromaculatus*), bluegill (*Lepomis macrochirus*), and largemouth bass (*Micropterus salmoides*). During fish tissue sampling, up to three individuals from each of the species were targeted for retention at each station. Results of fish community year 1 analysis were included in the ECT's Year 1 Comprehensive Annual Report included as an **Appendix I**.

Ongoing and Future Studies

Mixing/Dilution/Dispersion Design Evaluations and Models (2024-2025)

Evaluations of the mixing zone in the C-38 Canal will continue in 2024 and 2025. In addition to finalizing mixing zone evaluations with CORMIX, the ECT contractor proposed utilizing more complex modeling approaches to yield a more workable description of the system. Such a modeling approach would likely rely on a dynamic numerical or computational fluid dynamic code. Summary of the CORMIX-based and more advanced modeling results will be included in the next version of the ASR Science Plan once the work is completed and results are available.

The modeling team will provide additional recommendations for the recharge (intake) and recovery (discharge outfall) structure designs, to increase initial mixing and facilitate transport of the plume downstream. Intake structures will be designed to minimize the potential for impingement and entrainment of fish and other animals occupying the C-38 canal near ASR clusters. Outfall structures will be designed to reduce undesirable physical and chemical impacts to the receiving water body. The mixing zone modeling will also determine optimal ranges of recovered water volumes and dispersion durations to the receiving water body during dry, cool periods that minimize the thermal effects to biota.

Ecological Responses (2022-2030)

The long-term monitoring of black crappie and other key fish species, and ichthyoplankton along the C-38 Canal and norther Lake Okeechobee will continue in upcoming years. This monitoring will provide additional information on potential responses of key species to changing temperature and oxygen concentrations in the areas adjacent to the ASR clusters, which may occur during future ASR operations.

To protect aquatic life at surface water ASR withdrawal sites, the team will design and conduct impingement and entrainment evaluation studies in upcoming years. Entrainment is the unwanted passage of fish through a water intake, which is generally caused by an absent or inadequate screen surrounding the water intake. Impingement is the physical contact of a fish with such a barrier structure (screen) due to intake velocities which are too high to allow the fish to escape. The goal of the studies will be to optimize the intake designs to mitigate impingement and entrainment of species at the ASR intake points. These studies will be developed based on the latest available national USEPA guidelines.

2024 Peer-Review Panel Guidance

The following guidance was provided by the PRP in its 2024 report (Price et al. 2024; **Appendix B**).

Additional information should be provided on how the Tier 1 models (mixing zone and plume models) are being used and what stressors and receptors are being modeled or how they are being modeled. The models should partially be used to leverage the field data collected through calibration or establishing relationships. Their usage after the current Tier 1 assessments should be considered for future risk work and adaptive management predictions. Modeling will be needed to examine the impacts of extended loadings to the ecosystems at risk over longer-time periods. For future work, problem formulation products such as conceptual models, endpoints, and measurements should be updated to reflect risks from long-term ASR discharges. Prior to assessing risks, a robust scenario analysis should be conducted for identifying potential impacts for long-term use of the ASR.

7.2 NRC comment: Additional bench-scale chronic toxicity testing at points of discharge using larger, longer storage and recovery volumes and recovered water from multiple ASR sites should be performed, including changes in hardness and how that affects toxicity to sensitive aquatic species.

2020 Peer-Review Panel Guidance

The following guidance was provided by the PRP in its 2020 report (Arthur et al. 2020; SFWMD and USACE 2021b, **Appendix B**).

The PRP noted more research is needed into the ecological and ecotoxicological impacts of discharging ASR recovered water to the C-38 Canal, Lake Okeechobee, the Greater Everglades, and canals (Arthur et al. 2020; SFWMD and USACE 2021b, **Appendix B**).

2022 Peer-Review Panel Guidance

The following guidance was provided by the PRP in its 2022 report (Missimer et al. 2022; SFWMD and USACE 2022, **Appendix B**).

Include information on toxic effects that will not be detected in tissue concentrations. For chemicals that exert a mode of action that would not be reflected in the body residue values such as gill damage, should be noted. The bioconcentration studies should examine the steady state assumptions in the test design, potentially with interim sampling in the study design.

Progress Since Last Update

To further assess bioaccumulation and toxicity, as recommended by the NRC (2015), a mobile 20-foot-long temperature-controlled flow-through bench-scale laboratory **Figure 7-1** was constructed in 2023 for conducting additional bench-scale chronic toxicity and bioconcentration tests at multiple ASR locations, once they become operational (~2027-2030). This effort will support assessment of changes in contaminant bioconcentration and toxicity. The mobile laboratory design details are described the 2022 Draft ASR Science Plan (SFWMD and USACE 2022b, **Appendix E)**.

Ongoing and Future Studies

Bench-scale chronic bioconcentration and toxicological studies will be conducted using source water (recharge period) and recovered water (recovery period) at the C-38S and C-38N ASR locations once they become operational (~2027-2030). The surface water from these canals will be used to recharge the planned ASRs, following deoxidization and treatment to meet the primary and secondary FDEP drinking water standards. Experiments will be conducted during the recovery period, and ASR discharge water (recovered water) will be tested for toxicity using standard protocols. The recovered water will have undergone water quality changes during storage in the aquifer, and these toxicity tests will evaluate any potential toxicity, or reduction in toxicity, due to the ASR cycling. In addition, acute toxicity studies will likely be required by regulatory agencies for the ASR permits; these tests will be conducted using the methods required in the permits. The scopes of work which were developed in 2021 will be finalized before ASR water becomes available for the bioconcentration and toxicity tests (the timing of the experiments is directly linked to the timing of completion of the ASR wells). The first tests are expected to be conducted at ASR sites along the C-38 Canal and should be completed in the 2027-2030 period. Additional experiments may be conducted using the ambient C-38 Canal water prior to the ASRs become operational.

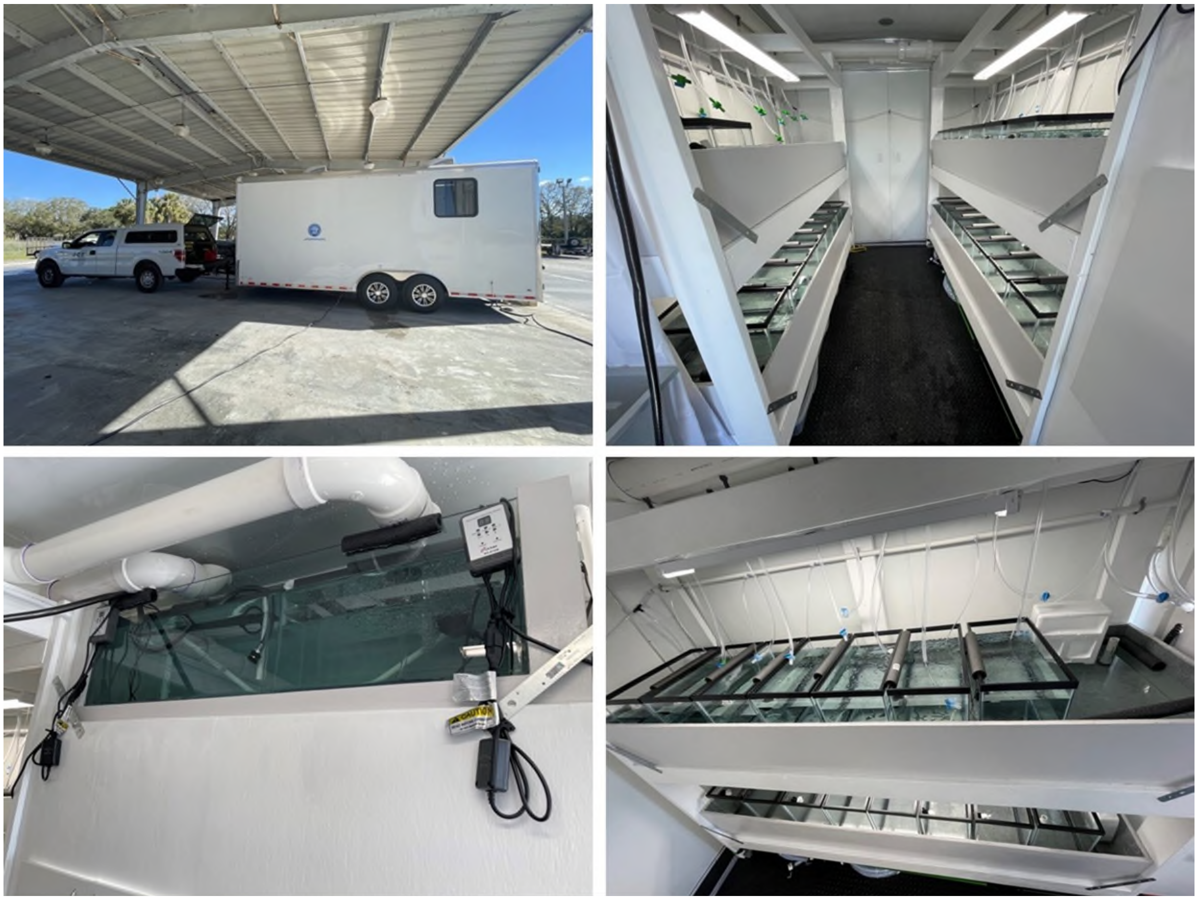

Figure 7-1. Temperature-controlled flow-through mobile laboratory constructed for conducting chronic bench-scale experiments at multiple ASR locations.

2024 Peer-Review Panel Guidance

The following guidance was provided by the PRP in its 2024 report (Price et al. 2024; **Appendix B**).

Additional information should be provided in the future version of the ERA Work Plan on how the measurement endpoints such as effects benchmarks and frog embryo toxicity tests will be used to infer community level impacts to amphibians. Native species in the area being assessed should be prioritized for assessment endpoints and toxicity testing with ASR water. If not, their use should be considered a measurement endpoint for native analogs. If non-native species tests are being run separately for regulatory purposes, then those outcomes should be incorporated into the assessment. Measures of effects (including toxicity testing, critical body residues, tolerance to physical and physicochemical water quality, in situ mesocosm and field monitoring) should start to be developed for usage in later tiers and predictive modeling when the scenarios start to become clarified. For example, exposure time to an effect and demographic studies may be important as ecological and exposure accuracy increase for later tier causal assessments.

7.3 NRC comment: Conduct long-term in-situ ecological and bioconcentration studies, including examining community-level effects and impacts of recovered water hardness on soft-water areas of the Everglades.

2020 Peer-Review Panel Guidance

The following guidance was provided by the PRP in its 2020 report (Arthur et al. 2020; SFWMD and USACE 2021b, **Appendix B**).

The PRP noted more research is needed into the ecological and ecotoxicological impacts of discharging ASR recovered water to the C-38 Canal, Lake Okeechobee, the Greater Everglades, and canals (Arthur et al. 2020; **Appendix B**). Some of the studies (e.g., periphyton studies), which were not successfully completed during the regional studies period, should be repeated.

2022 Peer-Review Panel Guidance

The following guidance was provided by the PRP in its 2022 report (Missimer et al. 2022; SFWMD and USACE 2022, **Appendix B**).

Timing of ichthyoplankton assessment should be expand to the early dry season to cover the timing of spawning by different fish species. Many species such as Largemouth Bass and Black Crappie are likely to be spawning as early as December and with intensity during January and February. It may be important to characterize the ichthyoplankton risk during the months and water levels when recharge activity is most likely as well. Expanded monitoring would also cover timing when both impingement and entrainment are possible.

Progress Since Last Update

A long-term environmental monitoring of the key biotic and abiotic environmental components **Table 7-1** was initiated in August 2022, as recommended by the NRC (2015) and the ASR PRP (Missimer et al. 2022; SFWMD and USACE 2022, **Appendix B)**. The key monitoring components were selected based on the ERA Inter-Agency Working Group recommendations and mentioned in the 2023 ERA Work Plan (**Appendix J**). The goal of this monitoring is to assess potential adverse impacts from operating multiple ASR wells on these components within the vicinity of the wells over extended period. The monitoring is conducted at six (6) locations adjacent to the C-38N and C-38S ASR clusters in the C-38 Canal, and two (2) locations south of the canal mouth in the northern part of Lake Okeechobee **Figure 7-2**. Results from the first year of the pre-operational monitoring conducted between August 2022 – August 2023 were described in the comprehensive annual report included in **Appendix I**. The timing of the pre-operational sampling and future sampling during the ASRs cycle testing are directly linked to the ASR wells' operational status. It is expected that the first cycle testing at C-38S and C-38N locations will begin in mid-2027 and ~2030, respectively (following buffer zone evaluation and construction of water treatment plants), however this schedule may change depending on the future conditions encountered at the well drilling locations.

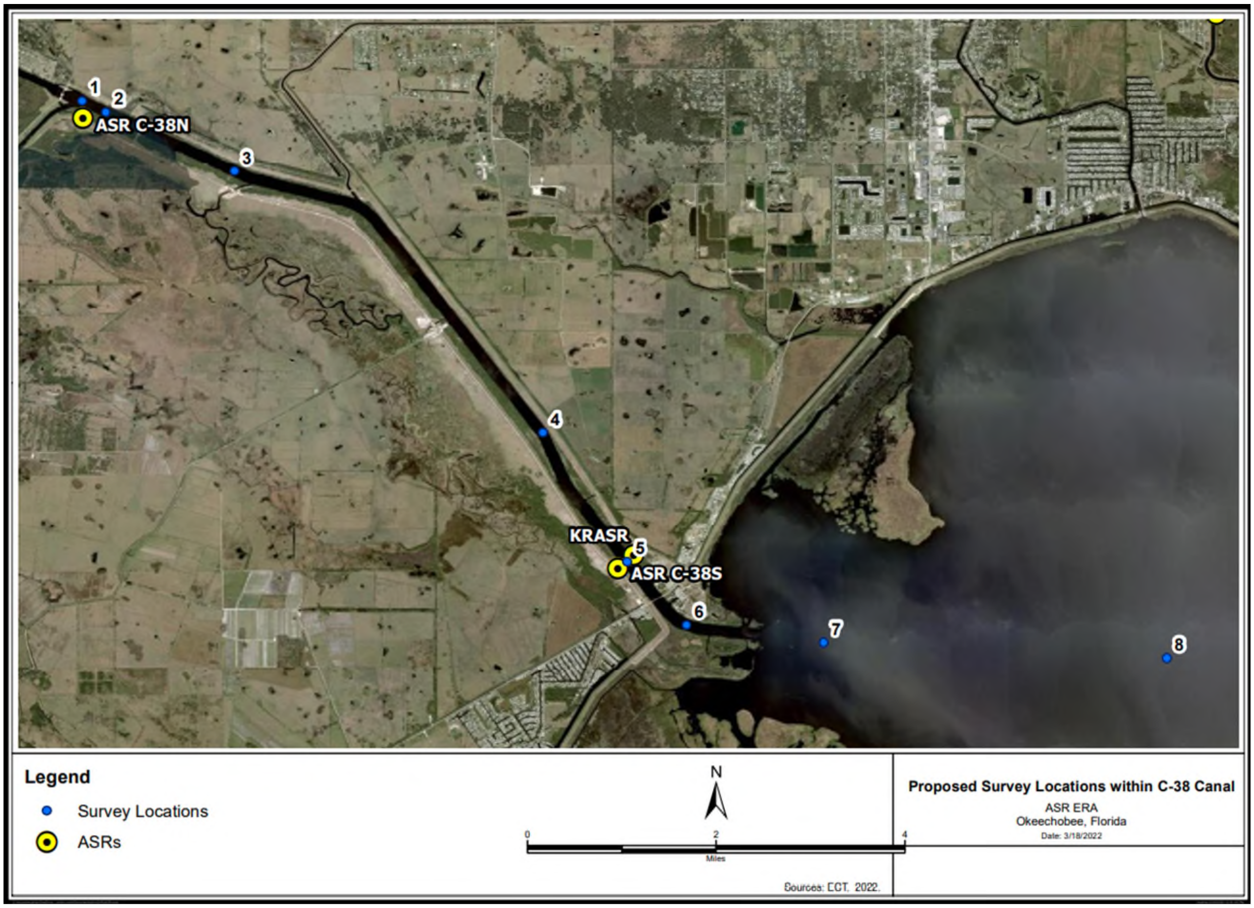

Figure 7-2. Monitoring locations along the C-38 Canal and northern part of Lake Okeechobee.

Ongoing and Future Studies

Pre-operational environmental monitoring of multiple receptors listed in **Table 7-1,** in the C-38 Canal and northern part of Lake Okeechobee is ongoing since August 2022, and it is expected to continue in the upcoming years to capture intra- and inter-annual variations in biological community structure and selected chemical compound concentrations in relation to changing physical-chemical water quality conditions and flow rates in the C-38 Canal.

The frequency of monitoring varied among the monitoring components **Table 7-1**. Periphyton surveys are conducted bimonthly to capture the subtle changes in community structure and chemistry (species composition, biomass, and nutrient and metal content) that can occur at small timesteps (from weeks to months). Water quality is monitored at the same frequency to capture the effects of intra-annual changes in precipitation and air temperature on physicochemical water quality parameters, which affect all biotic receptors. Benthic macroinvertebrates, sediments, mussels, and apple snails are monitored once during the wet season (between August - September) and once during the dry season (between February - April) due to the relatively stable nature of these populations within the study area. Fish are sampled twice in the wet season and twice in the dry season to capture the movements of various species during and beyond spawning periods. Ichthyoplankton is surveyed during the peak spawning periods of the local fish population (January-February and May-June), as recommended by the 2022 ASR Science Plan PRP. SAV surveys were conducted in the summer during the peak of the growth period (June-September). The initial 2022 and 2023 Submerged aquatic vegetation (SAV) surveys revealed very patchy and generally poor SAV cover, and were interrupted by extreme weather conditions related to the passage of hurricanes Ian and Nicole in

2022 and Hurricane Idalia in 2023, which severely affected the already sparce SAV communities due to sharp canal and lake stage increases and subsequent decreases in water clarity, and significant canal flow rate increases which decimated the remaining SAV stems near the mouth of the canal. Based on the preliminary results from the first two years of the monitoring, a decision was made to discontinue the surveys in the upcoming years due to absence of sufficient SAV communities for monitoring, which made the surveys financially non-viable.

The first year of the monitoring revealed distinct special and temporal variations in nutrient and metal concentrations in water, periphyton, and tissue samples, with the highest concentrations often detected in the lake samples (except for methyl mercury which exhibited the opposite pattern). Nutrient concentrations in water and sediment samples were also typically higher at the lake stations, while nutrient concentrations in periphyton were typically lower. Seasonal trends in water quality included significantly higher concentrations of aluminum, arsenic, orthophosphate, and zinc concentrations in the dry season and significantly higher concentrations of chromium in the wet season. Wet season metal concentrations were higher in the wet season samples. Periphyton species richness and fish abundance, richness, and diversity were lower in the lake, while ichthyoplankton was more abundant, rich, and diverse at the lake stations. Furthermore, fish populations were more abundant, rich, and diverse in the dry season while ichthyoplankton were more abundant, rich, and diverse in the wet season. Detailed description of spatiotemporal differences in community structure and chemistry of biotic and abiotic monitoring components, and factors driving their patterns are described in the comprehensive annual report included in **Appendix I**.

Data obtained through this pre-operational monitoring will in the future be compared to data that will be collected once ASR wells along the C-38 Canal (C-38N and C-38S) become operational (during the cycle testing period; approximately between 2027 - 2030). The timing of the monitoring that will be conducted during the cycle testing period will be closely linked to the construction schedule of the ASR wells. The pre- and operational ASR data collection plans are directly tied to the data needs of the quantitative ASR ERA described in the ASR ERA Work Plan (**Appendix J**), and the 2015 NRC and recent ASR Science Plan Panel recommendations for the in-situ environmental monitoring.

Table 7-1. Sampling schedule for different biotic and abiotic components of the 2022-2024 pre-operational monitoring along the C-38 Canal and northern part of Lake Okeechobee.

Monitoring Component	2022						2023												2024					
	July	August	September	October	November	December	January	February	March	April	May	June	July	August	September	October	November	December	January	February	March	April	May	June
Water quality		■		■		■		■		■		■		■		■		■		■		■		■
Periphyton		■		■		■		■		■		■		■		■		■		■		■		■
SAV		■	■																			■		
Benthic Macros		■	■					■						■						■				
Sediment			■					■						■			RE			■				
Apple Snails		■		■						■				■								■		
Mussels		■	RE					■						■						■				
Fish Population			■			■		■				■						■		■				■
Fish tissue		■						■						■						■				
Ichthyoplankton							■	■			■	■							■	■			■	■

RE = resampled

2024 Peer-Review Panel Guidance

The following guidance was provided by the PRP in its 2024 report (Price et al. 2024; **Appendix B**).

A more intense sampling during peak black crappie (*Pomoxis nigromaculatus*) spawning season is recommended to improve the ability to model population level impacts of impingement/entrainment when wells become active should intake designs result in unintended take of eggs or larvae. Future targeted sampling in the locations where modeling predicts thermal plumes and analysis is also recommended for the underrepresented tropical non-native species (*Oreochromis* spp. and *Pterygoplichthys* spp.) relative to others when assessing fish community composition. The analysis and collection could be streamlined in the future work and routine monitoring, but without losing critical information.

7.4 NRC comment: A refined ecological risk assessment, probabilistic in nature, should be conducted using robust data from multiple sites and modernized quantitative methods.

2020 Peer-Review Panel Guidance

The following guidance was provided by the PRP in its 2020 report (Arthur et al. 2020; SFWMD and USACE 2021b, **Appendix B**).

The PRP recommended that the refined ecological risk assessment should be probabilistic in nature and should be conducted using robust data from multiple sites and modernized quantitative methods.

2022 Peer-Review Panel Guidance

The following guidance was provided by the PRP in its 2022 report (Missimer et al. 2022; SFWMD and USACE 2022, **Appendix B**).

Working Group should establish a system to implement and update the ERA with new information, conclusions, and information gaps annually.

Upon completion of the ERA Work Plan, a summary of the ERA analytical approaches for evaluating risks from ASR monitoring operations should be included in the future Science Plan and iterations for review and discussion with the Panel. Information should also be provided on how environmental information will be used to trigger additional studies, when warranted, to support decisions.

For analyzing and characterizing risks, the Panel recommends the use of Bayesian networks in a risk assessment framework, if useful and appropriate to the quantitative work.

The conceptual models are informative but should be developed to contain more exposure routes, stressors, speciation, and media. Separate but interconnected conceptual models should include information from ecosystems at risk and stressor types and hypothesized exposure scenarios and interactions within the systems. Measurement endpoints and measures of exposure should also be clearly aligned and delineated to clarify how the assessment endpoints will be examined. The endpoints should be incorporated into the conceptual models. Tiered assessments may be helpful for focusing data collection efforts and needs from conservative to more realistic assumptions.

The plan should examine risks to estuarine, riparian, and wetland receiving environments more closely.

Progress Since 2022

ERA Work Plan was developed with assistance from the ERA Working Group, which was comprised of stakeholders from multiple state and federal agencies, academia, and non-governmental organizations, with interest in completing the ERA (**Appendix J**). This Plan addresses the 2022 ASR PRP recommendations (SFWMD and USACE 2022, **Appendix B)**. Based on the 2022-2023 ERA Working Group discussions and the 2015 NRC comments on the original ERA, a risk management goal for the updated quantitative ASR ERA is to prevent the development of site conditions due to the operation of the planned ASR wells that could potentially adversely affect biological receptors from exposure to stressors directly related to the operation of the ASR wells.

To address the risk management goal, the ERA Work Plan identifies stressors to ecological receptors that are directly related to the operation of the ASR wells. It also identifies groups of ecological receptors that have the potential to be impacted by the stressors. The Plan also provides a repeatable and defensible set of procedures to determine how significant the potential risks for adverse effects to ecological receptors impacted by the stressors are and whether they warrant changes to the ASR well implementation plan as presented in the ASR Science Plan. In addition, the Plan was designed to determine if the conclusions of the ASR ERA for the initial ASR well clusters (e.g., along the C-38 Canal) can be applied to ASR well clusters constructed in the future and at other well locations, and if the risks predicted at any given ASR well cluster are predictive of other wells in the drainage.

Furthermore, the Plan also describes how the potential for adverse ecological effects will be determined in the ASR ERA using a tiered assessment approach. In this approach, Tier 1 ERA will assess risks on ecological receptors at a local scale, in the vicinity of the well clusters in the C-38 canal. The decision process for determining which cases require risk assessment beyond Tier 1 will be based on a weight-of-evidence (WOE) approach that will allow for technically sound decisions based on the results of the risk characterization. The Plan also includes information on the stressor categories and how risk will be assessed based on the level of biological organization of each group of receptors. Furthermore, the Plan includes a decision-making framework which provides a repeatable and consistent process for deciding which stressors and receptors must be carried forward into detailed characterization of risk. A decision matrix is also provided in the Plan, which will be used for consistent characterization of risk for each assessment endpoint based on the WOE assessment.

The Plan also lists multiple probabilistic risk assessment (PRA) techniques that will be used in the Tier 1 ASR ERA. Those techniques include Monte Carlo, geospatial, and Bayesian network analyses. Results of the WOE analysis will be used to determine which PRA analyses would be best for the identified combination of stressors and endpoints, and which stressors and receptors should be carried forward into Tiers 2 and 3 of the ASR ERA. The specific procedures for completing Tiers 2 and 3 are not provided in the Work Plan due to the undefined nature of which risks assessment will require evaluation beyond Tier 1. Details on the ERA procedures and data needs for the additional ERA tiers will be provided as part of the Tier 1 ASR ERA. More information on quantitative ERA methodologies and approaches can be found in ERA Work Plan included in **Appendix J**.

Ongoing and Future Studies

Because the ERA Work Plan for completing the quantitative ASR ERA was developed before the ASR construction and operation plans were finalized, considerable data and information relevant to the ASR ERA will be collected in the period between the completion of the Work Plan in 2023 and the ASR ERA. To address potential changes to the project prior to the completion of the ASR ERA, the Work Plan includes an adaptive management decision process (**Appendix J**) that should help with the future revisions of ERA strategies should new information become available. The ASR ERA Work Plan may be periodically updated between the completion of the Plan and the initiation of the ERA, if new information becomes available and requires changes to the Plan. Current activities include environmental data collections to fill in the data gaps (**Appendix J**), which is required for the completion of the quantitative ASR ERA.

2024 Peer-Review Panel Guidance

The following guidance was provided by the PRP in its 2024 report (Price et al. 2024; **Appendix B**).

Once completed, a clear synthesis of the two ERAs together (the original SFWMD and USACE (2015) and current Tier 1 ERA (in progress)) should be provided with aligned conclusions from both as well as the unique conclusions addressed by each. The comparison should include description of methodological differences and improvements made. The conclusions should be used to develop the later tiers (Tier 2 and 3 ERAs). The frameworks in development should also begin to incorporate a solution-focused framework for assessment determinations (Finkel, 2011). For the future Tiers 2 and 3 ERAs, several considerations may be important beyond the Tier 1 information for choosing risk scenarios. The sensitivity of the receiving environments to ASR stressors may be important even if stressors do not exhibit local risks in the Tier 1 ERA. Exposure analysis approaches should be investigated to identify regions for the development of the future Tiers 2 and 3 ERAs. Additional information should be provided on the framework that will be used for Tiers 2 and 3 ERAs, including how the methodological decisions will be made based on Tier 1 results. Initial analysis plans may include the models and data sources being considered for future tiers for high-risk scenarios that will be used with the probabilistic work. The focus of the adaptive management process being put in place should start to become more developed for identifying potential causal factors and supporting risk management objectives in Tiers 2 and 3 ERAs. In the near-term risk assessment, the “ecosystems at risk section” that is recommended to be added to Tier 1 ERA should prioritize describing the locations being evaluated for Tier 1 ERA. In preparation for higher tier work, the ecosystems at risk section can start to include information on characteristics of the receiving environments and their potential susceptibilities to the ASR. If not already done ASR water for chemical analysis at the source should be collected to get a full understanding of the variability and types of loadings that enter the lake from the discharged water might provide valuable baseline probabilistic information for extrapolating in predictive risk assessments. The possibility of risks beyond the Tier 1 study from radionuclides may be considered depending on the future operations of the wells being planned, especially with capabilities for persistence, biomagnification, and higher trophic level effects. For all metals and higher trophic levels, indirect effects from the loss of prey species from exposure may be important to evaluate in later phases (Tier 2 and 3 ERA). Greater conservatism may be considered for some of the HQ screening approaches in determining future scenarios to explore in the tiered system. For endangered and threatened or listed species, it is recommended to use a lower HQ value than 1 as suggested in e.g., ECOFRAM (1999). A separate section examining listed species should be created in an ecosystem at risk section for problem formulation. Noting and recording when HQs are close to 1 is also recommended for all endpoints. The review Panel recommends considering publication for future phases and assessment results, if feasible. The panel highly encourages the use of the adaptive management step. Additional information may be developed and provided on decisions about later tiers on the adaptive management process, how the products from the risk assessment will be updated, and the infrastructure that will be put in place to support adaptive management.

A modeling approach with data collection may be beneficial for tracking the results of the risk assessment and management efforts. Early tier assessments should consider the possibilities of greater metal concentrations in the environment and intermediate sources such as soil and sediment from ASR operations. Longer term considerations may also be examined with water quality parameters such as temperature, hardness, and pH from repeated cycles with multiple ASRs.

8 WATER QUALITY

8.1 NRC comment: More research is needed to understand the impacts of different source water qualities on the long-term redox evolution of the aquifer and its effect on arsenic mobilization.

2020 Peer-Review Panel Guidance

The following guidance was provided by the PRP in its 2020 report (Arthur et al. 2020; SFWMD and USACE 2021b, **Appendix B**).

Page 10, PRP Report. As noted in **Section 6.2**, investigations of water-rock interactions during ASR have focused on processes controlling a limited number of mobilized constituents. However, several metals besides arsenic are mobilized during ASR, and while the concentrations do not exceed drinking water standards, their environmental effects are largely unknown. For all water quality analyses, the PRP suggests broad-spectrum hydrogeochemical analytical packages be used. These are cost-efficient, multi-method, multi-element analytical packages that provide robust information about constituents that may not be known concerns today. As scientific understanding continues, especially in the area of ecotoxicology, data within an expanded analyzed parameter list may become useful.

Work on ASR geochemical processes is central to understanding mobilization and/or fixation of chemicals of concern. Geochemical investigations by the USACE should continue to be supported, including recommended isotopic fractionation studies. The PRP recommends a future ASR plan include more water chemistry measurements related to monitoring recovered ASR waters. Routine determination of isotopic ratios of nitrogen, arsenic, oxygen, hydrogen, and sulfur measurements over time should assist in understanding the microbial processes responsible for fixation and mobilization.

Progress Since 2022

Source water quality characterization efforts are conducted at this time within the Ecological Risk Assessment (ERA) task at the C-38S ASR system location (see Comment 7.3 and **Table 7.1**). The source water dataset compiled from this effort will serve multiple purposes, including those identified in this task. However, isotopic composition (nitrogen, arsenic, oxygen, hydrogen, and sulfur) is not included currently in the suite of analytes. Redox-sensitive analyte concentrations currently in the ERA dataset include sulfate, iron, and total organic carbon. Source water quality characterization also will be conducted at other proposed LOWRP ASR systems.

Ongoing and Future Studies

Analysis of Redox-sensitive Constituents and Isotopic Fractionation during Cycle Testing (2024-2026)

The redox condition of surface water and groundwater is defined by systematic quantification of terminal electron accepting processes. That is, the dissolved constituents that accept electrons as the water quality evolves from oxic (surface water) to reduced (native groundwater). There are routine geochemical analyses (dissolved oxygen, nitrate, iron, manganese, sulfate/sulfide, and methane) that, as a collective, are used to quantify the redox condition. However, all constituents must be analyzed in each water sample obtained during cycle testing to completely characterize the redox environment. For example, transition metal analyses, at parts per billion detection levels, must be included with redox-sensitive species. These metals (e.g., molybdenum, vanadium, arsenic) occur in sulfide minerals in FAS lithologies and are released during pyrite oxidation. Many South Florida monitoring wells have stable isotope analyses of native FAS groundwater. The SFWMD's Regional Floridan Groundwater Monitoring program has developed a groundwater quality characterization database for all aquifers in the FAS. These data will serve as a basis for the use of stable isotopes in mixing studies.

Native groundwater quality characterization is an important part of ASR well construction at proposed LOWRP ASR sites. Groundwater quality analyses are completed using samples from discrete-interval packer tests. Native groundwater quality analyses also are completed after aquifer performance testing ends, which reflects groundwater quality of the entire open interval in the UFA and APPZ wells. Groundwater analyses include measurement of oxygen and hydrogen isotope activities, in addition to a full suite of major and trace dissolved constituents.

8.2 NRC comment: Determine how far arsenic can be transported within the aquifer using extended (>1 year) cycles and development of a buffer zone.

2020 Peer-Review Panel Guidance

The following guidance was provided by the PRP in its 2020 report (Arthur et al. 2020; SFWMD and USACE 2021b, **Appendix B**).

Page 9, PRP Report. Management of the volume and rate of growth of the buffer zone could assist in improvement of fouling issues, nitrogen and arsenic mobilization and transformation, and recovery efficiency. Investigating clustering of ASR wells could be helpful in increasing the extent of the freshwater buffer zone in the aquifer and reducing arsenic mobilization.

Progress Since 2022

Arsenic transport will be simulated prior to cycle testing at the proposed C-38S ASR system. The sequence of tasks outlined in the ERDC scope of work specifically support a quantitative evaluation of arsenic transport. These studies can be summarized as follows: 1. Laboratory-based batch tests using recently acquired UFA and APPZ core material from C-38S; 2. Use of batch testing results to quantify arsenic reductive dissolution rates under anoxic conditions; 3. Parameterization of a reactive transport model using laboratory data. These efforts are described in detail in Section 10 and are summarized below.

Ongoing and Future Studies

Local-scale Groundwater Flow and Solute Transport Model Development and Simulations (2024-2026)

A SEAWAT groundwater flow and solute transport model currently is under development. Aquifer performance test results completed in early 2024 provided permeability and transmissivity parameter data that were incorporated into this model. As of May 2024, the model grid has been defined and a steady state calibration technical memo has been drafted and is in review. This SEAWAT model will permit evaluation of well spacing at the C-38S ASR system as it expands from 10 MGD to a proposed capacity of 50 MGD.

Eventually, transient simulations showing solute transport during cycle testing primarily using TDS concentrations will be developed. These simulations will be compared to actual cycle testing results at the C-38S system.

Reactive transport simulations for non-conservative species (such as arsenic) require an additional code to quantify geochemical processes such as sorption, complexation, and dissolution and precipitation, The SEAWAT model developed previously for transport processes will be coupled to PHREEQC or similar code to simulate geochemical processes. Reactive transport simulations will be completed by ERDC and other collaborators.

Cycle Testing (2027 and Beyond)

The cycle testing plan will incorporate longer duration, larger volume recharge and storage phases. Typical cycle tests eventually will span multiple years.

Preliminary designs of proposed ASR systems at C-38S and C-38N include monitoring wells on both sides of the C-38 Canal. The proposed ASR system at C-38S is adjacent to the existing KRASR system and incorporates existing monitoring wells into a new system design. Thus, the monitoring wellfield at both ASR systems will enable detection of recharged surface water at greater distances than was possible during cycle testing at the KRASR site.

Although cycle testing schedules have not been developed yet, a guiding paradigm for cycle testing at the LOWRP ASR systems is that onset of recharge and recovery will be tied to lake levels. Although wet season recharge and dry season recovery occur on annual schedules, LOWRP ASR systems will have greater operational flexibility due to conjunctive use of the wetland attenuation feature. Greater operational flexibility will allow for longer duration, larger volume recharge and storage phases. Buffer zone development can be readily incorporated into the cycle testing plans at the proposed LOWRP ASR systems. In fresher portions of the UFA, the buffer zone will be characterized by non-conservative constituents such as carbonate alkalinity or sulfate, rather than chloride. In brackish portions of the UFA, buffer zone composition will be based on contrasting chloride concentrations between native groundwater and recharged water, which will supplement the non-conservative constituents. In the APPZ, buffer zone development will be controlled to a greater extent by aquifer characteristics due to fracture permeability.

8.3 NRC comment: Determine how development of a buffer zone can reduce sulfate concentrations in recovered water or determine limits on recovery based on sulfate concentrations.

2020 Peer-Review Panel Guidance

The following guidance was provided by the PRP in its 2020 report (Arthur et al. 2020; SFWMD and USACE 2021b, **Appendix B**).

Page 11, PRP Report. Sulfate loading can enhance methylmercury production in the Everglades (Orem et al. 2011). As sulfate concentrations have been found to be higher in recovered ASR waters compared to the receiving water body, the PRP recommends monitoring sulfate in recovered waters and investigating the effects of added sulfate to receiving wetlands, canals, and Lake Okeechobee in relation to methylmercury production in water, soils, and biota in those areas. The potential need for post-treatment or dilution of high sulfate concentrations in the recovered water should be considered because of sulfate's reactivity with mercury in the Everglades.

Progress Since 2022

Sulfate concentrations in native groundwater are greater than chloride concentrations in samples from the UFA and APPZ. The extent of mixing between fresh recharge and mostly brackish groundwater will partly minimize sulfate concentrations in recovered water. The extent of mixing differs in the UFA and APPZ, and this is best shown by permeability characteristics at C-38S aquifer performance test results. Permeability in the UFA occurs at discrete flow zones, where fluids are rapidly transported during recharge, largely as "plug flow". Fracture flow dominates in the APPZ. The extent of mixing in each aquifer will differ based on the nature of flow under transient conditions. Prior to cycle testing, permeability parameterization in transient SEAWAT simulations can provide some insight into the extent of mixing, and subsequent sulfate dilution during cycle testing.

Use of sulfate for buffer zone characterization may be useful to understand mixing between recharge and native groundwater. However, because sulfate concentrations exceed chloride concentrations, use of sulfate concentrations to calculate percent recovered volumes will result in lower recovery efficiencies. The ideal cycle testing strategy will limit percent volume recovered to less than 100% to develop a wider band of mixed water at some radius away from the ASR wells during successive cycle tests.

Ongoing and Future Studies

Characterize a Buffer Zone Based on Sulfate Concentrations at KRASR (2024)

Buffer zone characterization using sulfate is not explicitly planned as a transient SEAWAT model scenario at present. Transient simulations have not yet been defined in a scope of work, so this task could be added in the future. Buffer zone development will be shown by simulations of successive cycle tests using TDS. Transient solute transport simulations using TDS will serve as an approximation for sulfate in buffer zone development.

Cycle Testing (2027 and beyond)

The proposed cycle testing plan at the C-38S ASR system is under development, in preparation for UIC permit submission. In addition to regulatory compliance with Safe Drinking Water Act criteria, evaluation of a buffer zone development and solute transport will be incorporated as objectives in the cycle testing plan. Details of future studies beyond 2027 will be provided in subsequent updates of the ASR Science Plan as the ASR program progresses and additional information becomes available.

8.4 NRC comment: Further modeling on the fate of sulfate in recovered water should be conducted, along with additional study on the temporal and spatial variability of sulfate and mercury methylation in Lake Okeechobee.

2020 Peer-Review Panel Guidance

The following guidance was provided by the PRP in its 2020 report (Arthur et al. 2020; SFWMD and USACE 2021b, **Appendix B**).

The PRP is concerned that non-methylated mercury may be introduced into downstream waters and recommends that recovered waters be analyzed for total mercury as well as sulfate due to sulfate's connection with mercury methylation (Orem et al. 2011). Results from previous studies are encouraging in that methylmercury concentrations are low in the FAS and in recovered ASR waters (SFWMD and USACE 2013). However, microbial sulfate reduction under anoxic conditions has been found to enhance mercury methylation, the most toxic form of mercury that bioaccumulates in the food chain (Gilmour et al. 2011). As noted in **Section 8.3**, Methylmercury production in Everglades sediments is greatest at the range of sulfate concentrations between 1 mg/L and 20 mg/L (Orem et al., 2019). As sulfate concentrations have been found to be higher in recovered ASR waters compared to the receiving water body, the PRP recommends monitoring sulfate in recovered waters and investigating the effects of added sulfate to receiving wetlands, canals, and Lake Okeechobee in relation to methylmercury production in water, soils, and biota in those areas. Sulfate concentrations in recovered water will vary at each ASR system based on the percent recovered volume during each cycle. Sulfate concentrations will likely increase as recovery proceeds. Sulfate concentrations in native groundwater also will differ at each ASR system. Prior to cycle testing, the range of sulfate concentrations in recovered water discharged into the receiving surface water body will be simulated using CORMIX modeling methods as required for NPDES permitting.

Progress Since 2022

Results from ASR pilot studies indicated inorganic mercury and methylmercury concentrations declined to the minimum detection limit (well below regulatory criteria) during the storage phase of ASR cycle testing. There was no evidence of increased mercury methylation during ASR cycle testing. However, the potential impacts of sulfate and other water quality constituents (e.g., iron, dissolved organic matter) on mercury methylation and bioaccumulation in downstream waters were not investigated. This uncertainty can be best evaluated through cycle testing through potential use of a buffer zone. Mercury methylation continues to be an ongoing issue that requires proof that the reaction does not occur during ASR cycle testing.

Ongoing and Future Studies

Lake Okeechobee Environment Model (2024-2030)

The Lake Okeechobee Environment Model can be updated with the newest water quality and sediment data to assess the fate of recovered water within and downstream of Lake Okeechobee. Modeling may include updates for the new C-38 Canal flow targets and ASR configurations. If updated operations and configurations result in different temporal or spatial discharge patterns, then newer hydrologic modeling can be used to improve bench-scale toxicity tests, local and downstream dilution factors, and eventually the overall ERA. Results from the modeling efforts can inform chronic toxicity testing, in terms of dilution levels and/or exposures times.

Cycle Testing (2027-2030)

A more effective method of limiting sulfate discharge in recharge water is to develop a buffer zone with a lower sulfate concentration, so that a greater fraction of naturally occurring sulfate remains in the aquifer. This is an operational optimization that can be tested over a few cycles, during in which some fraction of recharged water remains in the aquifer. Cycle testing data will include evaluating sulfate trends in the aquifer, which are simpler to execute compared to regional surface water quality simulations. In addition, increased sulfate in surface water systems could be a focus of the ERA.

Additional Studies

The following additional studies may be conducted:

- Laboratory incubation of sediment cores taken from downstream of proposed ASR wells with recovered water and marsh water to obtain a series of sulfate concentrations from low (2 mg/L) to high (30 to 40 mg/L)
- Mesocosm experiments at a site downstream of the proposed ASR wells to examine mercury methylation rates and various sulfate dosing treatments under ambient environmental conditions
- Monitoring of water quality parameters along impacted areas of proposed ASR well discharges to understand relationships between recovered water constituents (e.g., sulfate, iron, dissolved organic matter) and methylmercury production and bioaccumulation in fish
- Modeling of wetland responses to mercury methylation from recovered water discharges with existing sulfate, iron, dissolved organic matter, and methylmercury data (water and mosquitofish) from South Florida wetlands

8.5 NRC comment: More understanding on the spatial variability of gross alpha and radium at future ASR locations should be addressed during longer-term testing.

2020 Peer-Review Panel Guidance

The following guidance was provided by the PRP in its 2020 report (Arthur et al. 2020; SFWMD and USACE 2021b, **Appendix B**).

Elevated concentrations of gross alpha and radium have been observed in water collected from some ASR systems in southwestern Florida. Water recovered from the KRASR system did not indicate concentrations of these constituents above background levels. However, due to the high degree of variability in concentrations observed regionally, monitoring of these constituents at future ASR locations is warranted.

Progress Since 2022

Radium isotopes (Ra^{224} and Ra^{226}) are one of the few constituents not released through water-rock interactions during cycle testing. Radium isotopes are naturally occurring in native groundwater in some areas of south Florida. Radium appears in recovered water as the result of mixing with native groundwater. The source of radium in native UFA groundwater samples from southwestern coastal areas of Florida is the uranium (U^{238}) decay series (for Ra^{226}) and thorium (Th^{232}) decay series (for Ra^{224}). High concentrations of uranium and thorium occur in highly insoluble, detrital phosphate minerals at the base of Hawthorn Group sediments, particularly in southwestern Florida coastal counties. Alpha-recoil during uranium and thorium decay creates minute crystal defects in phosphate minerals, through which radium is released to groundwater. Both radium isotopes remain dissolved as a divalent ion in native groundwater and may exceed drinking water standards in some areas.

Ongoing and Future Studies

Compilation of Existing Radium and Gross Alpha Data in the FAS (2023)

Existing gross alpha concentrations and radium isotope activities measured in the UFA, Lower Tamiami Aquifer, the APPZ, and the Boulder Zone were compiled from well construction reports available for download from the FDEP Oculus Database. Well locations and concentrations were incorporated into GIS layers to show the geographic distribution of gross alpha and radium isotopes in native groundwater in each aquifer. A technical memorandum summarizing this survey is in preparation.

Pre-operational Groundwater Monitoring (2022-2024)

Native groundwater samples will be collected from ASR and monitoring wells at existing and proposed ASR system locations prior to the commencement of cycle testing. The list of analytes is shown in the response to Comment 3.1.

Cycle Testing (2025-2026)

Generally, radium isotope analyses are merited when the gross alpha measurements meet or exceed the drinking water standard (15 picocuries per liter) in native groundwater samples. As a routine part of native groundwater quality characterization at proposed exploratory boreholes, gross alpha and radium isotope analyses should be included as part of the analytical suite. If gross alpha and radium isotope analyses meet or exceed their respective drinking water standards in native groundwater, then cycle testing strategies must include an option to minimize radium in recovered water. Because radium shows conservative behavior (except in groundwaters having very high sulfate concentrations), radium mitigation would be best accomplished through buffer zone development, leaving radium as it occurs naturally in the aquifer. Details of future studies beyond 2026 will be provided in subsequent updates of the ASR Science Plan as the ASR program progresses and additional information becomes available.

9 PLANNING-LEVEL COST ESTIMATE AND ASR WELL COST-BENEFIT ANALYSIS

9.1 PLANNING-LEVEL COST ESTIMATE FOR THE ASR SCIENCE PLAN

Planning-level cost estimates were prepared for the research activities described within this ASR Science Plan (**Table 9-1**). The cost estimates are based on recently conducted studies for other projects and programs within the SFWMD and are for planning purposes. The estimates are subject to change and will be updated annually as the ASR program progresses.

9.2 ASR WELL PROGRAM COST-BENEFIT ANALYSIS

The NRC (2015) review recommended analyses be undertaken to compare capital and long-term operating costs of ASR to other storage alternatives. “These analyses should consider existing uncertainties related to recovery efficiency, disinfection technology required, and the potential for gravity (artesian) flow of water recovered from ASR wells. Decision makers are unlikely to support continued research on ASR without clear documentation of potential benefits of ASR relative to other possible alternatives” (NRC 2015).

The District and federal policy directed the ASR Program to adhere to the drinking water standards implemented by the USEPA. The District remains committed to meeting these standards and will not seek variance from primary drinking water standards. The ASR project team will continue evaluating the economic costs and it will be a policy decision between the state and federal government in the future to implement ASR at full-scale. Costs can be evaluated by comparing the environmental, ecologic, and water supply benefits provided by the technology to the benefits of potential alternatives. The ASR program cost-benefit analysis will be presented during the annual progress review public workshops and in future updates of the ASR Science Plan. As the ASR program is implemented and augmented with results from the ASR Science Plan studies, a thorough analysis of the capital, operational, and maintenance costs of ASR will be conducted. The ASR cost-benefit analysis most likely will be performed in 2026 when the demonstration facility is constructed and membrane technology and treatment for the ASR Program is selected.

Table 9-1. Planning-level cost estimates for the 2024 (Version 2) ASR Science Plan.

* This is a planning-level cost estimate and does not include contingency. Cost is based on 2024 dollars and does not include future inflation escalation. Each cost estimate will be finalized upon detailed scoping of each task. Cost information was assembled by SFWMD Project Team based on best available information.

Research Activity	Estimated Cost by Fiscal Year							Total Cost
	FY20-23	FY24	FY25	FY26	FY27	FY28	FY29	
Future Construction and Testing (Chapter 3)								
Geochemical Core Analysis		$ 126,000	$ 16,000					$ 142,000
Seismic/Geophysical Evaluation and Borehole Fracture Analysis	$ 69,250	$ 483,000						$ 552,250
Core Analysis/Description		$ 300,000	$ 214,000					$ 514,000
Optical Borehole Image Logging	$ 45,430	$ 15,143						$ 60,573
Local-scale Groundwater Modeling at C-38	$ 63,000	$ 337,000						$ 400,000
								$ 1,668,823
Understanding Phosphorus Reduction Potential (Chapter 4)								
Nutrient Column Studies (Biodogging)	$ 285,000	$ 250,931						$ 535,931
								$ 535,931
Operations to Maximize Recovery (Chapter 5)								
Mixing Zone/Dispersion Model (Recovery)		$ 150,000	$ 125,000					$ 275,000
								$ 275,000
Disinfection/Treatment Technology (Chapter 6)								
Dissolved Oxygen (DO) Removal Technology Evaluation & Geochemical Benchtop Modeling	$ 9,000	$ 159,000						$ 168,000
Pathogen Inactivation Support Risk Assessment		$ 42,500						$ 42,500
								$ 210,500
Ecotoxicology and Ecological Risk Assessment (Chapter 7)								
Ecological Risk Assessment	$ 292,000			$ 100,000	$ 100,000	$ 100,000		$ 592,000
Long-term Ecological Monitoring	$ 1,000,000	$ 1,000,000	$ 1,000,000	$ 1,000,000	$ 1,000,000	$ 1,000,000	$ 1,000,000	$ 7,000,000
Chronic and Acute Toxicity and Bioaccumulation Studies				$ 100,000	$ 100,000	$ 100,000	$ 100,000	$ 400,000
Larval Fish Entrainment/Impingement and Temperature Effect Studies					$ 150,000	$ 150,000		$ 300,000
								$ 8,292,000
Water Quality (Chapter 8)								
Water Quality Monitoring During Cycle Testing					$ 200,000	$ 200,000	$ 100,000	$ 500,000
Sulfate/Methylmercury Studies			$ 250,000					$ 250,000
Gross Alpha/Radium Monitoring			$ 50,000	$ 50,000	$ 50,000			$ 150,000
								$ 900,000
U.S. Army Engineer Research and Development Center Studies (Chapter 10)								
Work Plan Preparation	$ 50,000							$ 50,000
Studies in FY24		$ 3,872,387						$ 3,872,387
Studies in FY25			$ 694,227					$ 694,227
Studies in FY26				$ 84,500				$ 84,500
								$ 4,701,114
ASR Peer-Review Panel								
Scientific Panel	$ 50,000	$ 25,000	$ 25,000	$ 25,000	$ 25,000	$ 25,000	$ 25,000	$ 200,000
Programmatic Quality Assurance Plan	$ 74,200		$ 25,000		$ 25,000			$ 124,200
								$ 324,200
Total by Fiscal Year	$ 1,937,880	$ 6,760,961	$ 2,399,227	$ 1,359,500	$ 1,650,000	$ 1,575,000	$ 1,225,000	**16,907,568**

10 UNITED STATES ARMY ENGINEER RESEARCH DEVELOPMENT CENTER STUDIES

10.1 COOPERATIVE RESEARCH AND DEVELOPMENT AGREEMENT

A Cooperative Research and Development Agreement (CRADA) was prepared and executed on June 15, 2023, between the U.S. Army Engineer Research and Development Center (ERDC) and the SFWMD to address uncertainties with ASR technology for the Lake Okeechobee Watershed Project (LOWRP). The original CRADA has been modified and was amended on November 30, 2023, and April 2, 2024 to better refine the Scope of Work and tasks associated with ASR uncertainties. The risks identified were grouped into three broad categories including water quality, construction cost and long-term Operation and Maintenance cost, and the studies are estimated to take approximately 3 years through 2026. Results of the studies will be provided in future updates on the ASR Science Plan.

10.2 SCOPE OF WORK SUMMARY

The first amendment to the CRADA was to refine the Scope of Work and develop a comprehensive plan to conduct scientific studies to address the major risks identified by USACE. To understand risks associated with these three categories, ERDC proposed modeling and lab-based investigations. The first category is water quality and is driven primarily by uncertainties associated with the rate and extent of mobilization of arsenic and other metals in the Floridan Aquifer System (FAS) but also includes concern for increased potential of mercury methylation in receiving surface water bodies due to elevated levels of sulfate in recovered groundwater. The second and third categories are associated with cost. First-cost construction and long-term O&M cost uncertainties are driven by the need for water treatment that may include: 1) pre-treatment of injected water to applicable standards, 2) any pre-treatment to minimize constituents in the injected water that may mobilize arsenic, 3) any treatment of the recovered water to the applicable standards of that receiving surface water body to include elevated sulfur concentrations and 4) pre-treatment (i.e., filtration) to prevent the aquifer from clogging from accumulated suspended solids in the injected water. ASR well performance constitutes a secondary uncertainty for long-term O&M cost since aquifer porosity and permeability may change over time due to bio-growth and/or solids precipitation and dissolution; mixing dynamics between fresh injected water and the brackish groundwater may also affect long-term performance.

To address concerns related to mobilization of arsenic and other metals in groundwater, ERDC and SFWMD will collaborate through modeling and lab-based investigations to characterize and quantify biogeochemical reactions, reaction kinetics, and groundwater flow parameters under conditions representative of the FAS during ASR. This information will then be used to parameterize a reactive transport groundwater model suitable for simulating key processes for water quality and the evolution of aquifer conditions over time during ASR cycling. Integrated results at the conclusion of the effort should provide: (1) a defensible and quantitative basis for strategies to prevent groundwater arsenic concentrations from exceeding applicable standards in the FAS due to injection of typical Lake Okeechobee surface water during ASR, (2) science-based information to inform decisionmakers on how to proceed with future ASR feasibility and field studies, and (3) a modeling framework to inform design of future ASR investigations and interpret their results. Given the number and complexity of these goals, a multi-year effort will be required. Five main tasks are envisioned as follows: 1) Task A: Collection of core material for laboratory investigations; 2) Task B: Batch and small-scale column studies to characterize arsenic speciation and distribution within FAS aquifer material and geochemical reactions that occur when FAS aquifer material is exposed to representative surface water; 3) Task C: Intermediate-scale reactive transport studies for quantifying arsenic speciation and distribution, and reactions within FAS aquifer material under ASR-representative conditions; 4) Task D: Development of a calibrated and validated reactive transport groundwater model capable of simulating field-scale ASR injections and associated changes in groundwater quality during storage over time; 5) Task E: Surface water treatment characterization.

These tasks are inter-related and dependent (**Figure 10-1**). Tasks B and C are designed to characterize arsenic-associated biogeochemical reactions (and associated reaction kinetics) that can be expected to occur within relevant zones of the FAS during ASR at the cm scale under potential pre-treatment regimes. Studies described below focus on locations within the two key zones of the FAS targeted for ASR storage: UFA and APPZ. The laboratory investigations proposed in Tasks B and C require: a) subsurface (core) material from the UFA and APPZ, b) groundwater from the UFA and APPZ, and c) physical samples of surface water that reflect the expected composition of treated water that will be injected into the FAS during ASR. The goal of Task A is to obtain the necessary subsurface core material and groundwater for Tasks B and C. Task E will develop a pilot system to evaluate proposed surface water treatment strategies and provide water samples for the batch and column studies in Tasks B and C. Results of the cm-scale analysis and parameterizations obtained from Tasks B and C will be integrated with available aquifer data and used in Task D to develop a reactive transport model, which can then be used to simulate 1) impacts of subsurface heterogeneity on ASR performance, and 2) fate and transport dynamics over operational space and time scales. This ability to track arsenic fate and transport will provide the basis for assessing how strategies designed to prevent mobilization of arsenic and other constituents of concern will perform across a well field over time.

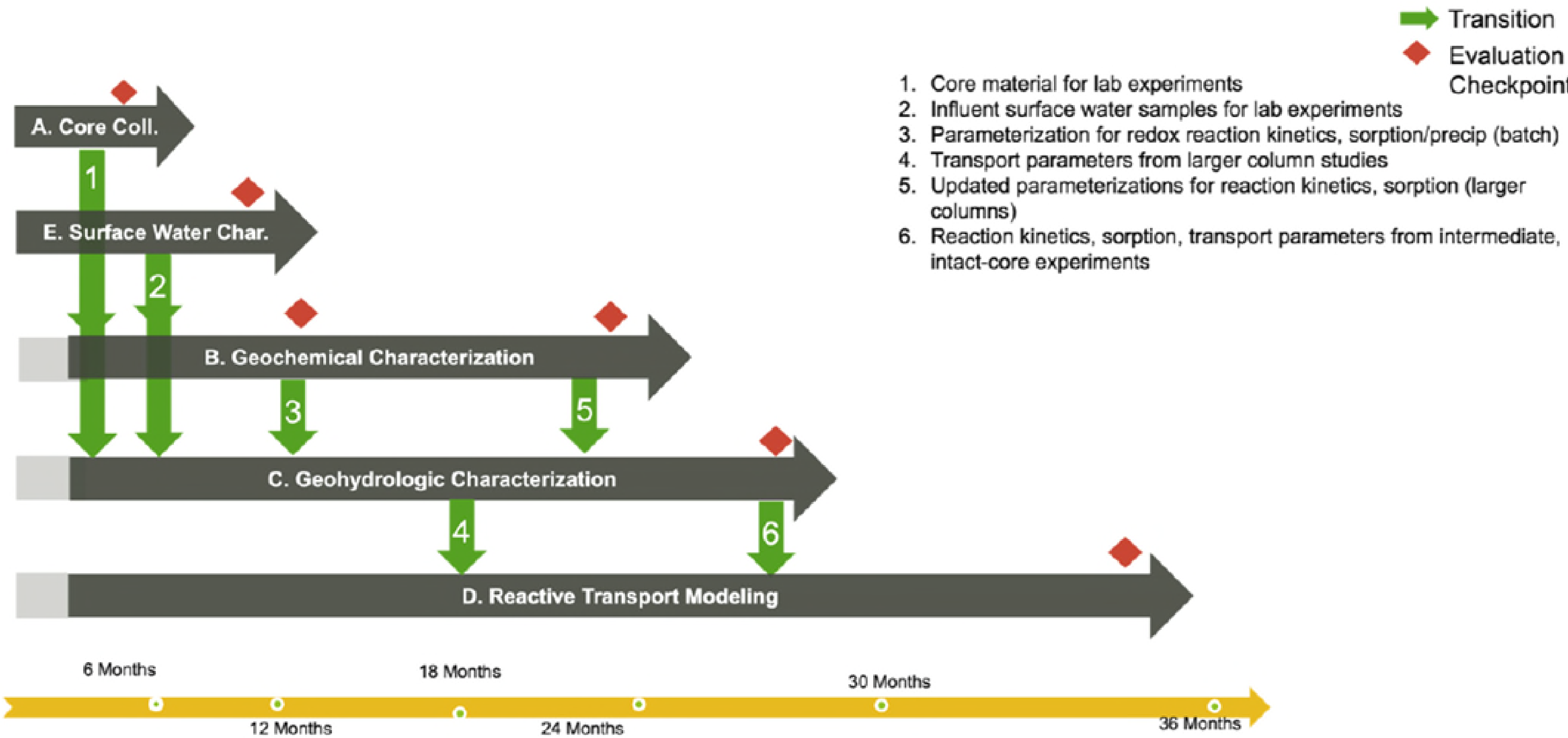

Figure 10-1. Timing and Dependencies for the proposed ERDC Tasks.

The proposed ERDC activities are underway, and some tasks and subtasks have been completed since the CRADA was executed. The tasks completed include:

- Preparation of a Work Plan has been completed. In order to develop a plan, ERDC and SFWMD conduced multiple workshops to develop a research plan, which also included subject matter experts from multiple agencies and consultants
- Core collection, preservation, preliminary and documentation for both the UFA and APPZ aquifers
- Design, purchase equipment, and assembly of a flow test pilot treatment skid

There are no scientific data or reports to share from ERDC since the CRADA is in the preliminary phase. This Chapter will be updated in future versions of the ASR Science Plan as the ERDC studies progress.

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