2022 Aquifer Storage and Recovery SCIENCE PLAN

DRAFT – OCTOBER 2022

Mechanical Integrity Test at L63N

Test/Exploratory Well Drilling at C38S

Proof of Concept Testing Kissimmee River ASR Well

L63N Continuous Coring Program Samples

500 – 510 feet bls

1,800 – 1,810 feet bls

PREFACE

The South Florida Water Management District (SFWMD) and United States Army Corps of Engineers (USACE) prepared this 2022 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. This 2022 ASR Science Plan shall serve as an update to the inaugural 2021 ASR Science Plan. 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 identified the potential use of ASR technology as a means of storing water in aquifers for later use. Acknowledging this unprecedented 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 (Kissimmee River) were published in 2013 (CERP ASR Pilot Project Technical Data Report) and 2015 (CERP ASR Regional Study Final Report). The investigations determined that 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 continued 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. While many design aspects have changed during the PIR/EIS review process, the ASR component of the plan remains the same. 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 Draft Revised 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 annually or as needed as the ASR program is implemented, and as data and science become available. The 2022 ASR Science Plans was developed with guidance from an independent ASR peer-review panel of eminent scholars and scientists. The document provides the plan of studies and investigations that will take place as the ASR program moves forward. The ASR Science Plan will be reviewed annually by the peer-review panel, to be kept apprised of the investigations' findings and to assist in developing future studies that ensure ASR technology is implemented in a science-based, 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 the development of this 2022 ASR Science Plan. This document was developed 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 by means of 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 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. In order 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 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, 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 scientists. The PRP will meet annually to review the investigations' findings and provide guidance on additional studies. The ASR Science Plan is intended to be a living document, updated annually or as needed based on the best 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.

The inaugural ASR Science Plan was published in 2021. This updated 2022 ASR Science 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 2022 ASR Science Plan are intended to be conducted at ASR locations identified in the 2022 LOWRP Integrated Project Implementation Report and Environmental Impact Statement, 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 Kissimmee River (C-38 Canal). The implementation schedule for the ASR component of LOWRP is the result of state legislative appropriations totaling $450 million for the design, engineering, and construction of ASR well clusters.

During development of the 2021 ASR Science Plan, the PRP provided guidance and suggestions on how to complete the following: 1) Evaluate stakeholder concerns about ASR implementation at the scale envisioned by LOWRP; and 2) Address uncertainties regarding ASR technology as highlighted by the NRC in 2015. In October 2020, the PRP provided a report of suggestions to integrate into the initial version of the ASR Science Plan. In June 2022, the PRP reviewed the progress of scientific investigations conducted since the 2020 review and described in the draft 2022 ASR Science Plan and provided report that includes comments and recommendations on the ongoing and future studies.

The studies included in the 2022 ASR Science Plan are organized according to the main topics of the 2015 NRC report.

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), Morpho, 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 2022 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 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 and will be coupled with future groundwater and wellfield design modeling.

Ecotoxicology and Ecological Risk Assessment (Chapter 7). The NRC recommended additional chronic toxicity and bioconcentration tests on selected species during extended storage and recovery 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. Evaluation of community-level effects and conducting quantitative ecological risk assessment (ERA) using a more refined, probabilistic methods was also recommended.

The ASR Science Plan includes a description of the ERA scope of work, quantitative ERA performed on the historical toxicology and bioaccumulation data, and a plan for completing the ERA Work Plan and quantitative final ASR ERA. This chapter also provides a description of the mobile lab design for future bench-scale bioaccumulation tests, 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 and presence of undesirable constituents in recovered water. The use of the 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 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.

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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
BLS	below land surface
CERP	Comprehensive Everglades Restoration Plan
CFR	Code of Federal Regulations
DASR	Data Access Storage and Retrieval
DM	data management
EML	Ecological Metadata Language
ERA	ecological risk assessment
FAS	Floridan aquifer system
FDEP	Florida Department of Environmental Protection
FGCU	Florida Gulf Coast University
ICU	Injection Control Unit
KRASR	Kissimmee River aquifer storage and recovery (site)
LOWRP	Lake Okeechobee Watershed Restoration Project
mg/L	milligrams per liter
NRC	National Research Council
ORP	Oxidation Reduction Potential
PIR/EIS	Project Implementation Report/Environmental Impact Statement
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
SAS	Surficial Aquifer Study
SAV	Submerged Aquatic Vegetation
SFWMD	South Florida Water Management District
SOP	Standard Operating Procedure
TDS	Total Dissolved Solids

UFA	Upper Floridan aquifer
UIC	Underground Injection Control
USACE	United States Army Corps of Engineers
USGS	United States Geological Survey
VSP	Vertical Seismic Profile

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 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. A full list of the scientific milestones, reports, and technical publications generated from the SFWMD and USACE ASR Regional Study projects is included in the **Appendix A**.

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 Aquifer Storage and Recovery (KRASR) site. 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 identify potential plans of study to address the remaining uncertainties from the NRC (2015) review as ASR wells are constructed in a phased approach.

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 $150 million 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. The current budget for the LOWRP is $450 million. 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 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), pre-operational environmental monitoring along the C-38 Canal and northern Lake Okeechobee, design of mobile laboratory for bench-scale chronic and acute toxicity and bioaccumulation studies, and quantitative ecological risk assessment scope of work and work plan.

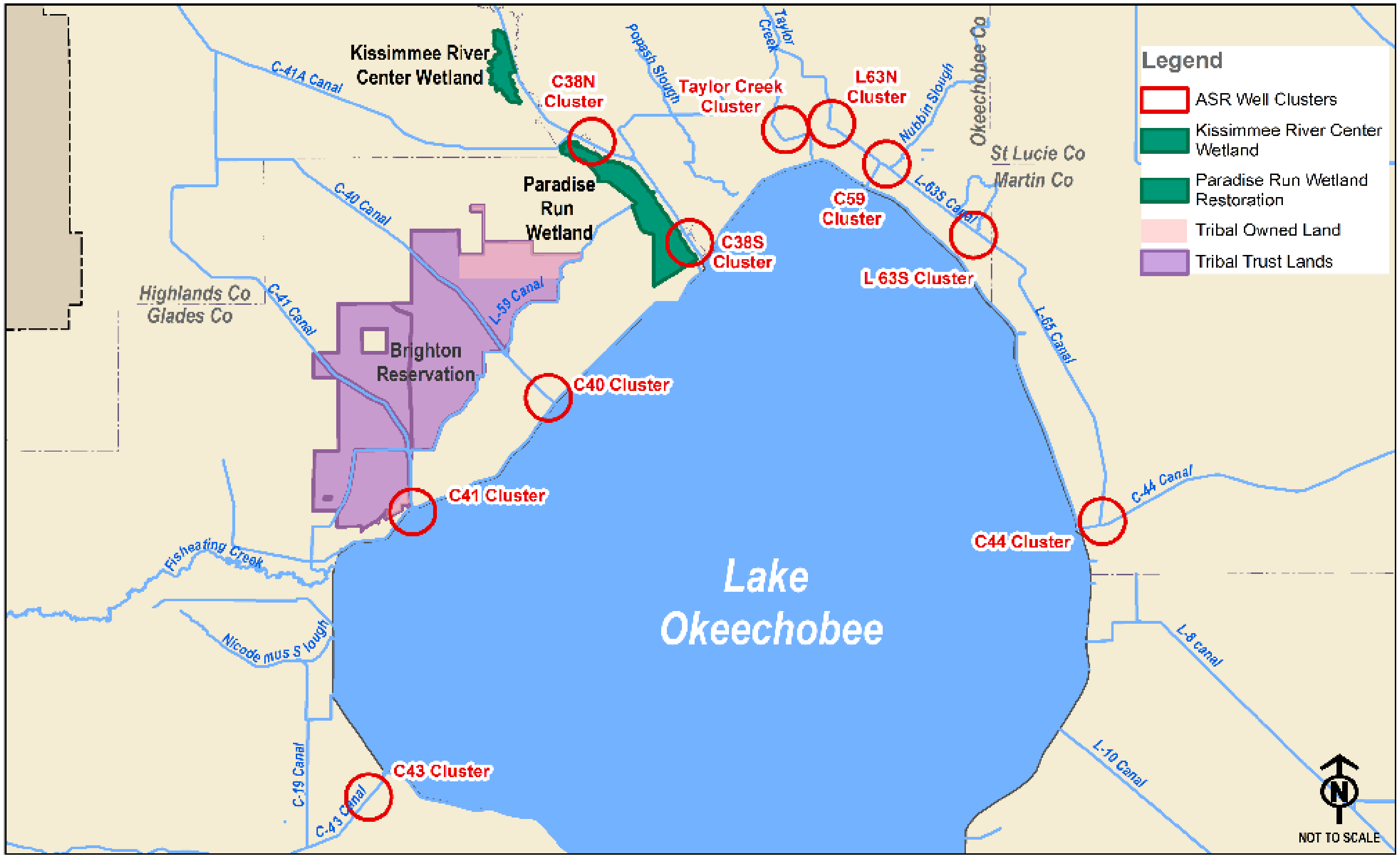

Figure 1-1. Lake Okeechobee Watershed Restoration Project Recommended Plan features

1.5 2022 INDEPENDENT PEER-REVIEW SCIENCE PANEL

An independent panel of scientists was assembled to review the phased approach of ASR construction and review the progress of scientific investigations outlined in the 2021 ASR Science Plan to address the technical uncertainties identified in the NRC (2015) review. The independent ASR peer-review panel (PRP) includes the following members:

- Thomas Missimer, Ph.D., P.G., Professor and Director of the Emergent Technologies Institute, Florida Gulf Coast University
- Reid Hyle, Fish and Wildlife Research Institute, Florida Fish and Wildlife Conservation Commission
- Rene Price, Ph.D., P.G., Professor and Chair, Department of Earth and Environment, Florida International University
- John Carriger, Ph.D., Research Toxicologist, National Risk Management Research Laboratory, United States Environmental Protection Agency

A 2-day PRP technical workshop was conducted on June 15 and 16, 2022 to review the progress of ASR studies conducted over the past year. The PRP subsequently published a final report of recommended future tasks based on the results of scientific investigations presented at the PRP technical workshop (Missimer et al., 2022; **Appendix B**).

The PRP will convene annually throughout implementation of the ASR program to review the progress of the scientific investigations contained in the 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. The 2022 ASR Science Plan describes the progress of scientific investigations conducted over the past years 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 and the Florida Department of Environmental Protection (FDEP). The ASR Science Plan is intended to be a living document, updated annually based on the best 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. During 2021, two continuous cores were collected at the C-38S and L-63N cluster locations. The cores provided important lithologic and fracture data from the FAS, where ASR wells are proposed to be completed. Portions of the cores were examined for geotechnical properties and mineralogy, and they will now be incorporated into USGS experiments for microbial activity and bioclogging.

While continuous cores are collected and exploratory wells are constructed, there is benefit from reactivating the existing ASR systems along the Kissimmee River (KRASR) and L-63N Canal. Both systems provided information about ASR performance in the Upper Floridan aquifer (UFA) and the Avon Park permeable zone (APPZ). If successfully reactivated, the KRASR can be used to continue chronic toxicity and bioaccumulations tests, and ecological, and nutrient reduction studies on recovered water. The

L-63N ASR well is completed in the APPZ and is permitted with an aquifer exemption; this allows for evaluation of ASR without a disinfection treatment process, which can provide assessment of microbial inactivation during storage. 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 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 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 ecosystem and in downstream Everglades communities. 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 the 2022 ASR Science Plan describe progress on the scientific investigations that have been initiated during 2021-2022, 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 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. Subsequent chapters include a summary of remaining uncertainties identified by the NRC, the 2020 PRP recommendations (Arthur et al. 2020), the progress on work completed over the past year, and ongoing and future work that is performed or will be performed to address the NRC uncertainties. Several chapters end with a summary of the 2022 PRP recommendations (Missimer et al. 2022) 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. **Figure 2-1** and **Figure 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 for mineralogic and geotechnical analyses
- Completed initial pre-treatment technology evaluation
- Developed a programmatic quality assurance plan (PQAP)
- 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
- Permit/procured exploratory well construction at C-38S and C-38N
- Continued repair and refurbish of the KRASR facility
- Evaluated the existing L-63N ASR system for reactivation
- Initiated construction of exploratory ASR and monitoring wells at C-38S and C-38N

2022-2023

- Perform 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
- Initiate cycle testing at the KRASR system if feasible
- Collect continuous cores at C-38S and L-63S locations
- Continue core analysis for mineralogic and geotechnical properties
- Initiate continuous core and monitoring well construction at C-40/C-41
- Complete a hydraulic model for C-40/C-41 preliminary design
- Continue construction of exploratory ASR and monitoring wells at C-38S and C-38N
- Design and permitting of exploratory ASR and monitoring wells at L-63N
- Initiate construction of exploratory ASR and monitoring wells at L-63N
- Initiate the design and permitting of surface facilities/treatment systems at C-38N and C-38S
- Perform exploratory geochemical modeling
- Complete a Work Plan for completing ERA
- Initiate pre-operational monitoring along the C-38 Canal and northern Lake Okeechobee
- Initiate acute and chronic toxicity and bioaccumulation experiments at C-38 N and S well locations
- Initiate long-term ecological monitoring along the C-38 Canal and northern Lake Okeechobee during cycle testing
- Complete mixing zone geochemical modeling
- Complete a survey of radium isotopes in UFA and APPZ in south Florida from existing data
- Conduct seismic geophysical surveys at C-44, C-40 and C-41
- Complete aquifer performance tests at C-38S and C-38N
- Develop a sub-regional groundwater flow and solute transport model for the C-38S and C-38N ASR systems

2023-2024

- Intermediate design of surface facilities/treatment systems at initialcluster locations
- Continue construction of ASR and monitoring wells at C-38S and C-38N
- Initiate construction of two new multi-well clusters at C-38S and C-38N
- Continue construction of ASR and monitoring wells at L-63N
- Perform subregional groundwater flow and solute transport modeling at new ASR cluster sites
- Initiate construction at the L-63N ASR system
- Develop cycle testing and groundwater monitoring plans for C-38S and C-38N ASR systems
- Initiate more detailed geochemical modeling effort
- Use the Lake Okeechobee Environment Model to initiate risk assessment
- Complete USGS study of pathogen inactivation and nutrient reduction/well clogging
- Complete pre-operation ecological monitoring along the C-38 Canal and northern Lake Okeechobee
- Continue long-term ecological monitoring along the C-38 Canal and northern Lake Okeechobee
- Continue chronic toxicity and bioaccumulation experiments at the C-38 and other ASR cluster locations

2024-2026

- 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-38N and C-38S

- Initiate cycle testing of multi-well clusters at C-38S and C-38N
- Conduct recovered water mesocosm tests at C-38S and C-38N cluster locations
- Perform a regional groundwater flow and solute transport model evaluation
- Finalize quantitative environmental risk assessment
- Complete long-term ecological and bioaccumulation studies in support of ERA
- Complete chronic toxicity and bioaccumulation experiments at different ASR cluster locations
- Initiate and complete mesocosm experimental studies in support of ERA
- Complete regional ASR ERA

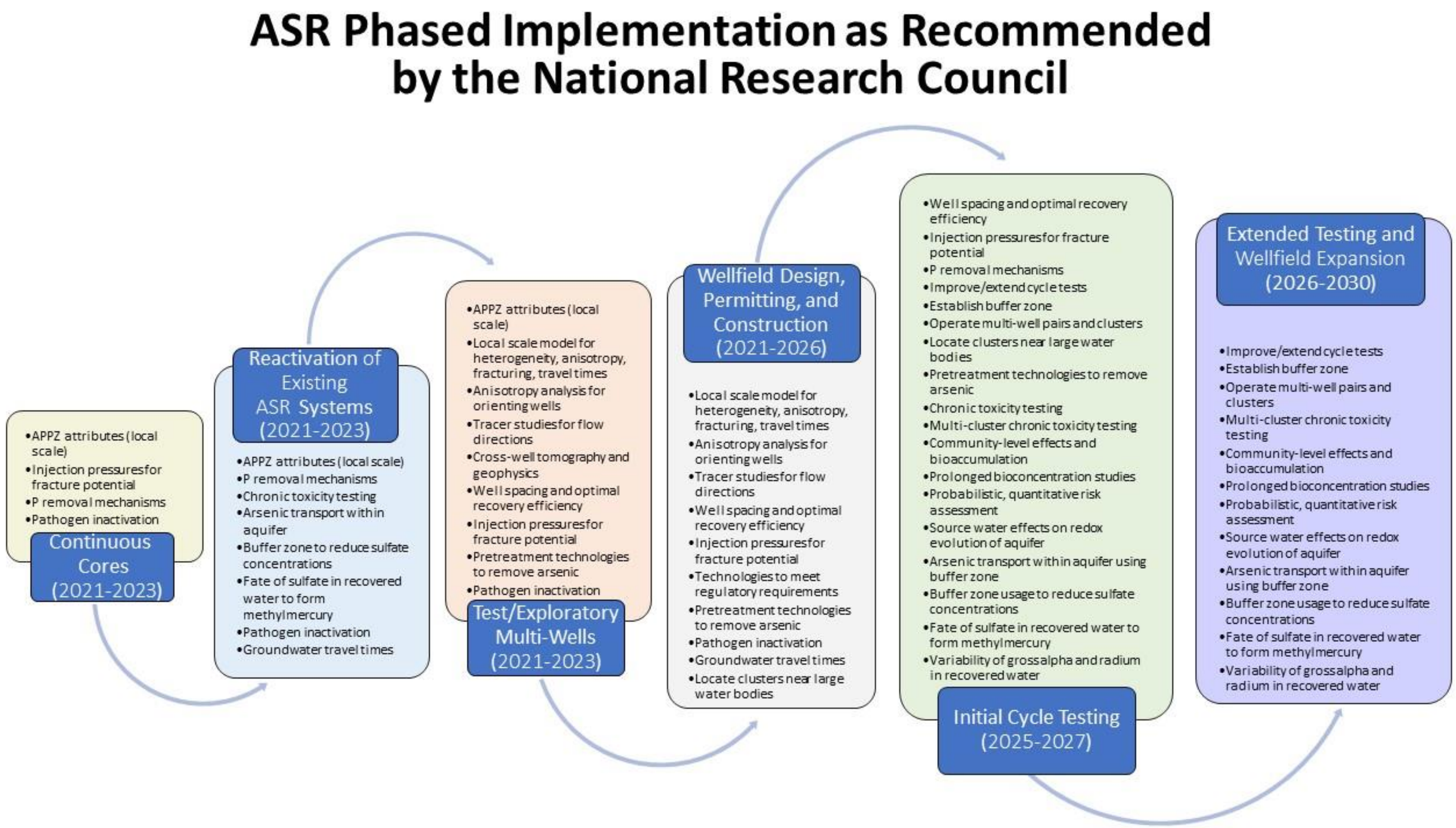

Figure 2-1. Phases of ASR project progression and proposed studies to address National Research Council comments

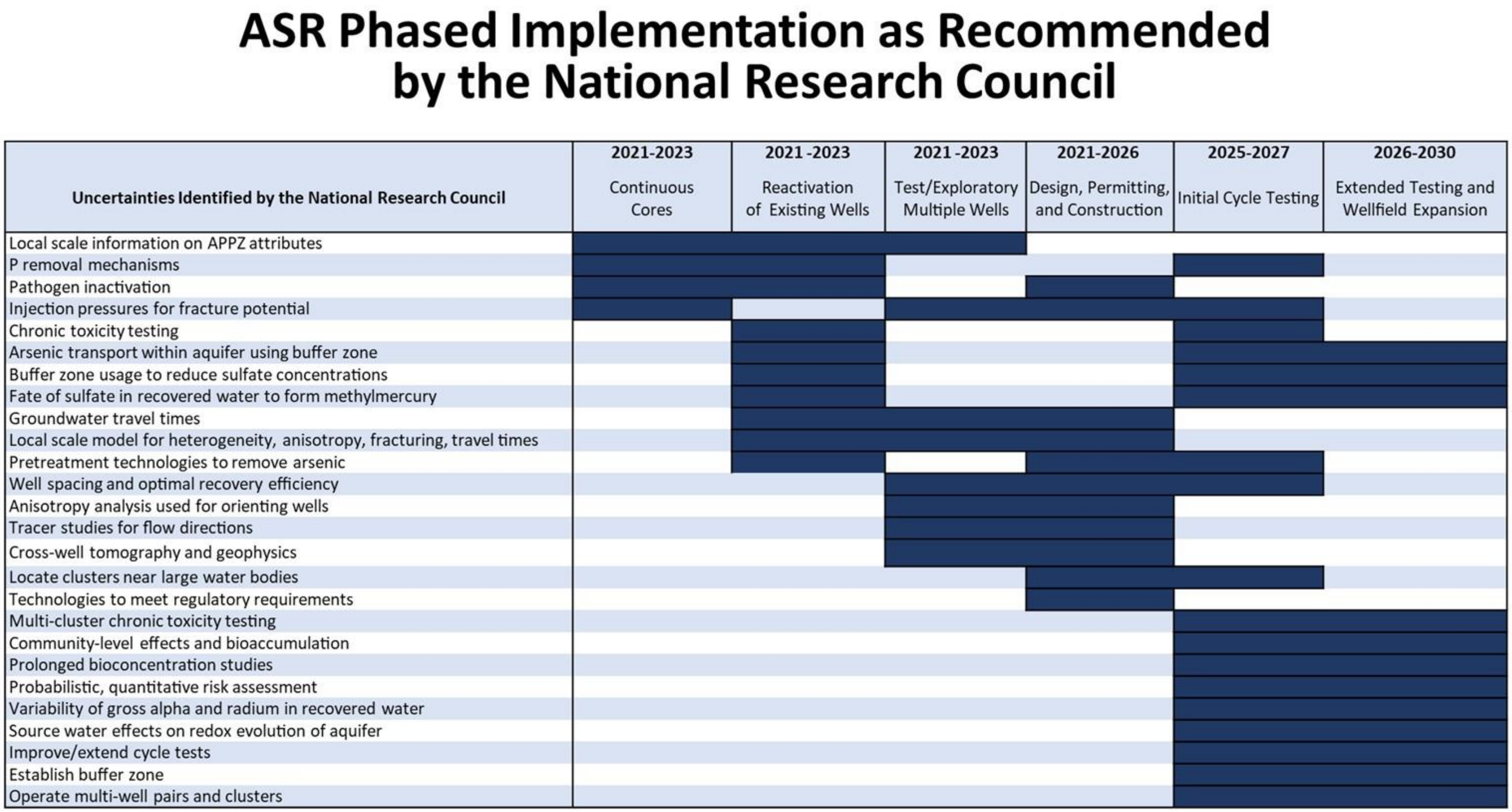

Figure 2-2. Proposed studies to address National Research Council comments during various phases of ASR implementation

2.3 PROJECT REPORTING: ASR REPORT CARD

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

2022 ASR Science Plan 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 atributes of APPZ										
Research Phosphorus removal mechanisms										
Reseach pathogen inactivation in the aquifer										
Couple pathogen inactivation with groundwater travel times	*									
Analysis of injection pressures for fracture potential	*									
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 remove arsenic										
Analysis of wellfield cluster for spacing and optimal recovery efficiency	*									
Anisotropy analysis used for orienting wells										
Tracer studies for flow directions										
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, including examining 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										
Construct and operate a single low-capacity water treatment plant to evaluate the tretament technology and costs involved in meeting drinking water standards at the wellhead										

Figure 2-3. 2022 ASR Science Plan report card

Note: Yellow-colored cells indicate work progress in 2021, green-colored cells indicate work progress in 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 linked to the progress on wells construction, and operational and permitting status (some of the studies and tests cannot begin until 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; Morpho, 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 Morpho/Metacat packages accessible through DataOne (**Figure 2-4**).

- Morpho/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 catlog 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.

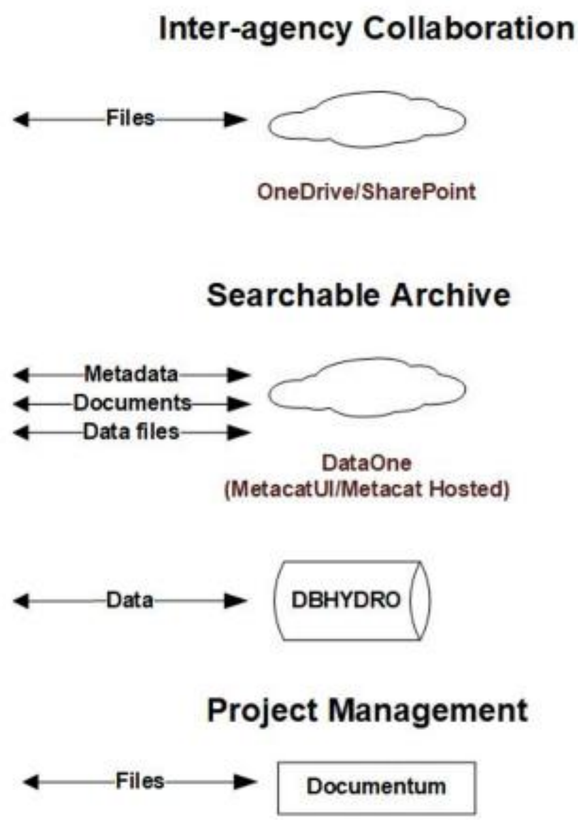

Figure 2-4. Data management tools to be used for ASR project data

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 2022) 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 approaches 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 Code of Federal Regulations (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. The ASR PQAP is included as **Appendix C** in this 2022 Science Plan.

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 FAS 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.

Progress Since Last Year

The APPZ is situated in the middle of the FAS and has been identified in LOWRP as a high-potential zone for subsurface water storage. To date, two of the five coreholes have been completed (L63N, and C38S). The third corehole is underway (L63S). Approval for the C40/C41 and C59 coreholes is pending. Markers are being placed in boxes where there are gaps in the recovered cores and thin sections will be archived with the Florida Geological Survey in Tallahassee.

Florida Gulf Coast University (FGCU) was contracted in 2021 to measure major and selected trace element concentrations in continuous cores, focusing on proposed ASR storage zones. These x-ray fluorescence data complement the mineralogical analyses of discrete samples (above) and provided insight on the occurrence of metal-rich zones within the Ocala Limestone and Avon Park Formations. The L-63N continuous core was transported to FGCU in 2021. A report of investigations was provided in September 2022 (**Appendix D**).

Rock Fracturing Analysis: The USGS (Davie, Florida) was contracted to interpret continuous cores from L-63N, L-63S, and C-38S sites to characterize the mineralogy, porosity, fractures, and sedimentary fabrics of continuous core samples. Initial analysis of fracture and rock fabric will be based on a synthesis of hand sample observations, optical borehole imagery, and geophysical logs. Continuous core samples from the L-63N site were transferred to the USGS for preparation and laboratory analysis in 2022. A draft report of investigations was provided in September 2022 and is under review at this time.

Ongoing and Future Studies

Borehole and Continuous Core Analyses (2021-2023)

An extensive hydrogeologic data collection program has been initiated at the L-63N, L-63S, C-59, C-38S and C40/C41 sites. As continuous cores are obtained, exploratory boreholes are completed as monitoring wells. The standard suite of geophysical logs (gamma-ray, caliper, resistivity, sonic, and temperature) and Optical Borehole Imagery are run as each portion of the borehole is completed prior to casing installation.

Groundwater Quality Characterization: During continuous coring, packer testing and groundwater quality sampling is performed at 30-ft intervals (below 500 ft bls) to clearly characterize groundwater quality variations with depth. Packer test samples are analyzed for the following constituents:

- 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 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, Non-carbonate Hardness, Total Organic Carbon, Total Dissolved Sulfide, Corrosivity, Cyanide
- Nutrients: Total Phosphorus, ortho-Phosphate, Total Nitrogen (calculated), Nitrate plus Nitrite, Ammonia, Total Kjeldahl Nitrogen
- Stable and Radioactive Isotopes: Deuterium, Oxygen-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
- Microbiologicals: *Cryptosporidium*, *Giardia lamblia*, *Escherichia coli*, Enteric viruses, Fecal Coliform, Total Coliforms, Heterotrophic Plate Count
- Mineralogic Characterization: Discrete core samples from the UFA and APPZ will be 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 C38S continuous core were selected and submitted for analysis in June 2022. The mineralogic report from the C38S continuous cores are included in **Appendix B.**

FGCU is preparing a proposal for analysis of the second corehole (C38S). A work order will be issued once the next statement of work has been approved. Well design may be modified based on the thickness and vertical extent of permeable zones of the APPZ in order to avoid potential groundwater quality issues between recharge water and lithologies showing high metal concentrations.

Reactivation of the L-63N ASR System (2022-2023)

Until recently, the L-63N ASR well completed in the APPZ had been inactive for more than 30 years. A design evaluation is under way to put the ASR well back into service after having successfully completed the mechanical integrity test in 2020. Because this well was completed in the APPZ, it provides a local assessment of the attributes and efficiency of surface water storage in that zone. Plans are also under way to add additional ASR wells at this site. A continuous core was obtained near the existing ASR well to characterize permeability, porosity, mineralogy, and geochemical composition in preparation for design of an expanded wellfield.

2022 Peer-Review Panel Guidance

The following guidance was provided by the PRP in its 2022 report (Missimer et al. 2022, 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 PRP believes that this information is very useful in terms of characterizing the geology, groundwater hydraulics, and water quality of the specific sites. The PRP recommends that all five sites be completed and the cores should be archived for future scientific studies by researchers.

It was observed by the PRP 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 PRP 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 PRP 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 designs, 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 1,300 ft in core L63N, 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 PRP believes that the geochemical properties of the core material measured using a hand-held XRF unit at Florida Gulf Coast University 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.

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.

Progress Since Last Year

A phased implementation of groundwater flow and solute transport modeling is planned for ASR clusters. Scoping is currently under way for development of a local-scale groundwater model near the sites of the C-38N and C-38S exploratory wells and will incorporate results of aquifer performance tests to be performed in early 2023. The groundwater model will integrate data from the nearby KRASR system to facilitate the design of multi-well wellfields at both locations. The local-scale groundwater model will also be utilized to assess the effects of aquifer heterogeneity, anisotropy, travel times, and fracture potential.

Ongoing and Future Studies

Aquifer Performance Testing at the C-38S Site (2022)

The detailed configuration of the exploratory wells and additional monitoring well locations at C-38S and C-38N are presented in **Figure 3-1** and **Figure 3-2**, respectively. After ASR and associated monitoring well construction is completed at each ASR cluster, APTs will be conducted. The first APT is scheduled to be performed at the C-38S site in January 2023. The C-38S wellfield will consist of two (2) 24-inch diameter ASR wells, one each completed in the UFA and APPZ. Currently there are four monitoring wells open to the UFA, including existing monitoring wells at the KRASR. A new surficial aquifer system (SAS) monitoring well will be constructed at the C-38S site to supplement an existing SAS well at KRASR (OKS-100). Additional APTs will be conducted at each ASR system location after the wellfield construction is completed.

The testing protocols at the C-38S wellfield will include the following tests:

- 5-day constant rate APT on the newly constructed UFA ASR well
- 5-day constant rate APT on the newly constructed APPZ ASR well
- 5-day constant rate APT on both the UFA and APPZ ASR wells
- 5-day constant rate test using natural artesian well flow from UFA and APPZ wells simultaneously

For each of the aforementioned APTs, all existing ASR and monitor wells onsite will be equipped with data loggers and transducers so that water levels are recorded and evaluated to determine the effects of pumping. Background water levels and barometric pressures will be recorded to remove natural variability (e.g., diurnal, semi-diurnal, etc.) to facilitate analysis. Recovered water quality constituents (TDS, temperature, pH, specific conductance and turbidity) will be measured throughout each APT. After the tests are completed, groundwater samples will be analyzed for primary and secondary drinking water standards.

Local-scale Groundwater Flow and Solute Transport Model Development for C-38N and C-38S (2022-2023)

Scoping and development of a local-scale groundwater flow and solute transport model was initiated in August 2022 for a domain that includes the C-38N and C-38S ASR system locations. Models will be developed using the SEAWAT code. SEAWAT is a finite difference code to simulate three-dimensional (3D) variable-density groundwater flow and solute transport. SEAWAT was used previously for the ASR Regional Study and KRASR model simulations and these model files will serve as a basis for the model development. APT results from the C-38S, and eventually the C-38N sites will be incorporated into this model. Testing scenarios are in development, but hydrologic issues such as interference effects from multiple active ASR wells, combined drawdown and head buildup effects, and solute transport between UFA and APPZ will be considered. Additionally, hydrogeologists will use the model to determine the appropriate distances between ASR wells and monitoring wells, which will affect decisions on pump sizes, piping, and treatment facilities. The model also may simulate the effectiveness of a buffer zone to maximize recovery efficiency and prevent recovery of undesirable groundwater constituents.

Multi-scale Groundwater Flow and Transport Model Development (2023-2025)

At this time, three phases of groundwater modeling are anticipated as the ASR program progresses:

- An early, local-scale model will be used by design engineers to determine individual multi-wellfield size, well depth, spacing, monitoring well placement, pumping, treatment, and expansion components.
- After individual wellfield clusters are designed, a sub-regional model evaluation will be conducted to determine the impacts that nearby well clusters might have on each other and on existing legal users.

After completion of exploratory wells at each proposed cluster location identified in LOWRP (**Figure 1-1**), a revised regional groundwater model will be used, updating the model prepared during the CERP ASR Regional Study.

2022 Peer-Review Panel Guidance

The following guidance was provided by the PRP in its 2022 report (Missimer et al. 2022; SFWMD and USACE 202, **Appendix B**).

The PRP 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 Injection Control Unit (ICU) and UFA layers on Table 6-1*. Also, the PRP 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.

*Table 6-1 - PRP referred to the Table included in one of the presentations during the PRP public workshop.

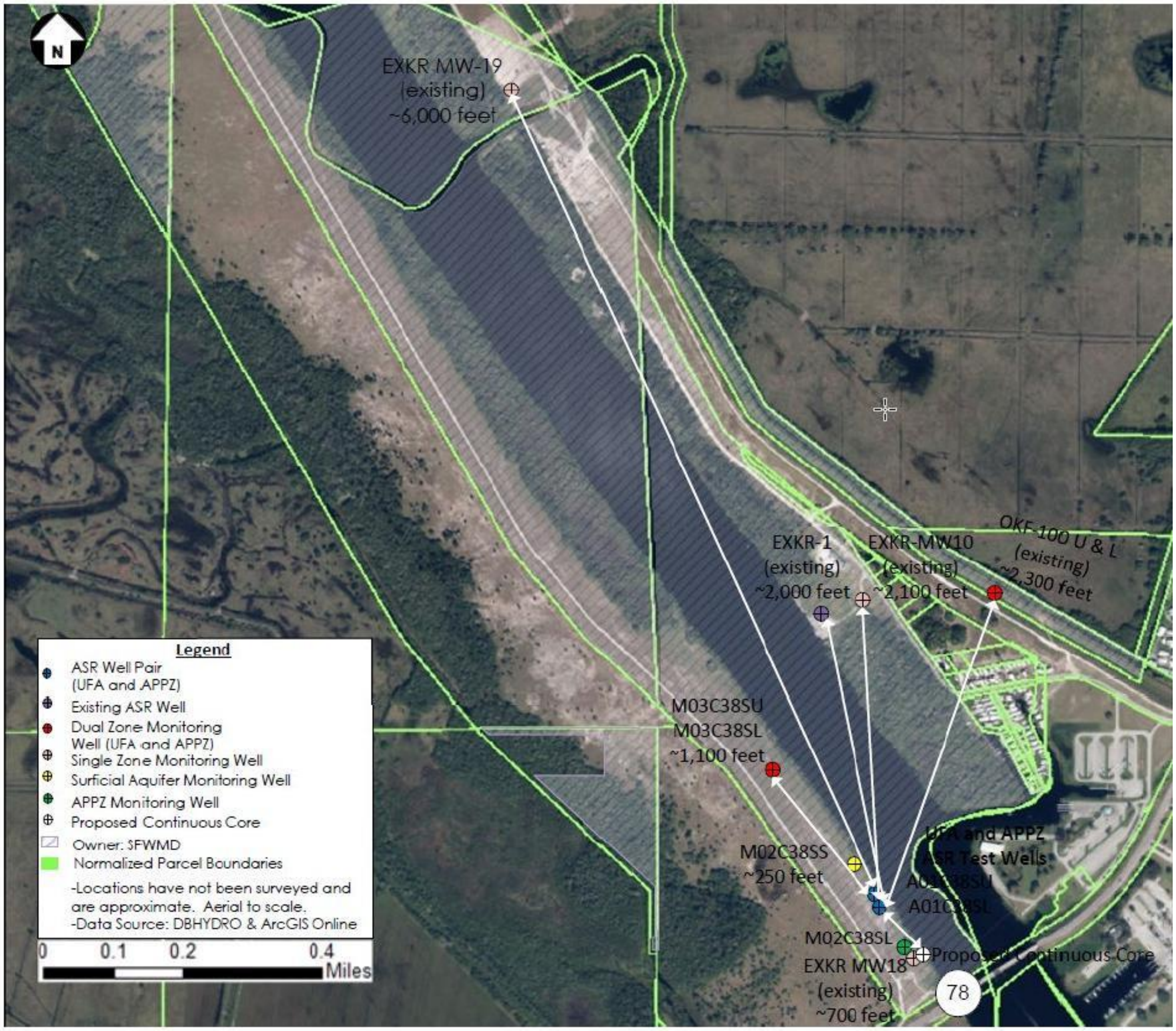

Figure 3-1. C-38S ASR test well and monitoring well layout

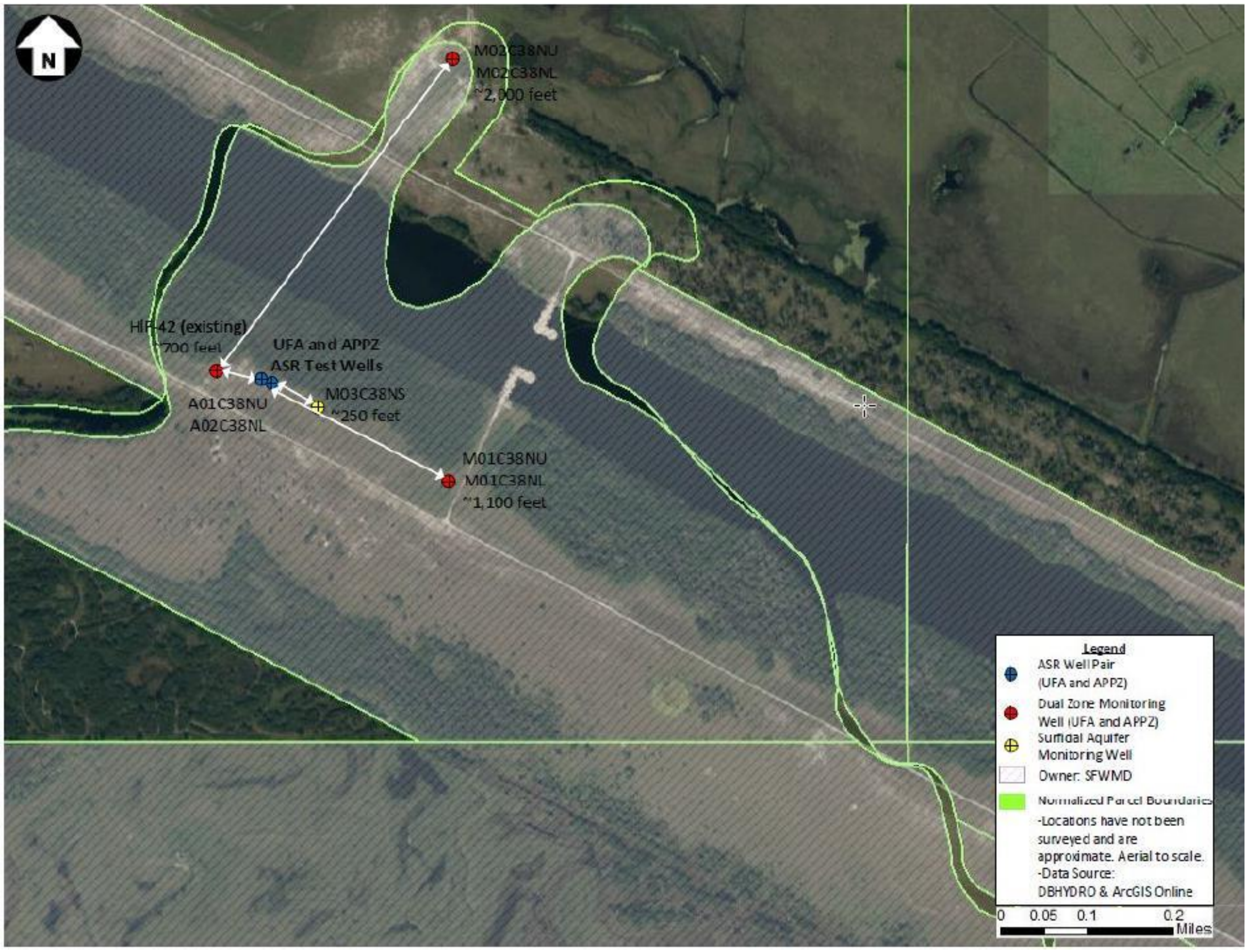

Figure 3-2. C-38N ASR test well and monitoring well layout

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 Last Year

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 develop 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 2023, 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 Last Year

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

Ongoing and Future Studies

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

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 comprise pumping out of the test wells or injecting into the wells for a brief period of time, depending on regulatory approval. Detailed scoping of the tracer testing methodology has not yet been undertaken.

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

Local-scale wellfield groundwater modeling will be performed during the preliminary design phase. This will inform planning efforts for tracer testing.

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, two-dimensional (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 Last Year

Scoping is currently under way for conducting 2D seismic surveys at ASR cluster locations where little hydrogeologic data are currently available, as a mean of providing reconnaissance information prior to well construction.

Ongoing and Future Studies

Land-based Seismic Geophysical Surveys (2022-2023)

Seismic surveys may be extended north of the previous survey areas, toward the proposed C-38N well cluster, and at other sites under consideration for well clusters. Seismic surveys would be useful for comparative analyses between the well clusters. After cycle testing is conducted on the C-38S and C-38N clusters, the surveys may help determine optimal structural aspects of future cluster sites under consideration. Scoping is under way for conducting land-based seismic surveys at additional well clusters, for comparative and reconnaissance purposes.

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 Last Year

The ASR pilot facilities constructed to date have been single well systems. Construction of well pairs is currently under way at the C-38N and C-38S locations. Upon completion of the well pairs (2022) and evaluation of the local-scale groundwater model, design evaluations will be undertaken to add additional ASR well pairs to each location.

Ongoing and Future Studies

Design Studies at C-38S and C-38N (2022-2023)

Analysis of optimal wellfield cluster configurations will be accomplished through local-scale wellfield groundwater flow and solute transport simulations. At C-38S and C-38N locations, it is likely that ASR well pairs (UFA/APPZ) will have a linear alignment due to real estate constraints (locations between the levee and the Kissimmee River), and to avoid impact to sensitive wetland environments at Paradise Run (C-38N). Additional design flexibility may be acceptable at the L-63S, C-59, and C-40/C-41 locations to evaluate other potential ASR well arrangements. Local-scale groundwater flow and transport model simulations at these locations will inform the wellfield design.

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 Last Year

Analysis for hydraulic pressure effects caused by recharge (injection) or recovery will be undertaken upon completion of the exploratory wells at C-38S and C-38N as discussed below. In order to obtain a better understanding of in-situ pressures at the UFA and APPZ storage zones, pressure transducers may be positioned at depth in monitoring wells.

Ongoing and Future Studies

Exploratory Well Testing at C-38S and C-38N (2022)

Hydraulic testing of the well pairs at C-38S and C-38N will include APTs of the UFA and APPZ wells individually and in tandem. These tests will provide hydrologic parameters for the interaction of the strata above, below, and between the wells and will inform the development of the local-scale groundwater model. Use of 100 pounds per square inch as a conservative limit for recharge (injection) pressure at individual ASR wells is sufficient for modeling purposes. The local-scale model at C-38S will incorporate pressure data measured at the depth in the UFA storage zone (585 ft bls) at monitor well EXKR-MW18 (now the UFA storage zone monitoring well at C-38S). Application of additional geophysical methods to evaluate potential rock fracturing is currently under investigation.

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 is not anticipated to be a significant process based on the kinetics of the aquifer environment. Also, 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 Last Year

A scope of work was developed for the USGS to conduct flow-through column experiments using portions of the continuous cores to document rates of native biofilm response to nutrient-laden surface water. 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. To date, the flow-through columns and testing equipment has been developed and is awaiting deployment to the KRASR project field office. It is anticipated that these experiments will be under way by late 2022.

Ongoing and Future Studies

<u>US Geological Survey Bioclogging Experiments (2022-2023)</u>

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 (2023)

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.

Pre-Operational Surface Water Monitoring in the C-38 Canal (2023-2024)

In preparation for the ERA of the C-38 Canal prior to ASR system operations, surface water, biological tissues, sediment, and periphyton samples will be collected and analyzed at different frequencies during 2022-2023. Surface water quality samples will be collected bimonthly (n=6 events) and analyzed for the following analytes:

- Nutrients: Total Nitrogen, Total Phosphorus
- Metals: Aluminum, Antimony, Arsenic, Cadmium, Chromium, Total Mercury, Methyl Mercury, Molybdenum, Nickel, Selenium, Zinc
- Major Inorganic and Organic Constituents: Sulfate, Alkalinity, Calcium, Magnesium, Total Organic Carbon (including molybdenum)

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 Last Year

This uncertainty will be addressed when the initial well clusters 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 previously conducted well siting and constructability analyses on the proposed C-38S and C-38N cluster locations. The evaluations indicated that future ASR wells most likely will be oriented in a relatively narrow, linear pattern within limited rights-of-way along canals owned by the state (**Figure 5-1** and **Figure 5-2**). The limited available land at these sites will not allow construction of wellfields in patterns of triangles or double lines. However, use of the local-scale groundwater model (2022-2023) may allow simulation of aquifer storage, transfer, and recovery. Characterization of the hydraulic extent of interactions between the UFA and the APPZ is a primary objective of aquifer performance testing and groundwater model simulations.

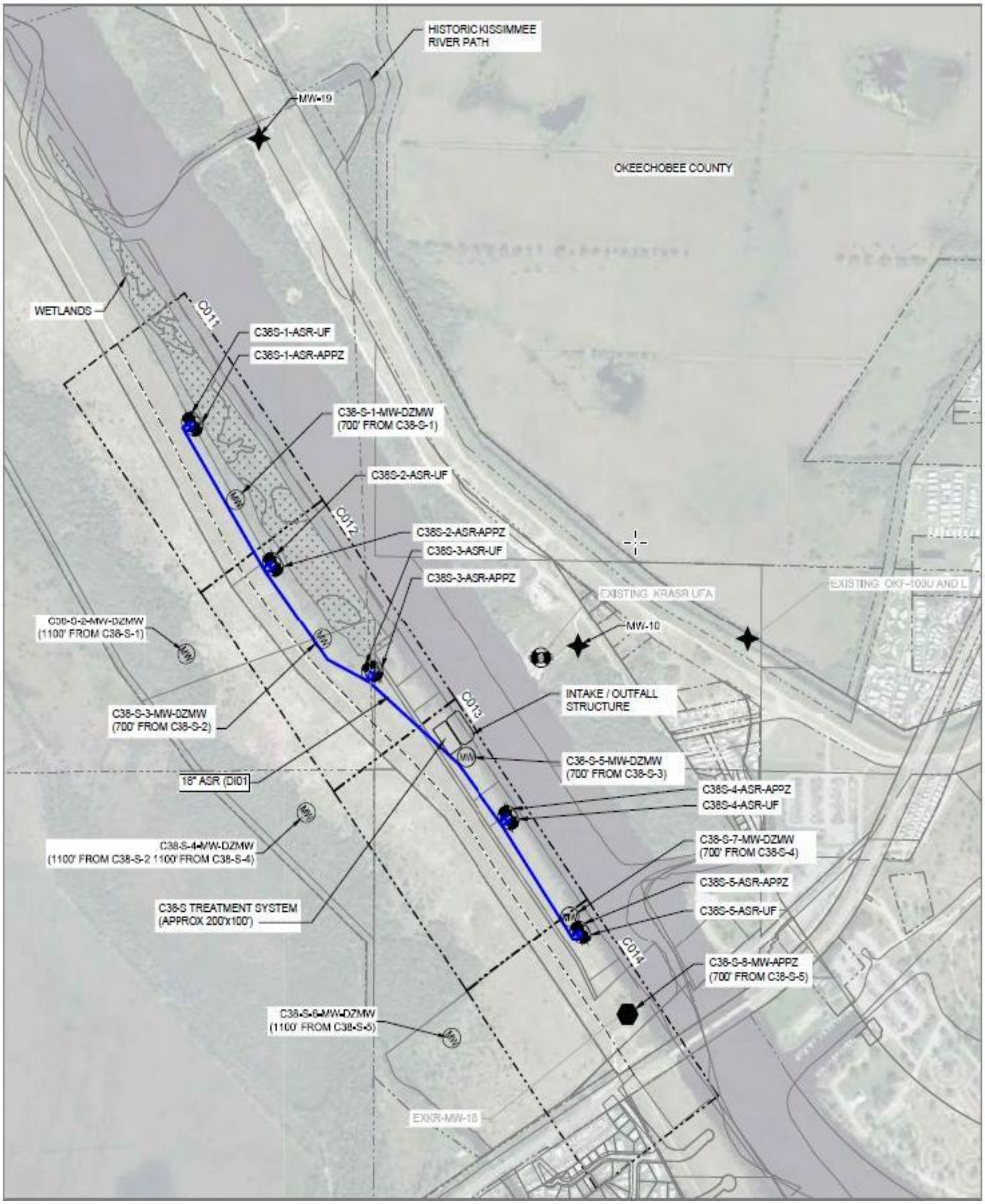

Figure 5-1. Conceptual layout of the C-38S ASR wellfield

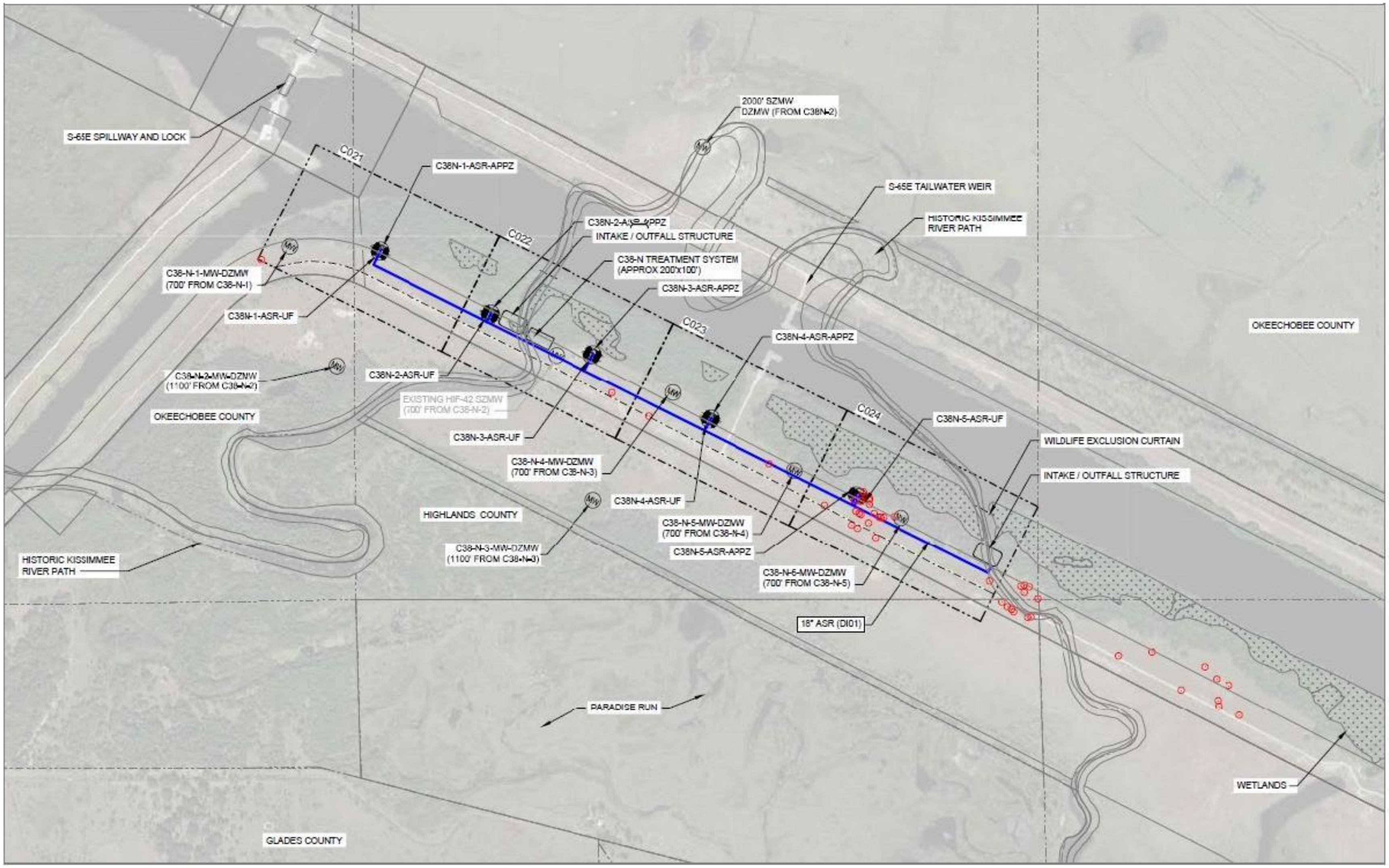

Figure 5-2. Conceptual layout of the C-38N ASR wellfield

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.

Cycle Testing (2024-2026)

Cycle testing at all proposed LOWRP ASR systems presents a unique opportunity to optimize operations to maximize recovered water volumes yet limit potential environmental impacts. Traditional metrics for recovery (volume recovered at chloride less than 250 mg/L) are not applicable to ASR in fresh aquifers because recovered water concentrations will not exceed 250 mg/L. Instead, the recovered water metric could be based on a maximum allowable sulfate or radium concentrations.

It is likely that native groundwater quality will differ between the UFA and the APPZ in many locations with regard to sulfate, chloride, and other major dissolved constituent concentrations. It is likely that recharge and recovery will not occur in all aquifers simultaneously. Operational scenarios that limit the discharge of chloride and sulfate during initial and later cycles will be considered during the modeling effort.

Consideration of Wells Completed Below the Underground Source of Drinking Water

The continuous core drilling program anticipates evaluating strata to depths of 2,000 ft bls. During these investigations, permeable zones may be encountered at depths below the underground source of drinking water. If favorable storage zones are determined to exist below the underground source of drinking water, these may be evaluated for use as “lake level attenuation wells” during prolonged periods.

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 Last Year

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 using local-scale groundwater flow and solute transport models.

Characterize a Buffer Zone Based on Sulfate Concentrations at KRASR

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 Kissimmee River or L-63 Canal. Native sulfate concentrations in the APPZ also exceed surface water sulfate concentrations. Geochemical mixing model simulations using existing KRASR data will characterize a buffer zone composition based on sulfate in both the UFA and APPZ (Mirecki, in prep). These simulations will define the sulfate threshold in recovered water that will reduce mercury methylation risk.

Reactivation of the L-63N ASR Well (2022-2023)

The current efforts to reactivate the L-63N ASR well, completed in the brackish APPZ, eventually will result in a request to initiate cycle testing in the permitting process. The proposed cycle testing program may include an initial period of recharge to initiate and evaluate the stability of a buffer zone in this highly transmissive aquifer. Future studies may refine a mode of operation that improves recovery efficiency through the creation of a sulfate- or chloride-based buffer zone.

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 Last Year

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 testing is planned at the UFA and APPZ at C-38S and C-38N, following completion of ASR test and monitoring wells starting in summer 2022. Groundwater quality will be characterized with data obtained from packer tests at 30-ft intervals in the exploratory borehole. Specific capacity tests are conducted at appropriate permeable intervals. After the wellfield is constructed, APTs will define hydraulic parameters of the UFA and APPZ. These parameters will be 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. The groundwater flow and solute transport model is under development and will be ready for use in mid-2023.

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 USEPA 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.

Progress Since Last Year

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. During 2021-2022, a “proof of concept” evaluation was conducted, wherein five vendors were selected to operate five different pilot-scale treatment trains that met the highest standards of dependability to meet regulatory requirements. The testing was conducted at the KRASR system from late 2021 to early 2022. The report of evaluation of that testing is currently under preparation and will be used as a basis for determining a selected treatment process for the first few well clusters that are constructed under this program.

Ongoing and Future Studies

Proof of Concept Evaluation (2022)

Upon completion of the proof-of-concept testing and review of the consultant analysis, a determination on the selected treatment process will be made.

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

The PRP has serious concerns with the cost of operating a more complex pretreatment system in future large-scale ASR implementation. The PRP 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 PRP also recommends investigation of possible different pretreatment system design wherein the storage aquifer contains saline water which would require desalination before it could be used for drinking water.

The PRP 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 PRP 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.

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.

Progress Since Last Year

Results of the proof-of-concept water treatment project 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.

Ongoing and Future Studies

Treatment Technology Evaluations (2020-2022)

As part of the proof-of-concept treatment technology evaluation, the ability of a treatment process to attenuate arsenic mobilization will be included in subsequent evaluation phases. A second phase of treatment technology evaluation is under development and likely will include demonstrations of multiple filtration and disinfection processes. Pilot system evaluation metrics probably will include chemical transformations that occur during treatment and might cause mobilization of undesirable constituents within the aquifer.

Exploratory Geochemical Modeling

An exploratory geochemical model to estimate arsenic mobilization currently is scoped and will use existing data from KRASR cycle testing and lithological and mineralogical data from KRASR presented in a Florida Geological Survey report (Fischler and Arthur 2013). A second effort has been scoped 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).

Cycle Testing (2024-2026)

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 beyond 2026 will be provided in subsequent updates of the ASR Science Plan as the ASR program progresses and additional information becomes available.

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 PRP 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 PRP looks forward to reading a more detailed plan for water quality monitoring during cycle testing.

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 Last Year

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.

Ongoing and Future Studies

<u>Pathogen Inactivation Studies (2020-2022)</u>

At this time, there are no additional studies planned for evaluation of this uncertainty. However, the USGS has proposed performance of a "Quantitative Microbial Risk Assessment" to evaluate the potential health effects of recharging partially treated water into the Floridan aquifer.

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 Last Year

USGS studies on pathogen inactivation were completed in 2021 and the results were published in the following year (Lisle and Lukasik, 2022). The results likely will determine conservative inactivation rates of a broad range of pathogens when subjected to conditions within the FAS. Those rates can be coupled with a local-scale groundwater model used for wellfield design to estimate zones within the aquifer where pathogens are likely to be active and where they are not.

Ongoing and Future Studies

Local-Scale Groundwater Modeling at C-38S and C-38N (2022-2023)

Pathogen inactivation time and travel distance studies are anticipated to be done after completion of local-scale groundwater model simulations. These simulations will include particle tracking simulations that can serve as a basis to estimate pathogen transport. Bacteriophage Tracer Study (2024-2026)

To characterize the fate and transport of microorganisms during a cycle test, a bacteriophage tracer study may be conducted where a known concentration of bacteriophage is added to the recharge water. Samples will be collected from select monitoring wells to estimate the bacteriophage's movement and attenuation via adsorption during the recharge and storage phases of the cycle test. The recovered water may be sampled for the presence of bacteriophage to estimate the survival of these surrogates for microbial pathogens during storage in different zones of the UFA. Performance of this type of study will require underground injection control regulatory review and approval. Results of the evaluation may be coupled with groundwater models to estimate transport mechanisms, travel times, and travel distances of pathogens within the aquifer during recharge. Details of studies beyond 2026 will be provided in subsequent updates of the ASR Science Plan as the ASR program progresses and additional information becomes available.

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. Table 8-7 of the ASR Regional Study Final Technical Data Report (SFWMD and USACE 2015) showed a qualitative risk associated with these effects but no mitigation strategy. 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 Kissimmee River and canals 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 Last Year

To date, the ASR systems that are being constructed or will be reactivated by the SFWMD are located along the Kissimmee River (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. A mixing-zone modeling work plan has been prepared. The plan includes the use of a desktop mixing zone modeling exercise (i.e., CORMIX) that will be calibrated with field sampling. The results of this effort will identify those stressors that would require mitigation prior to the discharge to surface water. The evaluation and selection of mitigation strategies would be conducted using a remedial feasibility analysis approach. Additionally, the plan will assess the design of the intake structure for both impingement and entrainment to evaluate potential mitigation strategy / modification to the design to mitigate ecological risk.

Ongoing and Future Studies

Well Siting Evaluation and Exploratory Well Construction (2020-2022)

In 2020, the SFWMD conducted well siting and constructability analyses on the proposed C-38S and C-38N cluster locations (SFWMD and USACE, 2021b; **Appendix F**). The results of these evaluations indicated that siting future well clusters along larger canals would be optimal for design of recharge and recovery components. Construction of exploratory wells at both cluster locations is expected to occur through 2022.

Mixing/Dilution/Dispersion Design Evaluations and Models (2023)

After construction of the exploratory wells along the C-38 Canal, design evaluations of the recharge (intake) and recovery (discharge outfall) structures will begin. Intake structures will be designed to minimize the potential for impingement and entrainment. Outfall structures will be designed to reduce undesirable physical and chemical impacts to the receiving water body. During design evaluations, mixing models will 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 (2024-2026)

One possible impact highlighted during review of ASR studies is the potential for spawning season disruptions due to temperature alterations. Black crappie is an important commercial species that spawns in Lake Okeechobee; therefore, it can be a subject of long-term monitoring. Size-class distributions of black crappie are monitored annually in Lake Okeechobee, and monitoring could be expanded to include Kissimmee River locations. Long-term monitoring efforts could include electrofishing or trawl sampling during spawning at upstream and downstream locations as well as fry sampling post-spawn. 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.

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 Kissimmee River, Lake Okeechobee, the Greater Everglades, and canals (Arthur et al. 2020; **Appendix B**).

Progress Since Last Year

A work plan has been developed to further assess bioaccumulation and toxicity. This includes a mobile 20-foot trailer flow-through bench-scale laboratory for conducting additional bench-scale chronic and acute toxicity and bioconcentration tests at multiple ASR locations, once they become operational. This effort will support assessment of changes in contaminant bioconcentration / toxicity.

The mobile laboratory design details are described in **Appendix E**. Additionally, draft scopes of work for future experimental studies were developed and presented to the ERA Working Group subject matter experts from different federal and state agencies, universities, and non-governmental organizations during three (3) 2021 meetings. The Group was tasked with evaluation of the planned work.

Ongoing and Future Studies

Different bioconcentration and toxicological studies will be conducted using source water (recharge period) and recovered water (recovery period). Source water tests will be conducted by sampling the canal water in the vicinity of ASR sites (e.g., water from C-38 Canal will be sampled in the vicinity of KRASR, C-38 S, and C-38 N). The surface water from these canals will be used to recharge the planned ASRs. These studies will provide the background conditions of the water to be pumped into the aquifer. Toxicity tests will also be conducted during the recovery period, and ASR discharge water (recovered water) will be tested for toxicity using similar 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 draft 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 (KRASR, C-38 S, and C-38 N), and should be completed in the 2023-2024 period.

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. 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.

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 Kissimmee River, 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.

Progress Since Last Year

A pre-operational environmental monitoring plan has been developed to assess potential impacts from operating multiple ASR wells on different biotic and abiotic environmental components within the vicinity of the wells. The plan describes the monitoring efforts at six (6) locations adjacent to the KRASR and two other ASR clusters (C-38N and C-38S) in the C-38 Canal, and additional four (4) locations south of the canal mouth in northern part of Lake Okeechobee (**Figure 7-1**) between August 2022 and June 2023. The goal of this work is to characterize the receiving water environmental conditions prior to the ASR recharge and recovery (cycle testing). Data obtained through this pre-operational monitoring will later be compared to data collected during the cycle testing once the ASRs become operational. The timing of the pre-operational (and future sampling during the ASRs cycle testing) sampling is directly linked to the ASR wells' operational status. It is expected that the first cycle testing along the C-38 Canal will begin in the late-2023 and cycling in December 2023 (following buffer zone evaluation), however this schedule may change depending on the future conditions encountered at the well drilling locations.

Figure 7-1. Monitoring locations along the C-38 Canal and northern part of Lake Okeechobee

Ongoing and Future Studies

The pre-operational environmental monitoring along the C-38 Canal and northern part of Lake Okeechobee began in August 2022 and is scheduled to end in June 2023. The data for the pre-operational studies will cover multiple receptors including: periphyton, submerged aquatic vegetation (SAV), macroinvertebrates (including benthic species such as mussels and apple snails), ichthyoplankton and fish, which may be affected or be a component in an exposure pathway. Data on water quality and sediment will also be collected.

The frequency of monitoring will vary among the monitoring components as shown in **Table 7-1**. Periphyton will be sampled bimonthly to capture the subtle changes in periphyton communities and conditions that can occur at much smaller timesteps. SAV survey will be conducted at the peak of the growing seasons in 2022 and 2023. Benthic macroinvertebrates, sediments, mussels, and apple snails will be sampled during the wet (June through October) and dry (November through May) season due to the expected relatively stable nature of these populations within the canal. Fish will be 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 will be sampled monthly during the peak spawning periods of the local fish population (typically from March to June, annually). Water quality will be sampled bimonthly to capture inter- and intra-seasonal variations caused by varying flow rates and temperature.

Data obtained through this pre-operational monitoring will later be compared to data that will be collected once ASR wells along the C-38 Canal (KRASR, C-38N, C-38S) become operational (during the cycle testing period). 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 post-operational ASR data collection plans are directly tied to the data needs of the quantitative ASR ERA and the 2015 NRC recommendations for the in-situ environmental monitoring.

Table 7-1. Sampling schedule for different biotic and abiotic components of the 2022-2023 pre-operational monitoring along the C-38 Canal and northern part of Lake Okeechobee

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

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 expanded to the early dry season to cover the timing of recharge and 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.

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.

Progress Since Last Year

Based on the NRC recommendations (NRC 2015) and the information included in the 2021 ASR Science Plan (SFWMD and USACE 2021a), it was determined that the ERA for the ASR project must be updated and expanded to better describe the potential risk to ecological receptors and communities following completion of the planned ASR construction projects north of Lake Okeechobee. To accomplish the goal, a path forward for planning and implementation of the revised ASR ERA was outlined in the Scoping Memorandum (**Appendix F** in SFWMD and USACE 2021a).

This memorandum contains the following primary elements needed for scoping the completion of the quantitative ASR ERA:

- Past experience from the previous ERA and comments from the NRC to identify preliminary aspects of a revised ERA (risk questions, endpoints, etc.)
- A preliminary identification of expected expertise needed to complete the ERA and a preliminary identification of stakeholders to invite to participate in the ASR ERA development process
- Development of an ERA Working Group with structure and goals
- Identification of expected data needs
- Identification of strategies to communicate the risk assessment process with the public

Following the completion of the Scoping Memorandum, a working group, comprised of stakeholders (> 70 experts) with essential expertise and an interest in the completion of the ASR ERA, was formed in September 2021. This working group is made up of subject matter experts from the District, USACE, and other state and federal regulatory agencies (e.g., Florida Fish and Wildlife Conservation Commission [FWC], United States Fish and Wildlife Service [FWS], FDEP, USGS) who are stakeholders in the ASR ERA process. In addition, subject matter experts from academia and non-governmental organizations (NGOs) who add significant value to the ASR ERA process were also invited to participate in this working group. The working group was tasked to determine the elements needed for the District to complete a comprehensive ERA Work Plan. Three monthly working group meetings were held between October and December 2021, and five additional meetings were scheduled between June and December 2022.

In addition to the Scoping Memorandum (**Appendix F**), a report was developed describing the results of a screening-level assessment of potential risk using the bioconcentration and toxicity testing data collected in the original ERA of the Regional Study (SFWMD and USACE 2015; **Appendix G**). To assess the risk of bioconcentrating chemicals to upper-trophic-level birds, mammals, and reptiles that may feed in the vicinity of the ASR wells, a conservative, screening-level exposure and risk model was used to estimate exposure to a wide range of receptors at maximum analyte concentrations measured in the bioconcentration study. The screening-level approach was used to minimize the potential for false negative conclusions regarding risk. Overall, risks to all upper-trophic-level receptors from all analytes measured in the bioconcentration studies were low. Risks from selenium exposure could not be entirely ruled out, but they were similar using data from downstream and in the mixing zone of the ASR well, and in the upstream or background samples. This result matched what was observed in the original ASR ERA, which did not indicate statistically significant bioconcentration of selenium in samples exposed to recovered ASR well water.

The working group will use the results of the original ASR ERA and expanded analyses to focus the bioaccumulation risk assessment in the updated ASR ERA on a narrow set of chemicals and receptors.

Ongoing and Future Studies

The ongoing ERA work includes developing a comprehensive ASR ERA Work Plan for the completion of the quantitative ASR ERA based on the working group recommendations. The Working Group will be tasked with determining the elements needed for the District to complete a comprehensive ERA Work Plan. Complete details of the elements required in the ERA Work Plan are provided in the ASR ERA Scoping Memorandum (**Appendix F**). In general, the ERA Work Plan will provide all necessary information required to implement the collection of new data, and analyses of both new and historic data for the ERA. The Work Plan will be developed in cooperation between the District and USACE, and the group of stakeholders to allow for concurrence with the ERA in terms of how the assessment is completed, the data required to complete it, and the steps taken to interpret the results of the assessment.

The Work Plan will be a comprehensive plan that includes the details of the goals, endpoints, analytical approaches for evaluating risks from ASR operations at a local and regional scales, data needs, data quality objectives, and decision-making processes needed to revise the ERA agreed upon by the Working Group and outlined in the ASR ERA Scoping Document (**Appendix F**).

The Work Plan will provide the following information:

1) Risk management goals, risk questions, and description of the risk management decisions required (using the data provided in the revised ASR ERA.

2) Revised Ecological Conceptual Site Model (ECSM) that includes the identification of stressors and stressor sources associated with ASR recovery water, release mechanisms into the environment, receptor groups potentially exposed, exposure scenarios to be considered, and the identification of completed exposure pathways.

3) The description of all assessment and measurement endpoints to be used in the updated ASR ERA, including all measures of exposure, effect, and ecosystem and receptor characteristics.

4) Presentation of all available data, discussion of the usability of those data, additional evaluations of the data beyond what was completed in the original ASR ERA (incorporated from the 2021 Historical Data Analysis; Formation 2021b; **Appendix G**), and identification of data gaps.

5) Incorporation and documentation of all data collection plans developed to fill the data gaps.

6) Plans for quantitative and qualitative risk analyses, and risk characterization plan.

The details of the Work Plan will be completed via a series of four (4) Working Group meetings. The final fifth (5th) meeting will be used for presenting and discussing details of the comprehensive ASR ERA Work Plan. The completed ASR ERA Work Plan will be included as an appendix in the next year's ASR Science Plan.

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. The interim work can be summarized each year, but longer-term or broader conclusions can be updated periodically with the information (e.g., every two years). This requires a robust problem formulation to be completed ahead of time.

Upon completion of the ERA Work Plan that is currently being developed, 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 PRP. 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 PRP recommends the use of Bayesian networks in a risk assessment framework, if useful and appropriate to the quantitative work. The Bayesian networks can be used for probabilistic calculations but also for causal predictive risk models capturing the information from the operational studies and capturing the structure of the conceptual models.

The conceptual models are informative but should be developed to contain more exposure routes, stressors, speciation, and media. Having one conceptual model may be difficult. 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.

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 Last Year

Numerous studies have been conducted on the geochemical aspects of the FAS associated with arsenic mobilization. Findings have been published in peer-reviewed publications and agency documents, including Petkewich et al. (2004), Mirecki (2004, 2006), Mirecki et al. (2013), SFWMD and USACE (2013), and Geddes et al. (2018) among others. Further investigations of groundwater quality changes during ASR cycle testing will be a primary objective of the data collection effort at each ASR system.

Ongoing and Future Studies

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

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. A comprehensive redox sensitivity monitoring program to occur during cycle testing can be prepared following geochemical benchtop modeling studies and findings from the exploratory well sampling program. The monitoring program will include analyses for species of arsenic, radionuclides, molybdenum, vanadium, and other constituents based on the benchtop studies that could be mobilized during changes in redox potential during recharge, storage, and recovery.

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 Last Year

The largest test cycle at the KRASR pilot project consisted of 7 months of recharge (at 5 million gallons per day), followed by nearly 1 year of storage and 6 months of recovery. There was no buffer zone within the aquifer prior to this cycle, in part because the native groundwater is fresh. During cycles 2 and 3 recharge, arsenic concentrations increased to approximately 140 parts per billion at a monitoring well 1,100 feet from the ASR well. However, during storage arsenic concentrations declined as a result of microbe-mediated geochemical reactions (Mirecki et al. 2013). There was no detectable trend of arsenic in monitoring wells 2,560 and 4,200 feet from the ASR well. This uncertainty can be best evaluated through cycle testing with large volume recharge, although exploratory geochemical models can be coupled with groundwater transport modeling to evaluate theoretical travel distances prior to cycle testing.

Ongoing and Future Studies

Local-scale Groundwater Flow and Solute Transport Model Development and Simulations (2022-2023)

Use of the particle-tracking module in the SEAWAT groundwater flow and solute transport model code will show the maximum extent of the recharge water, most likely based on changes in TDS with distance. These initial results will be useful to support UIC permit applications and improve understanding of flow in these hydrogeologically complex multi-well systems well before cycle testing commences. Development of an arsenic-specific reactive transport model will likely be developed for the C-38 and L-63 ASR systems after completion of the APTs and local-scale SEAWAT simulations.

Cycle Testing (2024-2026)

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 Kissimmee River. 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 Last Year

Cycle testing at the KRASR project resulted in recovery of water equal to the volume of water recharged. Thus, there was no development of a residual 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, stabilize and neutralize non-conservative geochemical reactions taking place within the subsurface, and reduce concentrations of metals recovered during later cycles. This uncertainty can be best evaluated through cycle testing, although predictive benchtop geochemical models can be coupled with groundwater transport modeling to evaluate theoretical travel distances prior to cycle testing, as noted in Section 8.2.

Ongoing and Future Studies

Characterize a Buffer Zone Based on Sulfate Concentrations at KRASR (2022-2023)

Increased sulfate concentrations in recovered water may stimulate mercury methylation in sediments of 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-28S and KRASR is fresh (chloride concentration approximately 300 mg/L) but native groundwater sulfate concentrations far exceed sulfate concentrations in the Kissimmee River or L-63 Canal. Native sulfate concentrations in the APPZ also exceed surface water sulfate concentrations. Geochemical mixing model simulations using existing KRASR data will characterize a buffer zone composition based on sulfate concentrations in both the UFA and APPZ (Mirecki, in prep). These simulations will define the sulfate threshold in recovered water that will reduce mercury methylation risk.

Cycle Testing (2024-2026)

At the KRASR site, even though native UFA water is fresh, sulfate concentrations (approximately 180 to 200 mg/L) exceed those in Kissimmee River surface water (approximately 20 to 40 mg/L). Cycle testing at KRASR (2010 to 2014) was largely exploratory because it was the first ASR system with a capacity of 5 million gallons per day located in an interior location. Now that water quality patterns are reasonably well understood at the scale of a single system, LOWRP ASR systems will provide the opportunity to characterize trends at a subregional scale. This includes strategies to reduce recovered volumes during successive cycles, enabling development and characterization of buffer zones in the aquifer, at locations having different groundwater quality characteristics. Buffer zone composition is a mixture of native groundwater diluted by recharge water. Progressive development of a buffer zone with lower sulfate concentrations, coupled with larger volume recharge phases will minimize sulfate discharge into surface water environments. A comprehensive monitoring program to occur during cycle testing can be prepared following geochemical benchtop modeling studies and findings from the exploratory well sampling program. 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.

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**, 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 species in the Everglades.

Progress Since Last Year

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. Predictive simulations via use of the Lake Okeechobee Environment Model may also be utilized.

Ongoing and Future Studies

Lake Okeechobee Environment Model (2023-2024)

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 new Kissimmee River 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 (2024-2026)

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 which some fraction of recharged water remains in the aquifer. Additional modeling should focus on sulfate trends in the aquifer, which are simpler to execute compared to regional surface water quality simulations. However, 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 Last Year

Radium isotopes (Ra^{224} and Ra^{226}) are one of the few constituents not released through water-rock interactions during cycle testing. Instead, 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 (Ra^{226}) and thorium (Th^{232}) decay series (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. Scoping is currently under way to conduct an analysis of existing groundwater data on radium and gross alpha from wells in the vicinity of the LOWRP ASR program, as described below.

Ongoing and Future Studies

Compilation of Existing Radium and Gross Alpha Data in the FAS (2022)

The SFWMD database DBHydro contains abundant groundwater quality data for the FAS. The database will be mined for radium isotope, radium, uranium, and gross alpha data in all aquifers of the FAS to define the occurrence of these constituents throughout south Florida. The deliverable will be a technical memorandum presenting the results of this desktop effort. DBHydro data will be supplemented with radium activities reported during construction of other ASR and deep injection wells. These data are compiled in well construction reports that are available on the FDEP Oculus database.

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 (2024-2026)

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). 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 2023 when the treatment technology evaluation is completed and integrated into the well cluster surface facilities design. 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.

Table 9-1. Planning-level costs estimates for the 2022 ASR Science Plan

Research Activity	Estimated Cost by Fiscal Year					Total Cost
	FY21	FY22	FY23	FY24	FY25	
Future Construction and Testing (Chapter 3)						
Geochemical Core Analysis		$50,300	$100,600	$100,600		$251,500
Seismic/Geophysical Evaluation		$235,000	$265,000			$5000,000
Core Analysis/Description		$226,000	$226,000	$113,000		$565,000
Geochemical Benchtop Modeling		$50,000	$50,000			$100,000
Optical Borehole Image Logging		$16,000	$32,000	$32,000		$80,000
Injection Tracer Test/Geophysics			$200,000	$200,000		$400,000
Groundwater Modeling			$250,000			$250,000
						$2,146,500
Understanding Phosphorus Reduction Potential (Chapter 4)						
Nutrient Column Studies (Bioclogging)	$8,000	$102,000	$300,000			$410,000
Special Monitoring During Kissimmee Cycle Test			$100,000	$250,000		$350,000
						$760,000
Operations to Maximize Recovery (Chapter 5)						
Mixing Zone/Dispersion Model (Recovery)			$150,000			$150,000
						$150,000
Disinfection/Treatment Technology (Chapter 6)						
Pathogen Inactivation Support Risk Assessment			$100,000	$155,000		$255,000
Specialty Groundwater Transport Model			$50,000			$50,000
						$305,000
Ecotoxicology and Ecological Risk Assessment (Chapter 7)						
Ecological Risk Assessment	$32,000	$270,000	$35,000	$100,000	$100,000	$537,000
Long-term Ecological Monitoring and Bioaccumulation Study		$210,000	$820,000	$450,000	$450,000	$1,930,000
Bench-Scale Chronic and Acute Toxicity and Bioaccumulation Studies		$91,000	$100,000	$250,000	$150,000	$591,000
Mesocosm Bioaccumulation studies		$35,000		$400,000	$150,000	$585,000
Larval Fish Entrainment/Impingement and Temperature Effect Studies			$150,000	$150,000		$300,000
						$3,943,000
Water Quality (Chapter 8)						
Enhanced Monitoring During Cycle Testing				$300,000	$300,000	$600,000
Sulfate/Methylmercury Studies				$350,000	$400,000	$750,000
Gross Alpha/Radium Monitoring			$50,000	$50,000	$50,000	$150,000

Research Activity	Estimated Cost by Fiscal Year					Total Cost
	FY21	FY22	FY23	FY24	FY25	
						$1,500,000
ASR Peer-Review Panel						
Scientific Panel	$45,000	$70,000	$70,000	$70,000	$70,000	$325,000
Programmatic Quality Assurance Plan		$74,000				$74,000
						$399,000
Total by Fiscal Year	$85,000	$1,429,300	$3,048,600	$2,970,600	$1,670,000	**$9,203,500**

* This is a planning-level cost estimate and does not include contingency. Cost is based on 2021 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 staff based on best available information.

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