APPENDIX F

Ecological Risk Assessment Report

Supporting documents for Ecological Risk Assessment, as Appendices

A. **Water Quality Data Collected at KRASR and HASR Pilot Sites**

B. **Part 1-Supporting Ecological Assessment Reports**

   Part 2 – Surface Water Quality Reports

C. **Toxicology Discussion From USACE and SFWMD (2013)**

September 2014

COMPREHENSIVE EVERGLADES RESTORATION PLAN

Regional Ecological Risk Assessment of CERP Aquifer Storage and Recovery Implementation in South Florida

U.S. Army Corps of Engineers
Jacksonville District

South Florida Water
Management District

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Executive Summary

The U.S. Army Corps of Engineers (USACE) in partnership with the South Florida Water Management District (SFWMD) prepared this Ecological Risk Assessment (ERA) on the use of Aquifer Storage and Retrieval (ASR) as part of CERP (Comprehensive Everglades Restoration Plan) (USACE, 1999) in response to concerns expressed by the South Florida Ecosystem Restoration Working Group (SFERWG) and the National Academy of Sciences Committee on the Restoration of the Greater Everglades Ecosystem (CROGEE) (National Academy of Sciences, 2001 and 2002).

Future full-scale implementation of the CERP, as envisioned in the Restudy (USACE, 1999), includes approximately 330 ASR wells in the Floridan Aquifer System (FAS) with a total capacity of approximately 1.7 billion gallons per day (bgd). The CROGEE reports recommended that potential water quality changes from the regional scale ASR application should be identified and evaluated and potential impacts to sensitive ecosystems should be evaluated. The ASR Pilot Projects and the ASR Regional Study (ASRRS) were designed to address many of the CROGEE comments and to reduce uncertainties related to full-scale CERP ASR implementation.

This ERA is prospective in nature in that regional implementation of ASR technology has not been initiated. The effects data developed used both standard tests as well as surrogate species applicable to south Florida ecosystems. In this manner the data developed at one ASR could be extrapolated to other aquatic ecosystems, acknowledging the uncertainties that aquatic ecology and regional water quality is variable. The ERA evaluated potential beneficial or adverse effects of ASR implementation in the Lake Okeechobee Basin and downstream in the Greater Everglades, including assessment endpoints and ecosystem attributes that are most sensitive and highly valued. The risk assessment process used for this report followed USEPA guidance on ERA studies (USEPA 1998). As part of an ERA, risk assessors evaluate goals and select assessment endpoints, prepare the conceptual model, and develop an analysis plan. During the analysis phase, assessors evaluate exposure to stressors and the relationship between stressor levels and ecological effects. During

risk characterization, assessors estimate risk through integration of exposure and stressor-response information, describe risks by discussing lines of evidence and determining ecological adversity, and prepare a report. The ERA team which included representatives from the USACE, SFWMD, USFWS, FDEP, Florida Fish and Wildlife Conservation Commission (FFWCC), University of Florida, and Golder Associates (Contractor to USACE and SFWMD) created a study plan that included identification of stressors and receptors and development of an ecotoxicology program and water quality and ecological monitoring. A Surface Water Modeling Sub-Team took the leadership in identifying the available regional water quality models and scoping the exposure modeling needed for the ERA. The SFWMD conducted ongoing aquatic baseline studies at all the pilot projects as well as other regional ecological studies. The USFWS conducted the ecosystem level risk assessment on fisheries and West Indian manatees. The FFWCC conducted fishery studies in the Lake Okeechobee basin. The USGS and University of Florida performed modeling and analysis to evaluate the potential for changes in mercury methylation in Lake Okeechobee and the Greater Everglades.

The ERA team developed a list of stressors using their knowledge of south Florida freshwater and estuarine habitats, surface water and groundwater quality, site specific hydrogeology, and operational water quality data collected at utility-owned ASR sites located in Florida. The preliminary water quality stressors were organized into five groups:

- general water quality constituents,
- nutrients,
- dissolved solids,
- metals, and
- radionuclides.

The team also identified and evaluated physical stressors such as temperature effects and impingement and entrainment of larval fish. Based on the ERA teams understanding of ASR stressors modes of action, fate and effects in south Florida ecosystems, along with water quality, the following assessment endpoints were selected:

- Reproducing populations of native fish;
- Survival of fish and aquatic Invertebrates;
- Periphyton and algae species diversity and abundance, and submerged aquatic vegetation (SAV); and
- Human health and wildlife protection.

The team evaluated the ecological effects of five plausible ASR implementation scenarios for the Lake Okeechobee basin. The alternatives considered were: 1) ALT1, no ASR wells; 2) ALT2, 200 ASR wells in Upper Floridan Aquifer (UFA); 3) ALT3, 100 ASR wells in UFA; 4) ALT4, 32 UFA wells, 48 Avon Park Producing Zone (APPZ) wells, and 120 Boulder Zone (BZ) wells; and 5) ALT4-S11 which has the same number of wells and placement as ALT4 but includes operational restrictions on the rate of recovery. The results of the assessment endpoint analysis for these CERP ASR scenarios are summarized below.

Water Quality:

The risks for impacts to water quality in the near-field (single ASR discharge) are moderate to low, and the benefits in the Kissimmee River from improved water clarity vary depending upon the ASR implementation scenario. ALT2 presenting the highest risk for increased sulfate and water hardness due to the large number of ASR wells; followed by ALT3 with half the number of ASRs. The risk to Lake Okeechobee water quality was high for ALT2 for sulfate load and water hardness, and moderate for ALT3. For Lake Okeechobee, the benefit of decreased total phosphorus load was moderate to low, and the benefit of increased water clarity was low to minimal. The risk to the Greater Everglades of sulfate load and its impact on mercury methylation was minimal to moderate depending upon the ASR scenario. The risk of increased water hardness to the Greater Everglades was considered low primarily because of the existing hardness load coming from EAA runoff.

The implementation of CERP ASR in the Lake Okeechobee basin will result in the removal of 20 to 30 mTons/yr of phosphorus from the surface water system. While this will contribute to goal of meeting the Total Maximum Daily Load (TMDL) established for Lake Okeechobee it is unlikely to measurably alter Lake Okeechobee water column phosphorus concentrations.

Reproducing Populations of Native Fish:

The effects evaluated were loss of dissolved oxygen refugia, water temperature changes, and impingement or entrainment of fish larvae by the ASR intakes. For alternatives with more wells or more pumps (ALT2 and ALT3, generally), the risk of adverse effects was higher. ALT4 and ALT4S-11 generally posed lower risks regardless of water body due the lower number of wells. The risk of any larval fish impingement or entrainment was high to moderate for all alternatives; however, the risk that this loss would be detectable in the fish population was considered low.

Survival of Fish and Aquatic Invertebrates:

Toxicological Effects: Based on the aquatic toxicological data developed for this ERA, the risk to the survival of fish and invertebrates from water quality changes is low under all scenarios. However, because of chronic toxicity observed at the Kissimmee River Pilot ASR facility, it is likely that future ASR implementation will require that mixing flow be provided in receiving water where ASR water will be discharged. Given that ASR discharges would occur during drought periods, the availability of flowing surface water for dilution of ASR releases is not certain. This is particularly apparent in the Lower Kissimmee River during the months of December, January, and May when historic flows at S-65E are much lower than the flows contemplated with any of the ASR implementation scenarios proposed for the Kissimmee. The requirement for dilution flow will likely influence the location of future ASR facilities and how they are operated.

Periphyton and Algae Species Diversity and Abundance, and submerged aquatic vegetation (SAV):

The potential risk of ASR recovered waters on the diversity and abundance periphyton and algal species is considered low to minimal for the Kissimmee River and Lake Okeechobee. For Lake Okeechobee, a low to minimal benefit as an increase in SAV biomass was predicted, and a moderate to low potential increase in SAV coverage was also anticipated. No significant change to SAV was predicted for the Kissimmee River primarily because the lower river is channelized and has limited SAV.

Human Health and Wildlife Protection:

The effect of ASR related sulfate loads on mercury methylation in the Kissimmee River and Lake Okeechobee are characterized as minimal. However, mercury methylation is just one aspect of the mercury problem and it is the accumulation of mercury in fish and wildlife that is the ultimate risk and subject to greater uncertainty. Within the Greater Everglades, the areas of changed MeHg risk attributable to the ASR related sulfate are predicted to be minimal particularly with the ALT4 and ALT4-S11 alternatives, and are located near major canal water release points in western WCA3, north-central WCA2, and northern Shark River Slough. Because the suggested relationship between sulfate and MeHg production is nonlinear and hump shaped, the ELM-Sulfate model prediction generally shows both regions of net increases and net decreases in MeHg risk in near proximity to each other. Given the complexity of mercury methylation in the environment and the fact that the suggested hump-shaped relationship with sulfate has large unexplained variability, the uncertainty with the methylation risk characterizations is considered to be moderate.

Uncertainty Assessment:

There is always uncertainty associated with risk assessment predictions, depending on the quality, quantity and variability associated with available information. When information is uncertain, it is standard practice in a risk assessment to make assumptions that are biased towards safety. In this case, the uncertainties inherent in modeling exposures are compensated for by the conservative input parameters used. Collectively, these conservative assumptions weigh heavily towards risk estimates that over-estimate the true risk. Thus, there is usually a high degree of confidence that risks have not been underestimated.

Biological uncertainty was recognized in this ecological risk assessment for fish and other aquatic life. Lack of data resulted in greater uncertainty with respect to effects on invertebrates and larval fish from entrainment (e.g., no larval fish data were available for Pool E of the Kissimmee River and only six separate intake samples were collected at KRASR of entrained larval fish and other aquatic organisms). The lack of data for spawning fish in the C-44 Canal at Port Mayaca also resulted in greater uncertainty about how ASR technology might affect fish reproduction in those ecosystems. Biological uncertainty was also concluded simply due to natural variation within and among species. For example, the constant temperature of the ASR discharge may differentially affect cool-water and warm-water fish species because they have different preferred spawning temperatures.

Additional sources of uncertainty for this ERA include:

1. Extrapolation of data from a one or two pilot ASR wells. (Future ASR wells are expected to have somewhat different recovered water quality);
2. Differing operating schemes than predicted by the models;
3. Potential error in MeHg impact projections due to model simplifications and limited understanding of the mechanisms that control methylation ;
4. Location of assumed ASR facilities and assumed storage aquifer. A different implementation scheme with different wells locations, aquifers might provide different risk profiles; and
5. Potential for under/over estimation of fishery impacts.

Contribution to CERP Performance:

As part of this ERA, the Lake Okeechobee Ecological and Water Supply Performance Metrics were assessed using the LOOPs (Lake Okeechobee Operations Planning

Spreadsheet) to further evaluate the ASR scenarios. Based on the standard lake ecological and water supply metrics, the original plan for 200 ASR wells (ALT2) would provide improved lake performance both on the ecological side for discharges to the Caloosahatchee and St. Lucie Estuary as well as on the water supply side for reduced LOSA shortages. ALT3 with half of the originally envisioned 200 ASR wells within the Lake Okeechobee basin does not perform as well as ALT2 but it still appears to improve most ecological and water supply metrics when compared to the baseline condition of no CERP ASR (ALT1). ALT4 and ALT4-S11 generally provide worse ecological and water supply conditions for periods of limited water availability. For periods of ample water availability, ALT4 and ALT4-S11 generally perform better than the baseline or ALT2 and ALT3. Placement of ASR wells into the Boulder Zone in ALT4 and ALT4-S11 results in an overall lower water budget for the lake because water injected into the BZ wells is not recovered. ALT4-S11 further constrains the Lake water budget due to the reduced recovery rate for UF and APPZ wells.

Assessment of CERP performance metrics for the Greater Everglades was not done for the ALT3, ALT4, and ALT4-S11 scenarios since these metrics are not available in the LOOPS model. Assessment of these metrics requires that the SFWMM (South Florida Water Management Model) or successor models are configured for these ASR implementation scenarios. In light of the reduced performance in the lake associated with the most feasible ASR alternatives (ALT4, ALT4-S11), it is apparent that the CERP plan should be revised to account for reduced ASR effectiveness.

Conclusions:

This ERA primarily investigated ecological and water quality impacts associated with CERP ASR in the Lake Okeechobee Basin. The overall finding of this ERA is that implementation of CERP ASR will not result in irreversible ecological or water quality impacts to the Kissimmee River, Lake Okeechobee, or the Greater Everglades. The risks posed by CERP ASR in the Caloosahatchee, C-51, North Palm Beach, and Site 1 basins were not explicitly addressed in this report; however, given the similarities between the Lake Okeechobee basin and these basins, the risks characterized here serve as reasonable estimates for these basins.

Although this ERA did not identify substantial ecological effects from a water quality perspective, there is an acknowledgement that water quality conditions would need to be monitored under ASR implementation primarily to satisfy CERPRA, UIC, and NPDES permit requirements but also to reduce the uncertainties identified in this report. In areas where ASR is proposed that have significant fisheries or high quality aquatic habitat, additional monitoring such as fishery surveys and stream condition index monitoring is recommended. This expected permit required monitoring and suggested supplemental monitoring should ensure that the uncertainty risks identified in this report are minimized.

Given that this ERA acknowledges that the risk characterizations are uncertain, CERP ASR implementation should be done in an incremental and geographically disperse manner in order to minimize the possibility of unforeseen ecological impacts. Implementation of ASR well cluster facilities with maximum capacity of 25 MGD at one or more locations within the Lake Okeechobee Basin would present limited ecological risk. Implementation of similar ASR well clusters in other basins would present slightly higher risk but these likely could be mitigated.

1.0 INTRODUCTION

The Comprehensive Everglades Restoration Plan (CERP) was developed to restore and preserve the Everglades and south Florida's natural environment, maintain flood protection, and improve the availability of water supplies (USACE 1999). Several technologies are being evaluated to store water to improve quantity, quality, timing and distribution of flows to the Everglades system. Aquifer storage and recovery (ASR) is one of the technologies being evaluated.

The objective of the ERA, and associated watershed modeling, is to organize, analyze, and present scientific information related to the potential ecological and water quality impacts anticipated with the implementation of a regional ASR project in south Florida. The *Central and Southern Florida Project Comprehensive Review Study (USACE, April 1999),* and the CERP plan include 330 ASR wells that are expected to pump up to approximately 1.7 billion gallons of per day (bgd) into the Floridan Aquifer System (FAS) during periods of surplus surface water. The CERP ASR components are expected to take surplus freshwater, treat it as required and then store it deep underground in the FAS for subsequent recovery. During dry periods, water recovered from ASR wells would be utilized to augment surface water supplies and maintain the surface water levels and/or flows within Lake Okeechobee, the St. Lucie and Caloosahatchee Rivers and associated canals throughout southern Florida.

During the development of the CERP, water resource managers recognized that ASR is a relatively new water resource technology that has not been previously installed on such a scale as that proposed in the CERP. Due to the limited understanding of a system-wide ASR project, an ASR Issue Team was formed by the South Florida Environmental Restoration Working Group (SFERWG) in September 1998. The team's charter was to develop an action plan and to identify projects necessary to address the surface water, hydrogeological and geochemical uncertainties associated with CERP ASR and it recommended further study on seven issues (USACE, 1999):

1. *Characterization of the quality of prospective source waters, including spatial and temporal variability;*
2. *Characterization of regional hydrogeology of the Upper Floridan Aquifer: hydraulic properties and water quality;*
3. *Analysis of critical pressure for rock fracturing;*
4. *Analysis of site and regional changes in head and patterns of flow;*
5. *Analysis of water quality changes during movement and storage in the aquifer;*
6. *Potential effects of ASR on mercury methylation and possible bioaccumulation for ecosystem restoration projects; and*
7. *Relationships among ASR storage interval properties, recovery rates, and recharge volume.*

These seven issues were later augmented by other key regional concerns raised by the CROGEE and the public. In its report entitled *Aquifer Storage and Recovery in the Comprehensive Everglades Restoration Plan: A Critique of the Pilot Projects and Related Plans for ASR in the Lake Okeechobee and Western Hillsboro Area,* published in February 2001 (CROGEE, 2001), the CROGEE recommended further investigation of three broad categories including:

- Regional science issues;
- Water quality issues; and
- Local performance/feasibility issues.

In general, the CROGEE's recommendations mirrored those published in the ASR Issue Team report, with one exception. The major omission noted by the CROGEE was that the overall effect of 1.7 bgd of recovered water discharged back to the south Florida ecosystem was poorly understood and the study lack a sufficient biological focus to address this uncertainty.

The second CROGEE review (2002) recommended further studies and the addition of monitoring of ecological indicators in order to document or predict the effects of ASR recovered water. Specifically, CROGEE stated that additional detail for the ERA was needed regarding *assessment endpoints* (specific attributes of the south

Florida and Greater Everglades ecosystem that are most highly valued and sensitive, and thus to be protected) and how these endpoints would be used to develop the *measurement endpoints* (measures of effects that can be related to the assessment endpoints). In response to the recommendations of the ASR Issues Team and CROGEE, the USACE and the local project sponsor, the SFWMD, developed the Regional ASR Study (RASRS) plan, which included the assessment of ecological and human risks associated with CERP ASR implementation. This ERA is being conducted as part of the RASRS to address the potential ecological, water quality, wildlife and human health impacts and risks associated with regional implementation of ASR in south Florida as part of the CERP.

1.1 ASR Pilot Projects

Studies to develop the necessary ecotoxicological, field ecological, and water quality data needed for the ERA were initiated in 2002 by the USACE and the SFWMD through two ASR Pilot Projects: the Kissimmee River ASR (KRASR) and the Hillsboro ASR (HASR). The SFWMD conducted baseline environmental monitoring program from 2004 to 2006 at the two pilot test facilities that were constructed and at the prospective sites at Moorehaven, Port Mayaca, and Caloosahatchee. The objectives of this program were to provide pre-operational baseline data summaries of the surface water, sediment, and biological constituents adjacent to the ASR sites and formulate recommendations for future monitoring (TetraTech EC, Inc. 2007).

From 2009 to 2013, cycle testing was conducted at the two ASR pilot project sites to evaluate the hydrogeologic and water quality performance of ASR systems.

A cycle test consists of three phases:

- Recharge of partially treated surface water into the aquifer;
- Storage of surface water in the aquifer; and
- Recovery of stored water and discharge to surface waters.

The USACE ASR Pilot Project Technical Data Report, Section 9, includes a thorough description of the assessment of the water quality changes during cycle testing at these two ASRs and is included as **Appendix A** (USACE 2013). Water quality data were used as inputs into surface water quality models used in the ERA.

1.2 Need for this Study

The need for this study is documented in the Project Management Plan (PMP) for the CERP ASRRS (USACE and SFWMD, 2003).

1.3 PMP and ERA Guideline Summary

Figure 1.1 illustrates the USEPA framework for the ERA. An ERA evaluates the likelihood that adverse ecological effects may occur as a result of the exposure of receptors to one or more stressors (such as water quality changes from ASR implementation). This is a "flexible process for organizing and analyzing data, information, assumptions, and uncertainties to evaluate the likelihood of adverse ecological effects." Within the ERA framework, *stressors* are defined as any physical, chemical, or biological entity that can induce an adverse response. *Receptors* are typically the valued ecological components that will be exposed to stressors. ERA "provides a critical element for environmental decision making by giving risk managers an approach for considering available scientific information along with the other factors they need to consider (e.g., social, legal, political, or economic) in selecting a course of action" (USEPA, 1998).

As shown in the figure below, the ERA includes three primary phases:

- Problem formulation;
- Analysis; and
- Risk characterization.

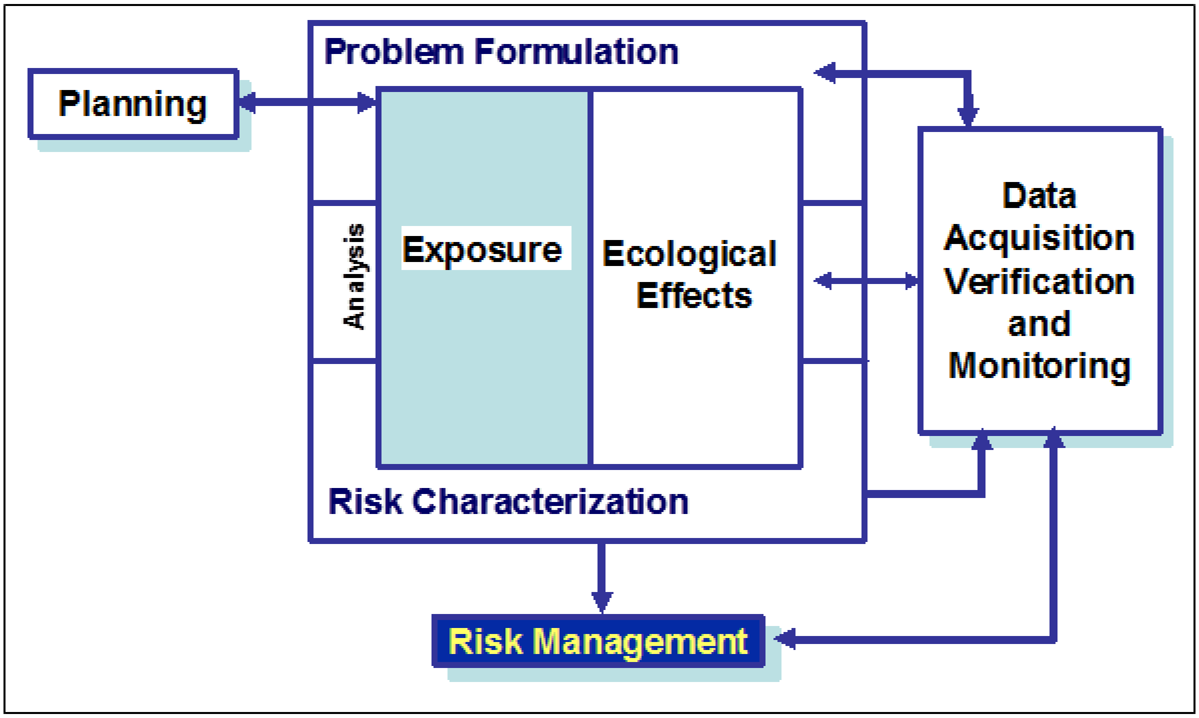


Figure 1.1. Ecological Risk Assessment Framework (USEPA, 1998).

In problem formulation, risk assessors evaluate goals and select assessment endpoints, prepare the conceptual model, and develop an analysis plan. During the analysis phase, assessors evaluate exposure to stressors and the relationship between stressor levels and ecological effects. In the third phase, risk characterization, assessors estimate risk through integration of exposure and stressor-response information, describe risks by discussing lines of evidence and determining ecological adversity, and prepare a report. The interface among risk assessors, risk managers, and interested parties during planning of the risk assessment is critical. Communication of risks at the end of the assessment is equally as important to ensure that the results of the assessment can be used to support management decisions (USEPA, 1998).

1.4 Risk Assessment Team

To facilitate the above activities, an interagency Risk Assessment Team was organized and tasked with the development of the data and models to be ultimately used in the ERA. The members of this team include scientists and engineers from the US Army Corps of Engineers, South Florida Water Management District

(SFWMD), Florida Department of Environmental Protection (FDEP), US Fish and Wildlife Service (USFWS), USGS, Florida Fish and Wildlife Conservation Commission (FFWCC), and Golder Associates, Inc. The team met quarterly or semi-annually during the development and execution of the study elements from 2004 through 2013.

1.5 Organization of the ERA

This report follows the outline recommended by USEPA (1998) as follows:

- Section 2.0 – Planning
- Section 3.0 – Ecological Risk Assessment
- Section 4.0 – Problem Formulation
- Section 5.0 – Analysis Phase
- Section 6.0 – Risk Characterization
- Section 7.0 – Conclusions
- Section 8.0 -- Recommendations

Due to the large volumes of data and models used for this ERA, much of this information is included in the Appendices.

2.0 PLANNING

2.1 Study Scope

The ERA process is typically used to organize and evaluate scientific information to quantify the potential risks, as well as benefits, associated with complex actions that resource managers may choose to implement. In the case of the CERP, ASR is one of several technologies that resource managers may implement to increase water storage capacity in south Florida, including the Everglades. Other water management strategies such as surface storage are not addressed here. In keeping with the RASRS scope, this ERA will organize, analyze, and present scientific information related to the environmental quality issues identified by the ASR Issues Team and CROGEE. This ERA will address a limited set of management options (scenarios) associated with full, partial, and no CERP ASR implementation. This ERA will focus on the CROGEE recommendations related to key ecological resources in the South Florida ecosystem that could be affected by regional ASR implementation. Geographically, the ERA focuses primarily on the Kissimmee River, Lake Okeechobee basin and the Greater Everglades.

The goals identified in the Restudy report are to enhance:

- Ecological values, and
- Economic values; and
- Social well-being.

Since the CERP ASR implementation is proposed as part of the larger Restudy plan, it follows that the general goals for CERP ASR should be the same overarching goals as the larger program. A set of ASR-specific ecological and watershed objectives was developed by the study team because regional CERP ASR implementation presents potentially unique ecological and human health risks. For the ERA, the following specific objectives were identified:

- Ensure that potentially toxic levels of ASR-related constituents are not released to surface waters in order to prevent significant water quality changes and subsequent contamination of sediments and biota;

- Contribute to the reduction in eutrophication potential of surface water bodies;
- Protect human health by reducing the ASR water quality contribution to the risk of methylmercury synthesis in the Everglades sediments, thus mitigating subsequent potential bioaccumulation by resource fish;
- Maintain self-sustaining native fish populations and their habitat, and diversity of native biotic communities; and
- Maintain water quality for designated uses throughout the watershed.

2.2 Data Gap Evaluation

Prior to the initiation of the cycle testing of the ASR Pilot Projects, data gaps were identified. Ecotoxicological data for ASR-recovered water was not available. Data collection was initiated by several agencies as part of the ASRRS, including information to screen potential constituents in ASR recovered water that could negatively impact fish and wildlife, vegetation, or human health. An Ecotoxicological Program to identify a set of tests to evaluate the ecotoxicity and bioconcentration potential of recovered waters was initiated by the SFWMD, and conducted by Golder Associates, Inc. to meet the PMP, CROGEE and ERA data requirements (Johnson, 2005).

To further refine the ecotoxicological program prior to Pilot Projects becoming operational, laboratory-generated and ASR recovered water from the Palm Beach County Water Utilities Department (PBCWUD) was used to evaluate the sensitivity of the set of tests selected (Johnson, Friant and Heintz, 2007). In order to evaluate bioconcentration of metals and radionuclides from ASR water, fish and freshwater mussel studies were added to the ecotoxicological program to fill this data gap. These methods were also evaluated using the bench-scale generated recovered water prior to the Pilot Projects.

3.0 ECOLOGICAL RISK ASSESSMENT

An *ecological risk assessment* is the scientifically based, systematic evaluation of potential risks to ecological systems from a human activity. Ecological risks are characterized in terms of the *exposure* of ecological systems or natural resources to a *stressor*, and the resulting ecological *effects* of that stressor on specified species, habitats, or other environmental resources of concern to society. A stressor is any physical, chemical, or biological entity that can induce an adverse response to a receptor. For an ecological risk to exist, two conditions must be satisfied (**Figure 3.1**):

1. The stressor (e.g., chemicals, physical) must be hazardous (have the inherent ability to cause adverse effects); and
2. The stressor must contact or be exposed to a receptor (e.g., a species, biotic community, ecosystem) for both sufficient intensity and duration to cause an adverse effect.

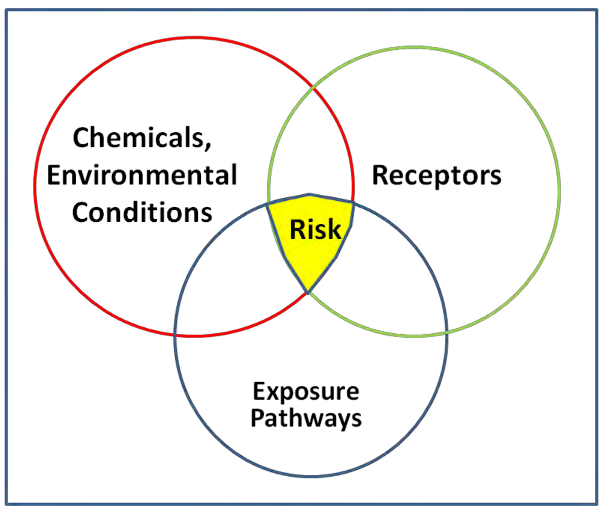


Figure 3.1. Elements of Risk

In the problem formulation phase, the three components of risk: stressors (chemicals, environmental conditions), receptors, and exposure pathways, are systematically screened in such a way that the remainder of the risk assessment deals only with the combinations of stressors, receptors and pathways that have the potential to cause adverse effects (risks).

In this study, the ecological risks from ASR regional scale implementation were assessed for South Florida ecosystems. A series of scenarios (number of ASR wells at specific locations) were evaluated and the potential risks and benefits characterized. An extensive ecological database and a well-developed set of sophisticated analytical tools (models) already existed to support these studies, but it was essential to apply and focus these tools onto the specific South Florida environments. This was done by the USACE, SFWMD, USGS, and the University of Florida.

The objective of this study is to address directly and in a scientifically defensible manner the real or perceived environmental issues (and benefits) concerning the implementation of a regional scale ASR system. Thus, the central question at hand is whether the implementation of this water management technology would result in ecological risks to ecosystems and humans in south Florida. The entire ERA (**Figure 1.1**) is aimed at answering that one question.

3.1 Technical Approach

This ERA follows the USEPA ERA framework (USEPA, 1998). The initial step, **problem formulation**, defines the site characteristics and the ecological conceptual model for the study. This step includes:

1. Compilation of existing data and information to characterize the ecological resources that could be affected by ASR recovered water discharges;
2. Acquisition and compilation of information related to the physical characteristics of the ecosystems (Lake Okeechobee, Greater Everglades);
3. Development of an ecotoxicological database for ASR recovered waters;
4. Development of a conceptual model and specific assessment endpoints for Lake Okeechobee and the Greater Everglades, using the expertise of local scientists and users of the ecosystems; and
5. Development of appropriate sets of plausible scenarios for ASR implementation.

The second step of the ERA is the **analysis** of the two fundamental components of ecological risks: *exposure and effects*. *Characterization of exposure* requires using models to predict the environmental fate and exposures of the assessment endpoints to the components of ASR water (stressors). This evaluation is conducted under a range of specific scenarios that might be implemented under environmental conditions that could occur at the time of ASR operations (e.g., Lake Okeechobee stage conditions).

The *characterization of effects* focused on those specific conditions that would be adverse to ecological resources in areas adjacent to ASR facilities. To support characterization of effects in a site-specific approach, the study expanded the existing environmental toxicity database for ASR recharge and recovered water by conducting selected toxicity and field studies on species indigenous to south Florida, as well as standard toxicity testing species, focusing on the particular ecological importance or societal value that these surrogates represented.

The third step of the ERA is *risk characterization*, in essence the integration of the exposure and effects quantifications. The fate of the ASR recovered water components was modeled using environmental fate and transport models developed by the USACE, SFWMD, USGS and others. Exposure scenarios for sensitive or important species/habitats (receptors and assessment endpoints) were developed for a suite of plausible ASR implementation alternatives. The scenarios indicate physical and water quality change distributions across important habitats of the lower Kissimmee River, Lake Okeechobee and the Greater Everglades, the cumulative exposures of key stressors, and modeled spatial distribution of secondary effects (e.g., mercury methylation in the Greater Everglades sediments). The analysis identifies areas of potential risk as well as water quality improvements, allowing direct comparisons of the ecological consequences of regional ASR implementation under different scenarios (number and location of wells). This provides the quantitative and scientific basis for answering the risk and benefit questions about implementation of ASR systems in the Lake Okeechobee Basin to meet the CERP goals.

3.2 Complexity of the ERA

Future full-scale implementation of the CERP, as envisioned in the Restudy (USACE, 1999), includes approximately 330 ASR wells in the FAS with a total capacity of approximately 1.7 billion gallons per day (bgd). **Figure 3.2** shows the locations of the six CERP ASR components. The downstream ecosystems that might be affected by ASR discharges are the Kissimmee River, Lake Okeechobee, Caloosahatchee Estuary, St. Lucie Estuary, Lake Worth Lagoon, connecting canals, and the Everglades Protection Area (Water Conservation Areas, Everglades National Park).

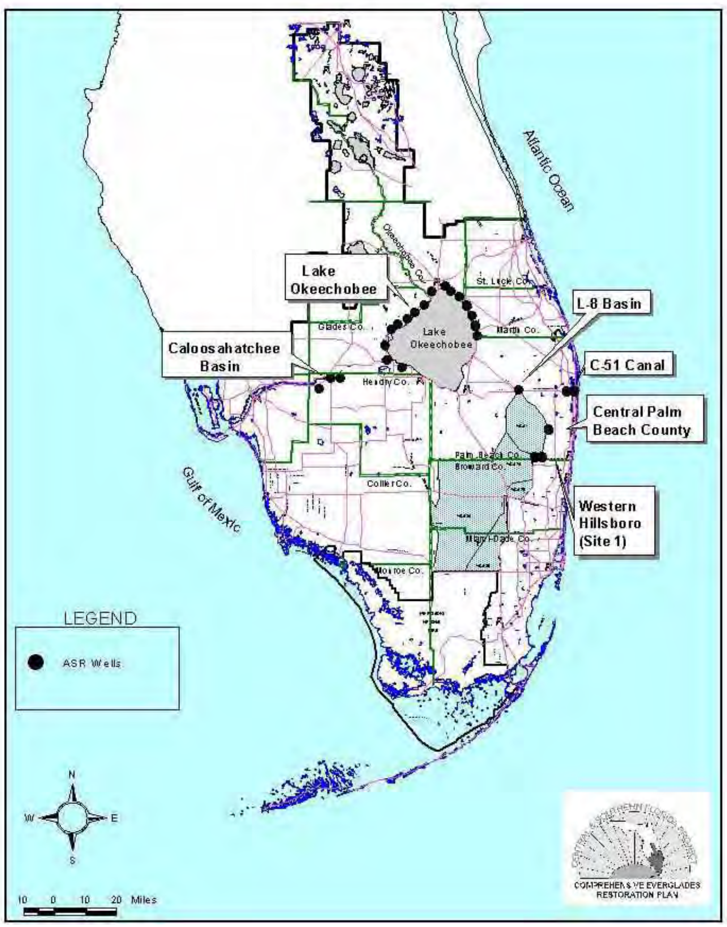


Figure 3.2. Proposed ASR Systems in the CERP ***(USACE, 2003)***

The extent to which storage and recovery of water from each of these ASR installations affects surface water ecology and human health is expected to be a complex function of the following physical, chemical, and biological processes:

- Potential for entrainment / impingement of receptors during recharge;
- Biological and chemical composition of the source water injected into the aquifer;
- Duration of storage;
- Geology of the aquifer unit;
- Degree of influx of aquifer water into the freshwater “bubble” during recovery; and
- Mixing ratio of recovered ASR water with natural surface water in the receiving ecosystem.

Physical impacts that might result include changes in water temperature, entrainment/impingement, mixing characteristics, light penetration, and sedimentation characteristics. Chemical impacts that might result include changes in pH, hardness, alkalinity, and the concentrations of dissolved organic carbon (DOC), DO, sulfate ($SO_4^{=}$), sulfide ($S^{=}$), metals (e.g., arsenic, cadmium, copper, mercury, and zinc) and radionuclides.

Biological impacts that might result include:

- changes in concentrations of bacteria, fungi, protozoa, phytoplankton and periphyton;
- stimulatory or toxic effects to primary producers;
- toxic effects to embryo-larval and adult fish and macroinvertebrates, macrophytes, and wildlife; and
- potential impacts on individual species at various life stages that could translate into subtle trophic level changes.

The ERA aspects of the RASRS plan, developed in 2002, were designed to combine extensive water quality and ecological testing at the five planned ASR pilot sites (Caloosahatchee, Moorehaven, Port Mayaca, Kissimmee River, and Hillsboro Canal) with hydrologic and water quality modeling in order to assess the ecological and human health risk associated with full-scale implementation of CERP ASR. Microcosm (laboratory), mesocosm (field), and pilot study (local receiving water) testing as well as hydrologic and water quality modeling were included in the original ASRRS plan to allow for successive scaling-up of study complexity in an effort to derive the long-term regional impact of CERP ASR implementation.

Given the inherent difficulty in extrapolating watershed scale impacts from short-term testing using single species results, the study planners acknowledged that there would be uncertainty in the predicted ecological and human health effects. Only two of the original five pilot ASR sites were constructed and operated. Despite the reduced availability of testing data from pilot sites, the goal of the ASRRS continues to be to quantify risks associated with CERP ASR implementation at a regional scale; however, the study narrowed its focus to the Lake Okeechobee Basin and the downstream Greater Everglades because these basins are most likely to be sensitive to ASR. The risk assessors have concentrated on quantifying risks associated with effects that are most likely to occur using a suite of standard and site specific tests and existing predictive regional water quality models. Studies conducted include standard USEPA acute and chronic toxicity tests, onsite flow-through and in-situ bioconcentration studies, regional field studies, and the use of regional surface water hydrology and water quality models.

3.3 CERP ASR Pilot Testing Program

The CERP plan included the ASR Pilot testing projects to investigate the engineering feasibility of ASR implementation at specific locations in south Florida. The ASRRS was initiated to investigate the hydrogeologic effects and some of the potential long-term, regional ecosystem effects of recovered water.

The KRASR and HASR pilot ASR facilities were commissioned and operated during the 2009 to 2013 period to gather hydrogeologic, water quality, and toxicological data **(Photographs 3.1 and 3.2).** The two photographs below show these two ASR Pilot project sites. Cycle testing is the permitted process through which ASR system performance is evaluated. A complete description of the CERP pilot project cycle testing at KRASR and HASR is included in the Central and Southern Florida ASR Pilot Project Technical Data Report (USACE, 2013).

Photograph 3.1. Kissimmee River ASR Pilot Facility.

Photograph 3.2. Hillsboro ASR Pilot Facility.

Figures 3.3 and 3.4 for the KRASR and HASR sites, respectively show the cumulative storage in the aquifer as affected by each of the cycle events. Both ASR systems had identical cycle test durations for cycle test 1, which consisted of one-month recharge, one-month storage, and approximately one-month recovery. Four cycle tests were conducted at KRASR and three at HASR.

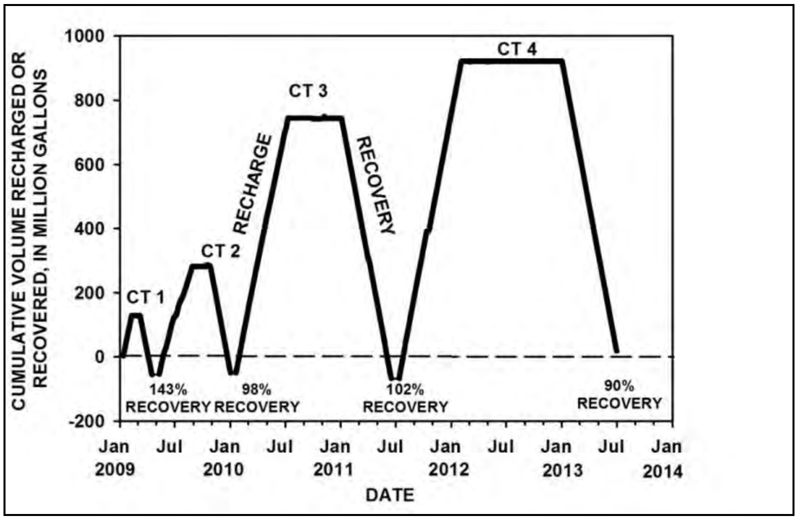


Figure 3.3. Kissimmee River ASR Cycle Testing

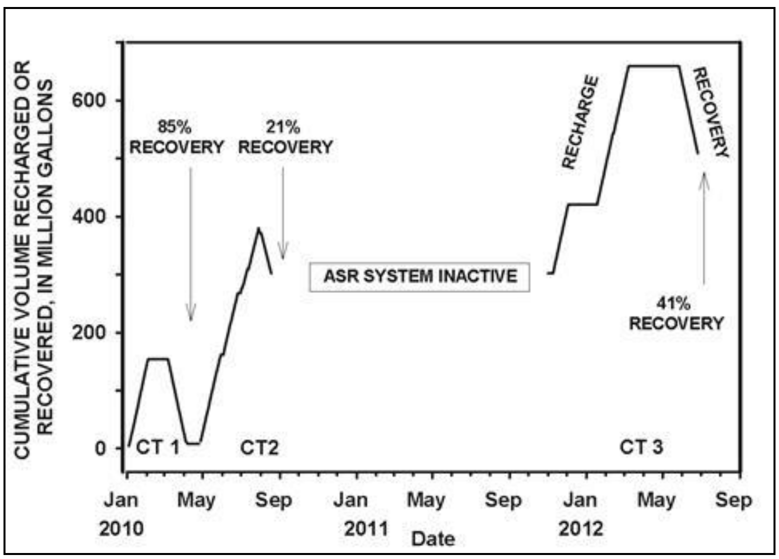


Figure 3.4. Hillsboro ASR Cycle Testing

The Kissimmee River and the Hillsboro Canal are classified as State of Florida Class III surface water with designated uses that include fish consumption, recreation, and propagation and maintenance of a healthy, well-balanced population of fish and wildlife. Lake Okeechobee which is the downstream water body for the Kissimmee River is classified as a Class I surface water body since it is used as a source of potable water. The ASR cycle testing programs were required through Underground Injection Control (UIC) and National Pollutant Discharge Elimination System

(NPDES) permits to comply with State and Federal regulations that protect both surface and groundwater quality. Surface water (recharge water) and native groundwater were characterized prior to and during cycle testing at both pilot sites so that water quality changes in the groundwater or recovered water could be identified and evaluated.

Ecotoxicological Program data was collected from the KRASR Cycles 1 through 4 including recharge and recovered water, as well field data collected in the vicinity of the ASR intake and discharge. HASR water was evaluated for ecotoxicological effects only as required by their FDEP permit.

4.0 PROBLEM FORMULATION

The Problem Formulation phase of the ERA is a process for "generating and evaluating preliminary hypotheses about why ecological effects … may occur, from human activities" (USEPA, 1998). In problem formulation, risk assessors identify stressors, affected receptors, select assessment endpoints, prepare the conceptual model, and develop an analysis plan (**Figure 4.1**). *Assessment endpoints* are the explicit expression of the environmental value that is to be protected and are usually defined as ecological entities and their attributes. A *conceptual model* is a written description and visual representation of predicted relationships between ecological entities and the stressors to which they are exposed.

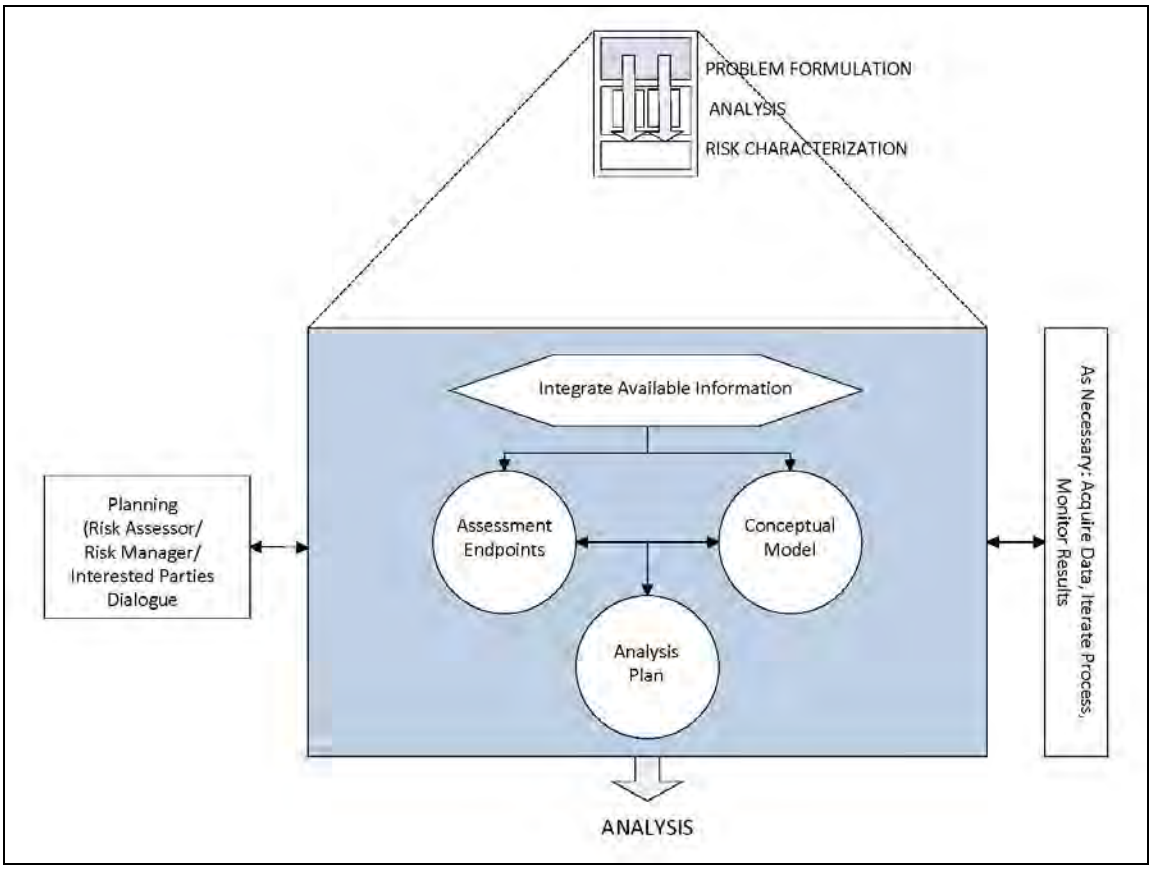


Figure 4.1. Problem Formulation (USEPA, 1998)

In 2003, the USACE published the ASRRS PMP. This project management plan preliminarily identified potential stressors and receptors and the tasks necessary to assess the ecological and water quality effects of regional ASR implementation. A plan for summarizing ecological affects in an EEE report was outlined in Appendix L of the ASRRS PMP. The original PMP study plan included ecotoxicological studies, a mercury methylation assessment, surface water quality (water quality monitoring and modeling), aquatic community characterization (benthic, fish communities, aquatic macrophytes, and a fish consumption survey). The USACE, SFWMD, USFWS and Golder initiated ERA planning meetings during 2005 to further develop the ecological effects hypotheses. These meetings included hydrogeologists and groundwater modelers so that the ERA team had a full understanding of the CERP ASR implementation alternatives under consideration. The team reviewed the overall ASR implementation plan and the predicted recovered water quantity and quality. The CROGEE publications (2001 and 2002), and the ecological and water quality studies outlined in Appendix L of the Regional ASR PMP (USACE, 2003) were reviewed. During these meetings, the team developed the initial planning questions below:

- What is the nature of the problem and the best scale for the assessment?
- What are the management goals and decisions needed, and how will risk assessment and benefit analysis help?
- What are the ecological values (entities and ecosystem characteristics) of concern?
- What is the local and regional ecosystem of concern?
- What are the critical ecological endpoints and ecosystems and receptor characteristics?
- If there is an effect, what is the likelihood of recovery or how can these effects be avoided or mitigated?
- What is our state of knowledge of ASR recovered water effects?
- What data and data analysis (and models) are available and appropriate for use?
- Who are the regional experts?
- Is a phased approach an option?
- What guidance is available to conduct this ERA?

To address these questions, sub-teams were formed to affirm or modify the Appendix L study plan and execute targeted studies.

- A Biology Sub-Team - Tasked with developing an Ecotoxicological Program to meet the needs of the ERA. This Team included representatives from the USACE, SFWMD, USFWS, FDEP, Florida Fish and Wildlife Conservation Commission (FFWCC), University of Florida, and Golder (Contractor to USACE and SFWMD).

- A Surface Water Modeling Sub-Team – Led identification of the available regional water quality models and scoping the exposure modeling needed for the ERA.

- Baseline Aquatic Data Collection Sub-team - The SFWMD conducted ongoing aquatic baseline studies at all the pilot projects as well as other regional ecological studies.

- Ecosystem Level Risk Assessment Sub-team - The USFWS conducted the ecosystem level risk assessment on fisheries and West Indian manatees.

- Fisheries Sub-team - The FFWCC conducted fishery studies in the Lake Okeechobee basin.

- Mercury Methylation Subteam - The USGS and University of Florida performed modeling and analysis to evaluate the potential for changes in mercury methylation in Lake Okeechobee and the Greater Everglades.

4.1 Initial Identification of Stressors

In the context of this study, stressors are defined as those physical and chemical conditions that when altered as a result of ASR implementation, may induce an adverse response on organisms or ecosystem function. Potential physical, chemical, and biological effects can be anticipated from ASR recovered water quality. Additionally, changes to the bioaccumulation potential of metals may occur in the receiving environments.

It is important to note that ASR could also result in environmental benefits since recovered water may augment scarce surface water supplies during drought or may have less color and lower nutrient concentrations than the source water body. The preliminary list of stressors shown in **Table 4.1** was developed using the Biology Sub-team's knowledge of south Florida freshwater and estuarine habitats, surface water and groundwater quality, site specific hydrogeology, and operational water quality data collected at utility-owned ASR sites located in Florida. The preliminary stressors were organized into five groups:

- general water quality constituents,
- nutrients,
- dissolved solids,
- metals, and
- radionuclides.
- Physical Effects

Table 4.1 -- Initial Stressors Selected for the ASR ERA

Stressor	Receptors of Concern/Indicator Organisms	Freshwater or Estuarine Habitat	Likely Effects
		NUTRIENTS	
TP, OPO_4, TN, NOX, NH_4	Macrophytes, Phytoplankton, Periphyton	Freshwater	Shift in community composition toward more or less pollution tolerant species.
		GENERAL WATER QUALITY CONSTITUENTS	
Color	Macrophytes, Phytoplankton, Periphyton	Freshwater	Shift in community composition toward more or less pollution tolerant species
Temperature	Fishes, Macrophytes, Phytoplankton, Manatees	Freshwater and Estuarine	Mortality, growth, reproduction
pH	Phytoplankton, Macrophytes, Invertebrates, Fishes	Freshwater	Change bioavailability of metals in water column due to increased pH
Dissolved oxygen	Fishes, Invertebrates, Macrophytes	Freshwater and Estuarine	Mortality, growth, reproduction
		DISSOLVED SOLIDS	
Specific conductance	Algae, Macrophytes, Invertebrates	Freshwater	Shift in community composition toward more pollution tolerant species

Chloride	Algae, Macrophytes, Invertebrates, Fishes	Freshwater	Shift in community composition toward more pollution tolerant species
Sulfate SO_4^{-2}. Sulfide S^{-2}	Macrophytes and Fish (affects mercury methylation)	Freshwater	Growth, fish mercury bioaccumulation
Hardness: Ca, Mg, Mn, K	Algae, Macrophytes, Invertebrates	Freshwater	Mortality; metal bioavailability; community composition shift
TSS, and precipitate formation	Macrophytes, Macroinvertebrates	Freshwater	Physical damage; community composition shift
Fe	Macrophytes	Freshwater	Growth, community composition shift
TRACE METALS			
Hg, total and methyl	Higher trophic level organisms including humans, macrophytes	Freshwater and Estuarine	Mortality, growth, reproduction, and development. Bioaccumulation in food web.
As	Higher trophic level organisms including humans, macrophytes	Freshwater and Estuarine	Mortality, growth, and reproduction
Mo	Fishes, Invertebrates, Macrophytes	Freshwater and Estuarine	Mortality, growth, and reproduction
Al, Se, Cd, Cr, Ni, Zn, B	Macrophytes, Fishes, and Invertebrates	Freshwater and Estuarine	Bioconcentration, community composition shift
RADIONUCLIDES			
Combined Radium, gross alpha (PCI/L)	Humans via fish/shellfish consumption	Freshwater and Estuarine	Human Health
PHYSICAL EFFECTS			
Entrainment and Impingement	Fish	Freshwater	Mortality and reproduction

Potential changes in the water quality of recovered water are discussed in Section 5 (Analysis). **Table 4.2** presents the estimated initial (pre ASR operations) surface and groundwater quality conditions and the ratio of aquifer concentrations to surface water concentrations which provides an indication of the potential for water quality changes to the receiving water at both ASR pilot sites. To highlight stressors that may pose the greatest risk, concentration ratios greater than 2.0 are shown in bold in this table. Dissolved oxygen (DO) is not included in Table 4-2 since re-aeration equipment at the two sites ensures that the minimum DO levels are maintained during discharge operations.

Table 4.2 -- Ratio of Upper Floridan Aquifer Groundwater Concentrations to Surface Water Concentrations for Selected Stressors

		Kissimmee River ASR Site			Hillsboro Canal ASR Site		
Stressor	**Units**	**Surface Water at ASR Site**	**Upper Floridan Aquifer (UFA)**	**Ratio of UFA to Surface Water**	**Surface Water at ASR Site**	**Upper Floridan Aquifer (UFA)**	**Ratio of UFA to Surface Water**
Nutrients							

Total Nitrogen	mg/L	1.803	0.35	0.2	1	0.66	0.7
Total Phosphorus	mg/L	0.053	< 0.01	0.2	0.033	0.026	0.8
General Water Quality Constituents							
Color	PCU	94	< 5	0.1	100	10	0.1
Temperature	°C	20-30	25		23-30	27	
pH	units	7.5	8		7.4	7.6	
Dissolved Solids							
Alkalinity	mg/L CaCO3	59	91	1.5	210	130	0.6
Hardness	mg/L CaCO3	100.6	340	**3.4**	260	940	**3.6**
Spec. Conduct.	uS/cm	204.4	1368	**6.7**	600	5370	**9.0**
TDS	mg/L	151.5	820	**5.4**	438	2800	**6.4**
Bicarbonate	mg/L CaCO3	45.4	90	**2.0**			
Chloride	mg/L	28	250	**8.9**	94	2100	**22.3**
Sulfate	mg/L	18.54	200	**10.8**	38	420	**11.1**
Sulfide	mg/L	0.05	0.8	**16**	0.05	2.8	**56**
Calcium	mg/L	26	53	**2.0**	70	158	**2.3**
Magnesium	mg/L	6.25	39	**6.2**	13	182	**14**
Sodium	mg/L	7	140	**20**	40	1228	**30.7**
Potassium	mg/L	0.1	8.3	**83**	40	46	1.2
TSS	mg/L	5.5	< 1	0.2	6	22	**3.7**
Iron	mg/L	0.55	0.027	0	0.34	0.58	1.7
Trace Metals							
Total Mercury	ng/L	1.83	<1		0.14	0.05	0.4
Methylmercury	ng/L	0.16			0.16		
Arsenic	ng/L	0.002			0.0035		
Antimony	ng/L	0.005			< 0.005	< 0.003	0.6
Aluminum	ng/L	0.08			0.05	< 0.1	**2.0**
Cadmium	ng/L	0.0007	0.0007	1.0	0.00017	0.001	**5.9**
Chromium	ng/L	0.0015	0.0018	1.2	0.0017	0.00083	0.5
Nickel	ng/L	0.0014	0.0014	1.0	0.0012	0.002	1.7
Selenium	ng/L	0.002	0.002	1.0	0.0042	0.0062	1.5
Zinc	ng/L	0.006	0.01	1.7	0.0042	0.003	0.7
Radionuclides							
Radium 228	pC/L	1.2	2.27	**2.0**	0.0512	1.89	36.9
Gross Alpha	pC/L	1.7	< 3.29		2		

This ERA considered the ways ecosystem characteristics directly influence when, how, and why particular ecological entities may become exposed and exhibit adverse effects due to a particular stressor. The following discussion presents information on each of the groups of stressors identified.

4.1.1 Nutrients

The Upper Floridan Aquifer (UFA) to receiving water concentration ratios shown in **Table 4.2** shows that native groundwater has lower nutrient (nitrogen and phosphorus) concentrations than found in ambient surface water at the Kissimmee and Hillsboro ASR pilot sites. Thus, just through dilution, CERP ASR operations are expected to reduce the total nutrient load present in surface water since not all of the injected water will be recovered and some native groundwater will be discharged into surface water bodies. It is also anticipated that phosphorus could be retained in the aquifer as a result of chemical/physical processes that occur during storage of ASR water. If ASR related reduction in nutrient loads are significant, an ecosystem community shift to a less eutrophic status could occur.

4.1.2 General Water Quality Constituents

The data in **Table 4.2** indicates that water discharged from ASR systems should have somewhat reduced color as a result of blending with native groundwater. Reduced color can increase light penetration and result in increased algae and macrophyte growth. The temperature of recovered water may be several degrees warmer or colder than the receiving surface water depending on the time of year. In the winter, recovered water temperature may be warmer than the ambient surface water temperature and thus provide a warm water refuge for fish, manatees, and other aquatic life. In the spring time, recovered water might be colder than normal ambient surface water temperature and thus affect fish spawning. The pH of the recovered water may differ from ambient surface water pH conditions and result in a change in the bioavailability of trace metals which may affect algae, invertebrates, and fish. Though DO is included in the list of stressors, presumably all future CERP ASR facilities, like the pilot sites, will include a re-aeration treatment unit so that discharged water meets the DO surface water criteria. However, considering that Florida surface waters may have DO concentrations less than 2 mg/L, it is possible that ASR could become an attractive nuisance if it temporarily and artificially improves stream conditions, but then it is shut off (and the DO drops to lethal levels through natural environmental conditions).

4.1.3 Dissolved Solids

Table 4.2 shows that concentrations of many of the dissolved solids are significantly higher in the groundwater than in the surface water. Chloride, sulfate, sulfide, magnesium, sodium, and potassium concentrations in the UFA groundwater are more than 10 times greater than that of either the Kissimmee or Hillsboro surface water. Though specific conductivity and chloride concentrations in the UFA are less than 10 times greater than surface water concentrations, they are known to exceed the Class I and III surface water criteria in areas where CERP ASR systems are planned. Additionally, if ASR wells are completed into lower Floridan Aquifer zones such as the Avon Park Producing Zone (APPZ) which has significantly higher dissolved solids content, ASR discharges may have even higher dissolved solids concentrations than those in **Table 4.2**. However, it is likely that the quantity of water recovered at these ASR systems will be constrained by the requirement that discharges not exceed water quality criteria for chlorides and specific conductivity. Many of the dissolved solids stressors could affect freshwater algae, invertebrates, and macrophytes by altering growth and reproduction. Discharge of sulfate may result in an increase in the rate of methylmercury (MeHg) production, with subsequent bioaccumulation and biomagnification up the food chain.

4.1.4 Trace Metals

Although none of the baseline UFA trace metal concentrations in **Table 4.2** exceeded Class III surface water standards, most of these constituents were included in the stressor list because their concentrations in the recovered water can be significantly affected by dissolution / precipitation / absorption that occurs during storage or other storage zones (e.g. APPZ) and locations might have higher baseline groundwater concentrations for these constituents. For instance, arsenic has been measured in ASR recovered water at concentrations well in excess of ambient groundwater concentrations at more than 10 ASR sites in Florida. Total mercury and methylmercury are not expected to be present at elevated concentrations in the recovered water; however, other constituents such as sulfate and sulfide contained in the recovered water may alter the existing mercury methylation rates in the receiving waters and thus increase the potential for bioaccumulation of mercury by aquatic life.

4.1.5 Radionuclides

Radionuclides are present in the UFA and APPZ groundwater at concentrations typically at levels below Class III surface water criteria but that exceed the background surface water levels. If present in the recovered water, it is possible that they may bioaccumulate in freshwater biota. For instance, Brenner (2000) found relatively high levels of the bioaccumulation of Ra226 in freshwater mussels living in a Florida freshwater lake despite low lake water concentrations of Ra226. Bioaccumulation of radionuclides in freshwater mussels could result in adverse wildlife or human impacts if the mussels are harvested for consumption.

4.1.6 Physical Effects (Entrainment and Impingement)

Physical effects to planktonic species (and early life stages of fish and invertebrates) due to entrainment and impingement by the water intakes were also considered as a potential stressors. The pumping of surface water during recharge represents a potential threat to fish and other aquatic resources at the intake structure. Entrainment occurs when an organism is drawn into a water intake and cannot escape. Impingement occurs when an entrapped organism is held in contact with the intake screen and is unable to free itself. The severity of the impact on the fisheries resource and habitat depends on the abundance, distribution, size, swimming ability, and behavior of the organisms near the intake, as well as water velocity, flow and depth, intake design, screen mesh size, installation and construction procedures, and other physical factors (Canadian Department of Fisheries and Oceans, 1995).

4.2 Assessment Endpoints

In developing assessment endpoints, it is important to select ecosystem characteristics that are critical to ecosystem function. Ecologically relevant endpoints may contribute to the food base (primary production), provide habitat (for food or reproduction), promote regeneration of critical resources (decomposition of nutrients), or reflect the structure of the community, ecosystem, or landscape (species diversity) (USEPA, 1998). Two elements are required to define an assessment endpoint. The first is the identification of the specific valued ecological entity. This can be a species, a community (such as benthic invertebrates), an ecosystem (Lake Okeechobee, Caloosahatchee Estuary), a specific valued habitat, a unique place (Greater Everglades), or other entity of concern. The second is the characteristic about the entity of concern that is potentially at risk and important to protect. The appropriate measures of effects will be identified in the conceptual model and will be discussed in the analysis plan.

Risk managers are more likely to use a risk assessment to make decisions when it is based on ecological values that people care about. Thus, candidates for assessment endpoints can include endangered species or ecosystems, commercially or recreationally important species, functional attributes that support food sources, or charismatic species such as manatees.

Based on the ERA teams understanding of ASR stressors modes of action, fate and effects in south Florida ecosystems, the following assessment endpoints were selected:

- Reproducing Populations of Native Fish;
- Survival and Reproduction of Fish and Aquatic Invertebrates;
- Periphyton and Algae Species Diversity and Abundance, and submerged aquatic vegetation (SAV); and
- Human Health and Wildlife Protection.

4.2.1 Reproducing Populations of Native Fish

Native fish can be impacted by the chemical composition of the recovered water as well as the temperature of discharged ASR water and mechanical entrainment of its larvae and juveniles associated with the pumps that withdraw recharge water from the surface water bodies. Water discharged from ASR wells into surface water bodies such as the Kissimmee River may alter the thermal suitability of fish spawning habitat which may directly affect fishery reproduction. Additionally, the action of extracting recharge water from surface water bodies may impinge or entrain invertebrates, fish fry and eggs as they pass through the screens and the pumps. This could reduce the food source for fish and invertebrates. The Kissimmee River and Lake Okeechobee have fisheries that are important for recreation, tourism, and subsistence fishing.

4.2.2 Survival and Reproduction of Fish and Aquatic Invertebrates

Extended contact with aquifer material and/or the mixing of connate groundwater with recharge water is likely to change the chemistry of the recovered water. The pH, alkalinity and hardness, in the recovered water are likely to be higher than in the receiving waters thus potentially affecting sensitive aquatic species. Increased trace metal concentrations in recovered water could impact algae or diatom primary production, affecting higher tropic levels such as macroinvertebrates and fish. Immediately downstream of the facility outfalls, exposure to ASR recovered water may last for some time after a recovery event. The concentration of various constituents (trace metals, nutrients, hardness, etc.) in the recovered water will change over the span of a recovery event as more recovered water is discharged. Aquatic animals directly downstream of the discharge could experience toxicity as a result of direct exposure to the recovered water or from exposure to a mix of recovered water and surface water. If significant in magnitude and duration, physical and chemical impacts from ASR discharges, could cause subtle and non-subtle biological changes in the south Florida ecosystem. Important attributes to these ecosystems include fish reproduction (embryo-larval-juvenile stages), growth and development, and invertebrate life stages.

4.2.3 Periphyton and Algae Species Diversity and Abundance and Submerged Aquatic Vegetation

Periphyton are ubiquitous in the Kissimmee River, Lake Okeechobee and the Everglades. Periphyton communities have been used as indicators of ecosystem health. The periphyton growing on stems of emergent plants in the river and lake shore, and in the littoral marsh are directly in contact with surface water, and as such, are sensitive indicators of water quality (Vymazal, 1995). Because periphyton form the base of a food web that supports fish and other organisms in the aquatic near-shore and littoral areas, changes in periphyton taxonomic structure and/or biomass can affect the organisms at higher trophic levels (Havens et al. 2001). The recovered water is likely to have reduced nutrient concentrations, increased total dissolved solids, and increased light transmittance. The changed chemistry could potentially alter periphyton and SAV species diversity and abundance which are assessment endpoints of interest.

4.2.4 Human Health and Wildlife Protection

The proposed CERP ASR implementation could affect wildlife through the potential for increasing the methylation of mercury in sediments, resulting in increased bioaccumulation of methylated mercury in wildlife. Human consumption of these fish could affect their health.

The ASR discharge water itself will not contribute to the existing mercury load in the surface water environment; however, the potential exists for increased loading of methylation precursors such as sulfate and iron may alter the rate at which mercury is methylated and subsequently bioaccumulated. Methylmercury is synthesized by sulfate-reducing bacteria (Jensen and Jernelov 1969) in the presence of inorganic mercuric ion, $Hg(II)^{+2}$, and sulfate, $SO4^{-2}$, but in the absence of DO. Once produced, methylmercury is rapidly taken up but only slowly eliminated from the bodies of aquatic organisms (Norstrom et al. 1976). The rate of clearance tends to decrease with increasing body size, so that top-predator fish like the largemouth bass (*Micropterus salmoides*) may bioaccumulate as much as 10,000,000 times the concentration of methylmercury in the surrounding water (Watras, 1992). Methylmercury is a potent neurotoxic compound, and USEPA (1997) recommends that fish contain no more than 0.3 milligram per kilogram (mg/kg) wet weight to protect humans pursuing a typical diet.

Sulfate and iron have been demonstrated to stimulate methylmercury production in controlled mesocosm experiments (Yu, et al, 2012). Stored ASR water will mix with connate water and may increase the loads of sulfate and iron in the receiving waters adjacent to and downstream of CERP ASR facilities. It is possible that methylation rates in downstream water bodies may change as a result of these discharges. Increased bioaccumulation of methylmercury in prey species would result in biomagnification of mercury in predators. In turn, anglers and hunters as well as higher trophic level species (birds, alligators, etc.) may be exposed to higher concentrations of mercury.

Manatees, a federally listed endangered species, may be affected by the ASR operations as a result of the discharge of water that is warmer than the ambient receiving water during the colder months of the year. This “attractive nuisance” of warm water discharges may adversely impact manatees if the ASR systems are abruptly shut off after manatees have congregated at ASR outfalls during cold periods.

4.3 Conceptual Model

A conceptual model is one of the early components in preparing for and estimating ecological risks to aquatic and terrestrial organisms and is generally a written and/or diagrammatic description of the potential interactions of various ecological receptors (collectively or individually) with environmental stressors. Conceptual models consist of two principal components (USEPA, 1998):

- A set of risk hypotheses that describe predicted relationships among stressor, exposure, and assessment endpoint response; and
- A diagram that illustrates the relationships presented in the risk hypotheses.

The objective of the Conceptual Ecological Model (CEM) developed for this ERA is to facilitate in the visualization of the relationships between ASR regional implementation and the potential ecological risks to organisms living in and around the receiving waters. To get a better understanding of the south Florida ecosystem, the ERA team reviewed the special edition of the journal Wetlands which presented a Total Systems Model and 11 south Florida regional CEMs as a restoration framework to support the integration of science and policy that are key components of the CERP (Journal of the Society of Wetland Scientists: Volume 25, No. 4, December 2005).

The preliminary hypothesis as stated in the ASRRS PMP was:

> "If water quality characteristics of the recovered water affect surface water quality at the Pilot ASR projects, in the near field environment, and the Everglades, there is a potential for various effects on flora and fauna in these receiving waters."

To expand upon this hypothesis, a preliminary ASR CEM, shown in **Figure 4.2**, was developed during the initial Ecotoxicology Program (Johnson et al., 2007) to illustrate the relationships between the biological components expected to be found in water bodies such as the Kissimmee River, Lake Okeechobee, and Hillsboro Canal. As part of this ERA, this initial CEM was expanded to include all aspects of ASR implementation, beyond ASR recovered water quality changes, and it is discussed in Section 5.0 Analysis Phase.

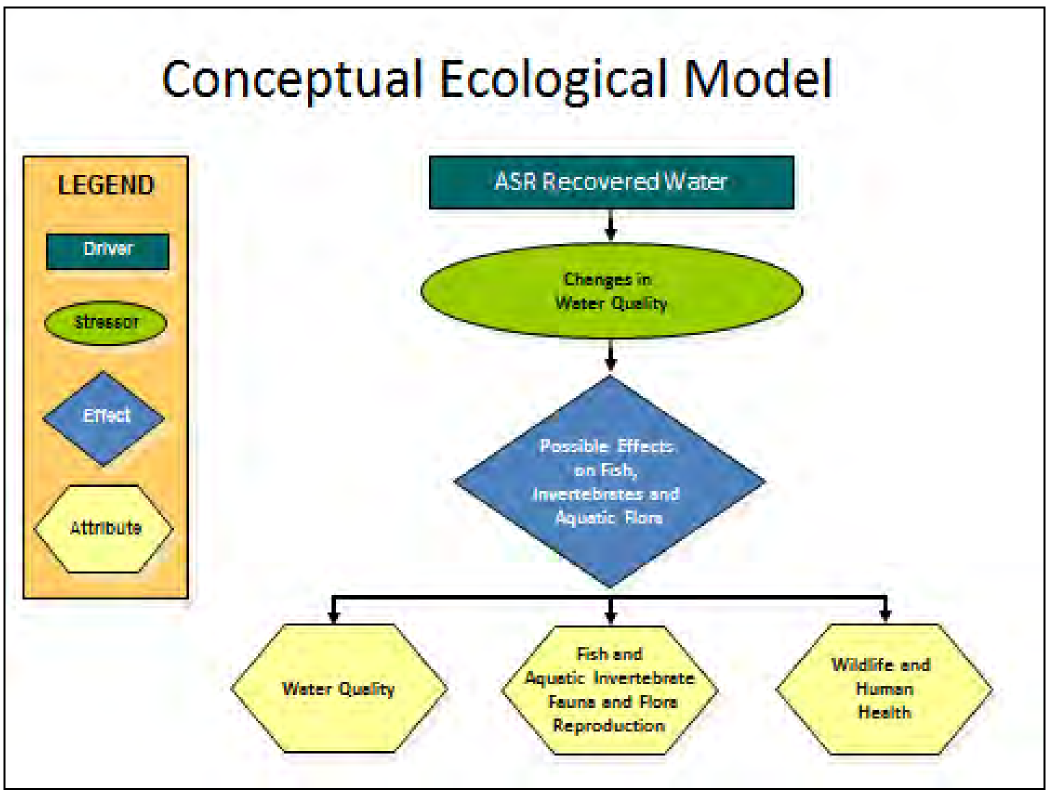


Figure 4.2. Initial Conceptual Ecological Model following the Everglades Restoration Program Methodology (Ogden et al., 2005)

The ERA team re-worded the initial PMP hypotheses and developed secondary hypothesis and benefit hypothesis in conjunction with the creation of a higher level CEM diagram.

Revised Primary Hypothesis:

> "Water quality of the recovered water does not negatively affect surface water quality downstream of the point of discharge to the level where negative effects on native flora and fauna are measurable in the local or regional level (Lake Okeechobee and Greater Everglades)."

Secondary Effect Hypotheses:

1. Would extended contact of recharge water with aquifer material change the chemistry of the recovered water? Would recovered water meet applicable surface water quality standards during discharge? The pH, alkalinity and hardness of the recovered water are likely to be greater than the surface water, especially in certain areas of the Greater Everglades.
2. Would trace metals and radionuclides leach from the aquifer material during the storage period? Increased trace metal concentrations could impact algae and diatom primary production.
3. Acute or chronic effects are observed on representative species at various life stages.
4. ASR related changes in sulfate load delivered to Lake Okeechobee and the Greater Everglades does not result in increased methylation and potential bioaccumulation of mercury by fish and wildlife.
5. If the dissolved solids concentrations in recovered water exceed mineral solubility, spontaneous calcium carbonate and gypsum precipitation due to supersaturation may occur as the recovered water is discharged into the receiving water. Could this affect light penetration and the character and rate of sedimentation in the downstream environment?
6. What are the potential effects of alkalinity changes in the receiving water?
7. What are the potential effects of changes in dissolved gases in the receiving waters?
8. Lake Okeechobee Basin ASR will reduce phosphorus concentration and load.
9. Surface water quality changes from recovered water do not have a measurable negative effect on local periphyton communities.

10. Do recovered water discharges effect SAV?
11. Benthic macroinvertebrates will be affected by ASR discharges.
12. Manatees will not be negatively affected by the thermal profile at the point of ASR discharge or at the local level.
13. The entrainment of fish larvae/eggs or invertebrates by the ASR intakes does not have an effect on the local fisheries.
14. The temperature and dissolved oxygen of recovered water discharge does not negatively affect fisheries at the point of discharge or in the local ecosystem.
15. What are the effects of ASR on Lake Okeechobee Fishery?
16. What are the effects of recovered water on other potential Lake Okeechobee Basin ASR sites?

Benefit Hypotheses:

- ASR discharges increase water clarity at the local level (Kissimmee River and other canals) resulting in increased submerged vegetation biomass or spatial extent, thus providing additional habitat for fish and shellfish.
- ASR reduces the concentrations of total phosphorus and/or total nitrogen in surface waters at the local level.
- Lake Okeechobee stage changes (due to ASR) results in increased submerged vegetation (adding water during low and removing peak at storms).
- Lake Okeechobee stage changes (due to ASR) do not result in increased SAV (adding water during low and removing peak at storms).

These initial hypotheses were used to sort through a large number of stressor-effect relationships, the ecosystem processes that affect them, and to select the final risk hypotheses to be evaluated in the Analysis Phase of the ERA.

The ERA team considered developing separate CEMs for each of the primary ecosystems (Kissimmee River, Lake Okeechobee, Greater Everglades) potentially impacted by CERP ASR; however, it was determined that a single CEM would be sufficient for all of the potentially affected ecosystems because they share similar ecological resources, management objectives and assessment endpoints. The final

CEM is provided in Section 5.0 Analysis phase. The format used for this CEM diagram is consistent with the previously developed conceptual models for south Florida that are represented by a driver (action/source of an environmental stressor), stressors (that which the system is responding to), effects (toxicity or other effects) and attributes (assessment endpoints of what is to be protected).

4.4 Analysis Plan

The Analysis Plan is the final step in problem formulation. Risk hypotheses were evaluated to determine how to assess them using available information. The following discussion presents the assessment design, data needs, data developed for the ERA, measures (effect, ecosystem and receptor characteristics, and exposure), and the methods for conducting the analysis phase of the ERA. The majority of the data were developed for the KRASR, and these results were extrapolated to other canals and water bodies.

The analysis plan was developed in a tiered manner and considered:

- Data availability and data generated;
- Surface water and groundwater characteristics;
- Recovered water characteristics;
- Measures of effect;
- Measures of ecosystem and receptor characteristics; and
- Measures of exposure.

4.4.1 Data Availability and Data Generated

The initial step in the development of the Analysis Plan was the evaluation of existing water quality, biological and toxicological data and information. Data gaps were identified and studies needed were identified and conducted. As the results from these studies became available, the original hypotheses were revisited, modified and additional data developed to reduce uncertainty. Intra-agency stakeholder meetings were organized and the tiered ERA framework was presented, discussed and modified as additional data became available.

A substantial volume of water quality data was developed through Pilot ASR testing at the two pilot projects (KRASR and HASR). These data included surface water and recovered water quality (**Appendix A**). Ecological data were also developed for all planned ASR pilot projects (TetraTech Inc., 2007), and regional biological data were compiled from the available literature.

An Ecotoxicology Program was carried out to develop site-specific aquatic toxicology data for these ASR Pilot projects (KRASR and HASR). The development of these data was tiered, peer-reviewed, and presented at stakeholder meetings. Based on the data collected, additional tests were conducted. Regulatory-based aquatic toxicity testing was also required and conducted.

4.4.2 Surface and Groundwater Characteristics

. The characterization of surface waters and groundwater at the KRASR and HASR pilot ASR facilities are summarized in Appendix A. **Table A-1** in Appendix A shows the range of major and trace inorganic constituents measured in recharge water at the KRASR site during cycles 1 through 4 (2009-2012). **Table A-11** shows the range of major and trace inorganic constituents measured in recharge water at the HASR site during cycles 1 through 3 (2010-2012). Surface water at the Kissimmee and Hillsboro sites generally met the applicable Class I and Class III water quality standards although phosphorus concentrations in the Kissimmee exceed the target lake phosphorus concentration of 40 ppb (**Table A-1**). Color and iron concentrations in the surface water at the Kissimmee ASR were highly variable over the course of pilot testing at this facility at times exceeding the Class I surface water criteria and the Safe Drinking Water Act, primary standards. Though Class I standards are not applicable at the Hillsboro site, the color and iron concentrations in the surface water at Hillsboro were well below those standards.

Groundwater quality measurements collected at the KRASR facility (**Table A-6**) show average concentrations of specific conductivity, and TDS that exceed Safe Drinking Water Act (SDWA) primary standards which are applicable to aquifers that are a primary drinking water source. Groundwater quality measurements collected at the HASR facility (**Table A-14**) show average concentrations of chloride, sulfate, sodium, specific conductivity, and TDS that exceed Safe Drinking Water Act (SDWA) primary standards.

4.4.3 Recovered Water Characteristics

Monitoring of recovered water discharge was conducted on weekly basis at the KRASR and HASR sites for: trace metals (As, Cu, Fe, Se, Mb, pathogens, specific conductivity, hardness, chloride, sulfate, sulfide, TOC, TSS, alkalinity, color, total Hg, MeHg, Total phosphorus pH, gross Alpha, turbidity, DO). The purpose of the water quality sampling was to measure changes in recovered water quality relative to recharge water as each recovery event proceeded. Results were intended to be used to determine total loads associated with discharge events as well as to identify potential ecological effects or water quality exceedances.

The quality of the recovered water from cycles 3 and 4 at the KRASR (**Table 4.3**) followed a typical pattern with the water quality closely matching the recharge (surface water quality) during the first few weeks of recovery. Towards the end of a typical recovery event, the recovered water quality becomes more similar to the baseline groundwater quality. For instance, specific conductivity in **Table 4.3** ranged from 416 µS/cm measured at the start of Cycle 4 to 1,021 µS/cm measured at the end. The baseline average surface water specific concentration from **Table A-1** at KRASR was 223 µS/cm and the baseline groundwater concentration from **Table A-3** at KRASR was 1,269 µS/cm. A similar pattern of increasing concentrations for TDS, Sulfate, Chloride, and Gross Alpha occurred as recovery proceeded most likely because these parameters are found at higher concentrations in the surface water than in the groundwater. Surface water quality exceedances were measured for arsenic and gross alpha at KRASR. Elevated arsenic concentrations occurred for the duration of the Cycle 1 and Cycle 2 event; however, during Cycle 3 and Cycle 4 the arsenic concentrations did not exceed the Class III criteria of 50 µg/L and only exceeded the Class I criteria of 10 µg/L during the first few weeks. Gross alpha exceeded the 15 pCi/L Class I/III criteria at 18.2 pCi/L on one occasion during Cycle 4.

Not as much recovered water quality data is available at HASR relative to the KRASR dataset because the HASR facility was operated for only three cycles and the recovery portion of these cycles did not last more than four weeks. The short recovery period at HASR is the result of having baseline groundwater concentration of TDS, and chloride well above water quality criteria for discharge of this water to surface water bodies. The quality of the recovered water from cycle testing at the HASR (**Table 4.4**) followed a typical pattern with the water quality closely matching the recharge (surface water quality) during the first few weeks of recovery. Like KRASR, towards the end of the recovery event, the recovered water at HASR quality becomes more similar to the baseline groundwater quality. The recovered water concentrations for color and iron were much less variable at the HASR site relative to the KRASR site. Arsenic concentrations in the HASR recovered water were lower than the applicable surface water criteria during cycle 4 and were generally lower than that observed at KRASR. Overall, the recovered water quality met the surface water criteria with the exception of DO which was observed to be below the 5 mg/L standard on several occasions.

Table 4.3 -- Summary of Major and Trace Dissolved Inorganic Constituents, Nutrients, and Radionuclides in the Recovered ASR Water at KRASR (EXKR-1 Well and POD) During Cycle 3 and Cycle 4

Constituent or Parameter	Unit	Criteria (Class I, III Surface Water Quality)	Value					
			Mean	Std Dev	Median	Maximum	Minimum	N
Nutrients								
Total N	mg/L		0.64	0.18	0.56	0.99	0.48	9
Phosphorus, Total as P	mg/L	0.04	0.014	0.015	0.011	0.078	0.004	48
General Water Quality Constituents								
Color	PCU	< 15	29	14	30	70	5	50
Temperature	° C		25.5	0.8	25.3	28.1	23.7	64
Specific Conductance	µS/cm	1275	756	173	775	1021	417	64
pH	Std units	6 to 8	7.9	0.2	7.9	8.1	7.0	64

Dissolved Oxygen (at POD)	mg/L	> 5.0	7.3	0.3	7.4	8.3	6.9	33
Turbidity	NTU	< 29	0.8	1.2	0.4	5.3	0.1	64
Dissolved Solids								
Total dissolved solids	mg/L		410	104	420	600	49	50
Hardness	mg/L							
Calcium	mg/L		39	4	39	45	31	30
Magnesium	mg/L		19	6	19	39	11	30
Sodium	mg/L		68.3	24.5	68.0	140.0	28.0	31
Potassium	mg/L		5.6	1.0	5.8	8.6	4.0	30
Sulfate	mg/L		94	32	100	140	0	50
Sulfide (at POD)	mg/L		0.46	0.22	0.46	0.90	0.02	27
Chloride	mg/L	<250	115	34	120	160	46	49
Tot Alkalinity as $CaCO_3$	mg/L	> 20	71	15	70	100	5	32
Diss. Organic Carbon	mg/L		5.4	1.8	5.0	9.7	3.3	24
Total Organic Carbon	mg/L		5.5	1.6	5.3	9.8	3.3	28
Trace Metals								
Aluminum	µg/L		5.2		5.2	5.2	5.2	1
Antimony	µg/L	< 4,300						
Arsenic	µg/L	< 10, <50	3.2	3.0	2.5	18.0	0.8	57.0
Cadmium	µg/L	< 0.23	0.043		0.0 43	0.043	0.043	1
Chromium	µg/L	< 73						
Copper	µg/L	< 7.9	1.4		1.4	1.4	1.4	1
Iron	µg/L		191	256	100	1400	43	53
Manganese	µg/L		6	9	2	32	2	12
Mercury (Ultra-trace)	ng/L	12	0.14	0.14	0.15	0.68	0.02	20
Methylmercury	ng/L		0.05	0.06	0.02	0.19	0.02	20
Molybdenum	µg/L		33.3	6.9	34.0	44.0	18.0	22
Nickel	µg/L	44.2						
Selenium	µg/L	< 5.0						
Zinc	µg/L	< 101	3		3	3	3	1
Radionuclides								
Gross Alpha, in pCi/L	pCi/L	15	5.3	3.6	4.5	18.2	1.2	26

Radium-226	pCi/L	5						

Summary of water quality data collected at KRASR at the EXKR-1 ASR wellhead and POD (point-of-discharge). Where analytical results were lower than the minimum detection limit (MDL), the reported MDL was used to compute summary statistics. Summary statistics were computed using a combination of the POD and EXKR-1 recovery data for all parameters except dissolved oxygen and sulfide since re-aeration at the cascade aerator affects these parameters. Blank table entries indicate that a parameter was not sampled or insufficient data exists to calculate the statistic.

Table 4.4 -- Summary of Major and Trace Dissolved Inorganic Constituents, Nutrients, and Radionuclides in the Recovered ASR Water at HASR (POD) During Cycle 3.

Constituent or Parameter	Unit	Criteria (Class III Surface Water Quality)	Value					
			Mean	Std Dev	Median	Maximum	Minimum	N
Nutrients								
Total N	mg/L							
Phosphorus, Total as P	mg/L		0.04	0.08	0.00	0.19	0.00	5
General Water Quality Constituents								
Color	PCU		42	28	40	80	1	5
Temperature	° C		27.0	0.9	27.0	28.3	26.2	5
Specific Conductance	µS/cm	1275	618	151	595	822	441	5
pH	Std units	6 to 8	7.3	0.2	7.4	7.5	7.0	5
Dissolved Oxygen (at POD)	mg/L	> 5.0	5.1	0.5	5.2	5.7	4.5	5
Turbidity	NTU	< 29	1.6	0.9	1.4	3.0	0.8	5
Dissolved Solids								
Total dissolved solids	mg/L		362	89	370	484	270	5
Hardness	mg/L							
Calcium	mg/L		51	15	56	65	30	5
Magnesium	mg/L		9	2	8	13	7	5
Sodium	mg/L		54.9	18.8	48.5	85.9	37.3	5
Potassium	mg/L		5.5	1.7	5.8	8.0	3.8	5
Sulfate	mg/L		27	13	26	45	14	5
Sulfide (at POD)	mg/L		0.08	0.05	0.07	0.16	0.03	5
Chloride	mg/L		88	28	86	131	58	5
Tot Alkalinity as $CaCO_3$	mg/L	> 20	108	36	108	140	74	5

Diss. Organic Carbon	mg/L		13.7		13.7	13.7	13.7	1
Total Organic Carbon	mg/L							
Trace Metals								
Aluminum	µg/L							
Antimony	µg/L	< 4,300						
Arsenic	µg/L	< 50	2	2	1	5	1	5
Cadmium	µg/L	< 0.23						
Chromium	µg/L	< 73						
Copper	µg/L	< 7.9						
Iron	µg/L		105	28	93	152	80	5
Manganese	µg/L							
Mercury (Ultra-trace)	ng/L	12	1.22	0.37	1.03	1.86	1.00	5
Methylmercury	ng/L		0.09	0.04	0.08	0.13	0.05	5
Molybdenum	µg/L		7.7	3.4	6.5	11.4	4.1	5
Nickel	µg/L	44.2						
Selenium	µg/L	< 5.0						
Zinc	µg/L	< 101						
Radionuclides								
Gross Alpha, in pCi/L	pCi/L	15	2.5	0.6	2.4	3.3	1.6	5
Radium-226	pCi/L	5						

Summary of water quality data collected at KRASR at the POD (point-of-discharge). Where analytical results were lower than the minimum detection limit (MDL), the reported MDL was used to compute summary statistics. Blank table entries indicate that a parameter was not sampled or insufficient data exists to calculate the statistic.

4.4.4 Measures of Effect

A battery of aquatic toxicity tests was identified and evaluated to be used for the development of the ASR toxicity database. Initial ASRRS ecotoxicological research studies were conducted prior to cycle testing at CERP ASR systems using source waters, laboratory-generated recovered waters, and Palm Beach County Water Utilities Department (PBCWUD) ASR recovered waters (Johnson, 2005; Johnson et al., 2007).

During the initial cycle test at Kissimmee, toxicity testing was conducted during recharge and recovery. The purpose of these toxicity tests was to evaluate the potential toxicity of the source (recharge) water and recovered water to various sensitive aquatic test species representing several trophic levels. For all other cycle tests, no toxicity testing was conducted during recharge but several testing events occurred during recovery. Acute, chronic and bioaccumulation tests were conducted using algal, invertebrate and vertebrate species. NPDES and CERPRA permits for operational testing at KRASR and HASR also included acute and chronic toxicity testing requirements. The toxicity and bioconcentration tests conducted included:

- 96-hour acute *Ceriodaphnia dubia* test;
- 96-hour acute Cyprinella leedsi test;
- 96-hour chronic growth test with the green algae *Selenastrum capricornutum*;
- 7-day chronic static-renewal survival and reproduction tests with the water flea *C. dubia*;
- 7-day chronic static-renewal embryo-larval survival and teratogenicity test with the fathead minnow *Pimephales promelas*;
- 21-day chronic static-renewal survival and reproduction test with the water flea *Daphnia magna*;
- 96-hour Frog Embryo Teratogenesis Assay with *Xenopus* (FETAX);
- 28-day flow-through bioconcentration studies using bluegill (*Lepomis macrochirus*) and a freshwater mussel (*Elliptio buckleyi*) during Cycle 1 recharge and recovery; and
- *In situ* bioconcentration studies using caged freshwater mussel studies (*E. buckleyi*) during Cycle 2 and field collections of indigenous freshwater mussels collected from the vicinity of the ASR pilot project during Cycle 4.

The results for the KRASR and HASR aquatic toxicity and bioconcentration studies are summarized in **Appendix C** and discussed in Section 5 (Analysis Phase).

Periphyton studies were also conducted in the Kissimmee River during KRASR cycle tests 1 and 2 as recommended by the ASRRS Biology sub-team. Change to the taxonomic structure (species composition) of periphyton is a particularly sensitive indicator of stress, and has been used in the Florida Everglades in research aimed at establishing a standard for phosphorus concentrations (e.g., McCormick and O'Dell 1996). For these reasons periphyton could be a bio-monitor (measure of effect) for evaluating potential effects of ASR recovered water. Data were generated to assess ASR recovered water discharge-related changes in periphyton species diversity as well as abundance.

Aquatic biota responds to both natural and anthropogenic affected conditions such as water quality and physical habitat. As organisms integrate these factors over time, a characteristic community structure emerges. FDEP protocols for Stream Condition Index (SCI) sampling are intended to measure how anthropogenic actions affect benthic invertebrate communities by measuring taxa richness and diversity and comparing these results to unimpacted baseline habitat datasets. SCI testing was conducted during Cycle 4 at the Kissimmee River ASR facility and at nearby control sites to determine if ASR recovered water discharges could change SCI of the receiving water.

4.4.5 Measures of ecosystem and receptor characteristics

Measures of ecosystem and receptor characteristics influence:

- behavior and location of biological entities selected as assessment endpoints,
- the distribution of a stressor, and
- life-history characteristics of the assessment endpoint, or its surrogate, that may affect exposure or response to the stressor (USEPA, 1998).

Examples include:

- water temperature, hardness, and flow;
- abundance and distribution of suitable breeding substrate for fish;

- abundance and distribution of food sources for larval fish;
- appropriate substrate for benthic organisms; and
- natural mortality rates.

For this ERA, the USFWS reviewed regional fisheries information and developed a list of ecosystem characteristics that influence the distribution of the attributes selected (i.e., fish and invertebrates). This information was used in the Analysis Phase to evaluate potential risk (effect and exposure).

4.4.6 Measures of Exposure

Measures of exposure are measures of stressor existence and movement in the environment and their contact or co-occurrence with the assessment endpoint. Examples of measures of exposure are:

- recovered water constituent changes in the receiving waters, sediments, and fish tissue;
- nutrients, temperature, or clarity changes in the receiving water due to ASR recovered water;
- potential for entrainment or impingement of biota during recharge; and
- number of ASR wells discharging to a canal and size of plume.

4.4.6.1 Selection of surface water models and methods

A variety of simulation models were used to develop regional projections of hydrologic and water quality impacts associated with the implementation of ASR in the Lake Okeechobee Basin and the Greater Everglades. The models below were used to define the exposure scenarios used in the risk characterization phase of the ERA.

1. SFWMM 2x2 (Regional Surface Hydrology Model)

   The location, frequency, magnitude, and duration of CERP ASR recharge and discharge events are provided by the D13R version of the SFWMM2x2 regional surface hydrology model. The Regional ASR Study used the ASR D13R output to drive the operation of the ASR wells in the

Regional Groundwater Models (see below) as well as to define critical exposure conditions for surface waters exposed to ASR discharges. This model was set up to simulate the 1965 to 1995 period. Additional SFWMM 2x2 modeling was not done to develop other CERP ASR implementation scenarios for this ERA due to the cost and time involved. The Lake Okeechobee Operations Planning Spreadsheet (LOOPS) model, described below, was used to the develop Lake Okeechobee Basin ASR implementation hydrology other than that defined by the D13R assumptions.

2. Lake Okeechobee Operations Planning Spreadsheet (LOOPS)

The LOOPS spreadsheet model (Niedrauer, et. al, 2006) simulates the effect of lake operations schedules on Lake Okeechobee stages. This tool is set up to simulate the 1965 to 2005 period of record with boundary conditions for surface water inflows to the lake and rainfall and evapotranspiration for this period. For this ERA, the LOOPS model was modified to include ASR operations for CERP ASR within the Lake Okeechobee Basin. Its specific use in the ERA is as a means to predict the timing of ASR recharge and recovery in the Lake Okeechobee basin under ASR implementation scenarios other than D13R. The LOOPS ASR simulations utilized the 2008 Lake Okeechobee Operations Schedule rather than the prior Water Supply Environment (WSE) operation scheme assumed in the D13R simulations. The LOOPS model also includes several Lake Okeechobee / Northern Estuaries performance metrics that have been evaluated for the Regional ASR study.

3. Density Dependent Regional Ground Water (WASH, SEAWAT)

The regional groundwater model was used to determine the hydrogeological impact (pressure, drawdown, etc.) of operating CERP ASR facilities. The ASR implementation scenario from the SFWMM2x2 D13R simulation was initially modeled using this GW model. These results showed that the full 333 well Restudy ASR scenario was not technically feasible due to high groundwater pressure during recharge and excessive groundwater stage depression during recovery. To address this, the groundwater modelers developed several smaller CERP ASR implementation scenarios in an effort to determine how many wells could be placed and operated in South Florida without causing unacceptable hydrogeologic impacts. These scenarios were used in the ERA to bound the ecological and water quality impacts expected from CERP ASR under realistic implementation schemes.

4. LOEM WQ Model

The LOEM (Lake Okeechobee Environmental Model) is a 3-D finite element water quality simulation model that is based on the Environmental Fluid Dynamics Code (EFDC) package (Hamrick, Wu 1997). The model simulates hydrodynamic and water quality conditions (nutrients, temperature, and toxics) on a 1 square kilometer basis. For the ERA, the existing LOEM model was modified to include an enhanced SAV model and boundary conditions were developed to simulate the 1999 to 2009 period with and without ASR operations(AEE, 2012) (Jin and Ji, 2012). The model was configured to simulate the WQ impact to Lake Okeechobee of several critical ASR discharge events as predicted by the D13R version of the 2x2 surface hydrology model and ASR implementation scenarios developed by the groundwater modeling team. Model output was used to evaluate SAV response to ASR implementation and to determine ASR impacts to water quality parameters such as TP, chloride, and sulfate.

5. ELM-Sulfate Model

Sulfate dynamics within the EPA play a qualitative role in regulating mercury methylation and bioaccumulation by fish. The Everglades Landscape Model (ELM) was originally developed to simulate the landscape vegetation response to changes in hydrology and nutrients within the Everglades Protection Area (EPA). ELM version 2.8.6 (Fitz, 2013) was modified for this ERA to include the simulation of ASR related changes to sulfate loads within the EPA. Rather than use the D13R hydrology, the ELM-Sulfate model used the revised CERP0 hydrology since this extended the simulation period from 1995 to 2000. The output from the ELM-Sulfate model was used to evaluate the potential for ASR discharges into the Everglades to change the existing mercury methylation conditions.

6. Water Quality Spreadsheet Models

Several water quality spreadsheet models were developed to create boundary conditions for the LOEM and ELM-Sulfate modeling effort. LOEM model boundary conditions were developed using a spreadsheet that incorporated LOOPS output and KRASR recovered water quality data to generate time-varying water quality boundary conditions for ASR inflows and outflows to the lake. ELM-Sulfate model boundaries were developed using spreadsheets that coupled LOEM sulfate concentration predictions for the ASR scenarios with SFWMM CERP0 hydrology. Other spreadsheets were used to estimate sulfate uptake in the EAA stormwater treatment areas, estimate changes to pollutant loading in Lake Okeechobee, and to estimate average temperature changes resulting from ASR discharges in the Lower Kissimmee River in different months of the year.

4.4.7 Development of exposure scenarios

In order to develop exposure scenarios, the distinctive characteristics of the proposed activity must be defined. Contamination of the environment is often a secondary consequence (and it can usually be avoided through management and mitigation). Therefore, the scenarios producing chemical releases resulting in water quality changes to the environment should be developed within the context of knowledge of the proposed activity (in this case, the storage and discharge of ASR water). Furthermore, the relative likelihood of the scenarios must be determined (particularly in light of existing prevention and mitigation measures). A scenario consequence analysis was conducted in order to develop an understanding of the plausible conditions that could result in detrimental water quality changes in the south Florida environment (given the mitigation measures that will likely be in place).

The scenario-consequence analysis methodology involves developing a hypothetical set of conditions (*scenarios*) that are internally consistent and scientifically defensible, and that specify all important factors needed to evaluate effects (Harwell *et al*., 1995). A scenario is meant to be neither a prediction of the future nor a proposed plan of action. Preferably, a suite of scenarios should be developed to cover the range of situations that are sufficiently plausible to warrant further evaluation. The range of conditions in the set of scenarios forms the initial point-of-departure for conducting sensitivity analyses. The purpose is to allow the evaluation of the consequences of those ranges of conditions, so that particular scenario-specific parameters that would make a significant difference to the risk estimate could be separated from those ranges of conditions that make little impact. This is very important in identifying the variables that “drive” the risk and, therefore, the confidence in the risk-based decision. These variables would also be the focus of risk management measures. By using this approach, uncertainties caused by inadequate data and understanding or by inherently unknowable situations can be accommodated while proceeding with detailed analyses of effects.

In this case, scenarios have been developed with the goal of describing a range of conditions that plausibly might occur during regional ASR implementation in south Florida. The specificity of scenarios allows full exploration of relationships between ASR discharges of recovered water and ecological effects at a level of resolution not possible from generic analyses; this in turn can yield important insights and identify areas where further research or analysis is needed. Development of scenarios is often best accomplished through an expert judgment process. This was accomplished by consulting the Project Development Team to discuss the range of conditions and the specific parameters for assessing ASR recovered water discharges.

The approach used for this ERA was to be consistently, conservatively plausible in the selection of the scenarios, but not to attempt to identify the "worst case" or "most likely" or other metric to characterize the scenario along that spectrum. Rather, scenarios were selected that are plausible and that could lead to ecological effects.

The scenario development process and resulting scenarios selected for use are described below.

4.4.7.1 ASR Implementation Scenarios

This ERA is focused in on potential effects of ASR implementation to Lake Okeechobee, its tributaries, and downstream basins. The Lake Okeechobee ASR scenarios include well placement in the Kissimmee River Basin which is the most ecologically significant tributary of the lake. None of the scenarios include ASR facilities in the Greater Everglades since the original CERP plan does not have any ASR wells located in this area. The Greater Everglades is included in the exposure pathway since it lies downstream of Lake Okeechobee.

Hydrologic, hydrodynamic, hydrogeologic, and water quality simulation models were used to develop plausible ASR implementation scenarios for the Lake Okeechobee Basin and to characterize ASR exposure pathways in terms of timing, intensity and special distribution **Figure 4.3** shows a generalized scheme for the models and how they were linked to develop the exposure pathways and profiles.

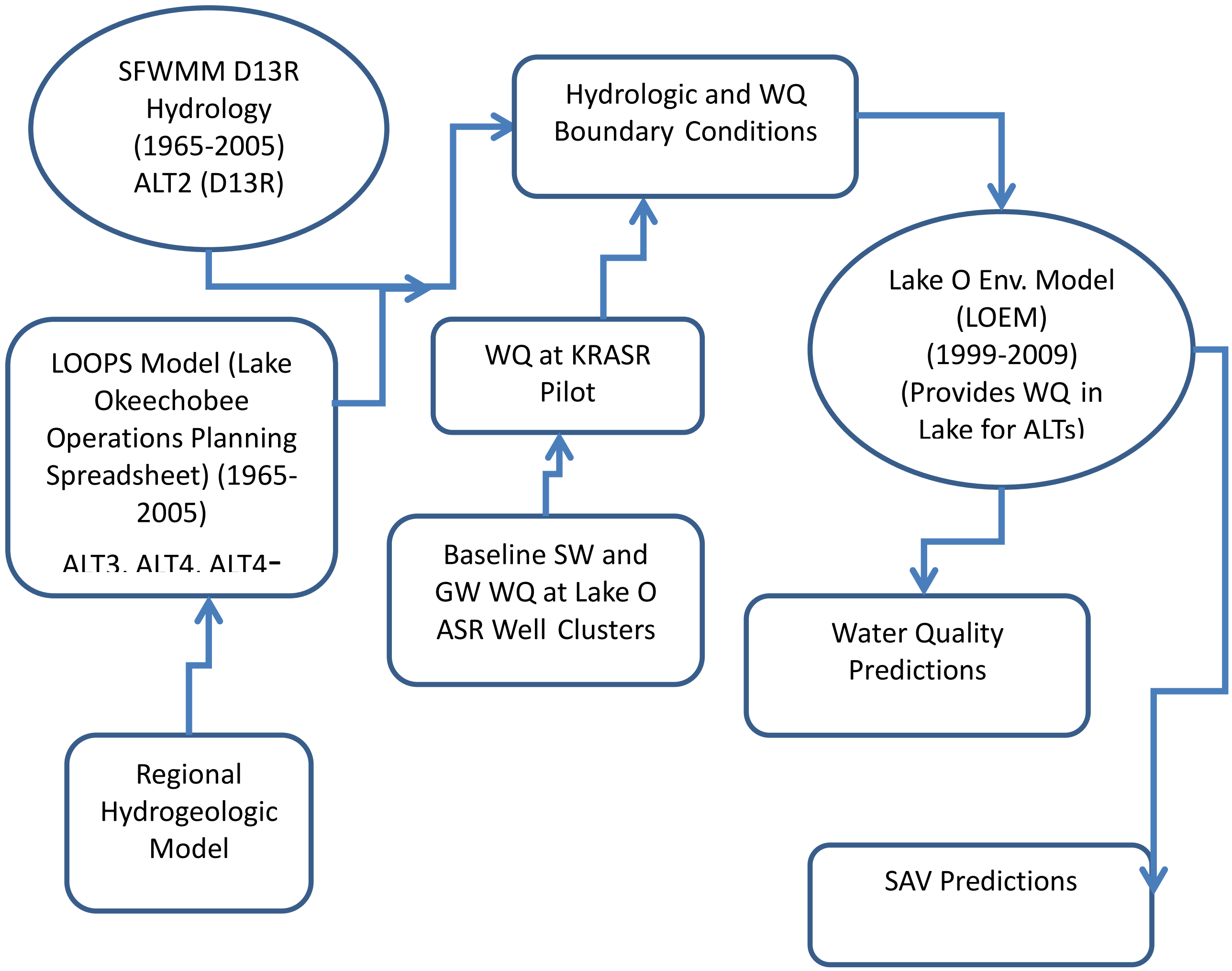


Figure 4.3. Modeling Scheme Used to Evaluate Water Quality Impacts of ASR Scenarios in Lake Okeechobee

The original CERP plan to construct and operate 200 ASR wells within the Lake Okeechobee Basin was specified in the Central and South Florida Restudy Report (USACE, 1999). The D13R scenario originally prepared for the Restudy Report did not consider possible hydrogeologic or engineering constraints on the number and placement of CERP ASR facilities. Since the placement and operation of CERP ASR wells are key to defining the spatial component of the exposure pathways, additional CERP ASR scenarios were developed to ensure that the RASRS considered consistent and plausible alternatives.

The additional ASR scenarios were initially developed using a regional groundwater model to determine the hydrogeologic feasibility of well placement and operation scenarios. These scenarios as defined by the number of wells, aquifer placement, and assumed recovery efficiency, were input into the LOOPS model to determine the timing and duration components of the exposure pathway. The output from the LOOPS model was used to define the timing and duration of ASR exposure for each alternative scenario as well as to provide ASR flow boundary conditions (recharge and recovery event timing and duration) for the Lake Okeechobee Environmental Model (LOEM).

The LOEM is a hydrodynamic and water quality model of Lake Okeechobee. It was used to simulate the water quality and SAV impacts due to changes to the lake operation schedule. The water quality assumptions for ASR exposure were developed from available surface and groundwater quality data as well as water quality data collected from the Kissimmee ASR Pilot site.

4.4.7.2 Lake Okeechobee Basin ASR Well Scenarios

The Restudy specified the number of ASR wells for the Lake Okeechobee Basin but not how these wells would be geographically distributed within the basin. The RASRS team identified favorable locations for ASR well clusters in the Lake Okeechobee Basin based upon criteria such as proximity to sufficient quantities of source water, hydrogeologic conditions, availability of publicly-owned land to site facilities, and minimization of potential environmental impacts. **Figure 4-4** shows the location of potential ASR well clusters within the Lake Okeechobee Basin.

Figure 4.4. Potential Well Cluster Locations Within Lake Okeechobee Basin

Tables 4.5, 4.6, and 4.7 show the geographic distribution of ASR wells within the Lake Okeechobee basin for three potential ASR scenarios, Alternative 2, Alternative 3, and Alternative 4.

The original CERP ASR configuration assumed that all ASR wells would be placed in the UFA zone (500 to 800 ft below land surface) and that these wells would have a recharge and recovery flow capacity of 5 million gallons per day (mgd) and an average recovery efficiency of 70 percent. (Recovery efficiency is the ratio of the volume of stored water recovered from the aquifer divided by the quantity of water stored in the aquifer during a given cycle.) To accommodate the injection pressure limitations and recovery drawdown constraints, the project team considered alternatives with fewer ASR wells placed around the Lake and the placement of some of these wells into lower zones of the Floridan Aquifer such as the Avon Park Producing Zone (APPZ) (800 to 1,100 ft below land surface) and the lower Boulder Zone (BZ) (2000 ft below land surface). The recovery efficiency of the APPZ wells was assumed to be 30 percent and the recovery efficiency of the BZ wells was assumed to be zero percent.

<u>Alternative 1</u>

Alternative 1 (ALT1) is the no-action alternative. Under this alternative, no ASR facilities or wells would be constructed or operated.

Alternative 2

Alternative 2 (ALT2) includes 200 wells (5 mgd capacity each) within the Lake Okeechobee Basin. The geographical distribution of these wells is shown in **Table 4.5.** This scenario matches the original D13R scenario from the CERP report in terms of the number of wells in the basin, their placement in the UFAZ, and their assumed recovery efficiency of 70 percent. The main difference between ALT2 and D13R is that ALT2 uses the 2008 Lake Okeechobee Regulation Schedule (LORS) to control the Lake outflows; D13R utilizes a prior Lake operation schedule. The LORS lowered the average Lake Okeechobee Schedule by approximately 1 ft in comparison to the prior schedule; however, the timing and duration of ASR operations compare favorably between the D13R and ALT2.

Table 4.5. Geographic Distribution of Alternative 2 ASR Well Clusters

ALT2 (Equivalent to D13R and Scenarios 1, and 2 from the Hydrogeologic Modeling Report)			
ASR Well Distribution	**Upper Floridan**	**APPZ**	**Boulder Zone**
	# Wells	**# Wells**	**# Wells**
Kissimmee River	**75**	**0**	**0**
North of Lake O	**25**	**0**	**0**
C-40	**10**	**0**	**0**
C-41	**10**	**0**	**0**
Taylor Creek Res	**30**	**0**	**0**
Nubbin Slough	**10**	**0**	**0**
Lakeside Ranch	**20**	**0**	**0**
Port Mayaca	**20**	**0**	**0**
Moorehaven	**0**	**0**	**0**
Total	**200**	**0**	**0**

Alternative 3

Alternative 3 (ALT3) includes 100 wells (5 mgd capacity each) within the Lake Okeechobee Basin. **Table 4.6** shows the geographical distribution of the wells in this alternative. This scenario is essentially ½ the size of ALT2 and it also has the wells placed in the UFAZ. This scenario is essentially equivalent to Scenario 4 in the Hydrogeologic Modeling Report (USACE 2013).

Table 4.6. Geographic Distribution of Alternative 3 ASR Well Clusters

ALT3 (100 Wells in Okeechobee Basin)			
ASR Well Distribution	Upper Floridan	APPZ	Boulder Zone
	# Wells	# Wells	# Wells
Kissimmee River	30	0	0
North of Lake O	20	0	0
C-40	5	0	0
C-41	5	0	0
Taylor Creek Res	15	0	0
Nubbin Slough	5	0	0
Lakeside Ranch	10	0	0
Port Mayaca	10	0	0
Moorehaven	0	0	0
Total	100	0	0

Alternative 4

Alternative 4 (ALT4) includes 200 wells (5 mgd capacity each) within the Lake Okeechobee Basin; however, some of these wells were moved away from Martin and St. Lucie Counties and wells were placed in the APPZ and BZ portions of the Floridan Aquifer in order to ensure that they don't result in excessive injection pressures during recharge or groundwater stage drawdown during recovery. **Table 4.7** shows the geographical distribution of the wells in this alternative.

Table 4.7. Geographic Distribution of Alternative 4 ASR Well Clusters

ALT4 (Equivalent to Scenario 9 from Hydrogeologic Modeling Report)			
ASR Well Distribution	Upper Floridan	APPZ	Boulder Zone
	# Wells	# Wells	# Wells
Kissimmee River	15	0	70

North of Lake O	**8**	**2**	**0**
C-40	**2**	**0**	**8**
C-41	**0**	**0**	**10**
Taylor Creek Res	**0**	**10**	**10**
Nubbin Slough	**0**	**0**	**0**
Lakeside Ranch	**4**	**10**	**21**
Port Mayaca	**19**	**0**	**1**
Moorehaven	**0**	**10**	**0**
Total	**48**	**32**	**120**

Alternative 4-S11

Alternative 4-Scenario 11 (ALT4-S11) has the same number of wells and placement as ALT4. This scenario was developed by the hydrogeologic team to further refine the operating scheme of ALT4 to reduce recovery flow rates so that ASR operations would not exceed Martin and St. Lucie County groundwater protection rules that require the maintenance of artesian conditions in the Floridan Aquifer. While this scenario meets the maximum hydraulic pressure and drawdown constraints and is the current preferred alternative for ASR implementation around Lake Okeechobee, it is not unique since other well location and operating schemes could be developed that also meet these constraints. **Table 4.8** shows the recovery rate adjustment factors used to limit the drawdown effect caused by rapid removal of ASR stored water. For instance, at Kissimmee River, in ALT4-S11, the rate of recovery from each well would be 1.25 million gallons per day (MGD) which is 25 percent of the injection capacity of 5 MGD at each well. Similarly, at Port Mayaca recovery is limited to 2.5 MGD per well which is 50 percent of the rated 5 MGD injection capacity.

Table 4.8. Recovery Rate Adjustment Factors for ALT4-S11

Cluster Site	UF	APPZ	BZ
C-40 Canal	100%		0%
Nicodemus /C-41 Canal	0%	100%	0%
North Lake Okeechobee	25%	100%	0%
Kissimmee River	25%	0%	0%
Taylor Creek	0%	50%	0%

L-63N	0%	50%	0%
Lakeside Ranch	0%	0%	0%
Port Mayaca	50%	0%	0%
Moorehaven	0%	0%	0%

4.4.7.3 Kissimmee River ASR Scenarios

CERP ASR facilities along the Kissimmee River would pull surface water from the river and discharge recovered water back into the river and this water would eventually flow into Lake Okeechobee. The number of wells and targeted aquifer zones for the Kissimmee Basin are included in the Lake Okeechobee ASR scenarios detailed in **Tables 4.5 through 4.7**. **Table 4.8** shows the adjusted recovery rates for the Kissimmee ASR installations for ALT4-S11. Like other ASR installations within the Lake Okeechobee Basin, the Kissimmee ASR facility operations are expected to be operated to optimize Lake Okeechobee stage conditions. **Figure 4.5** shows a conceptual layout for ALT4 and ALT4-S11 for the Kissimmee River ASR facilities. This scenario has three well cluster installations located below S-65E. Each cluster would have a single intake and single discharge structure and a maximum flow capacity of 25 MGD.

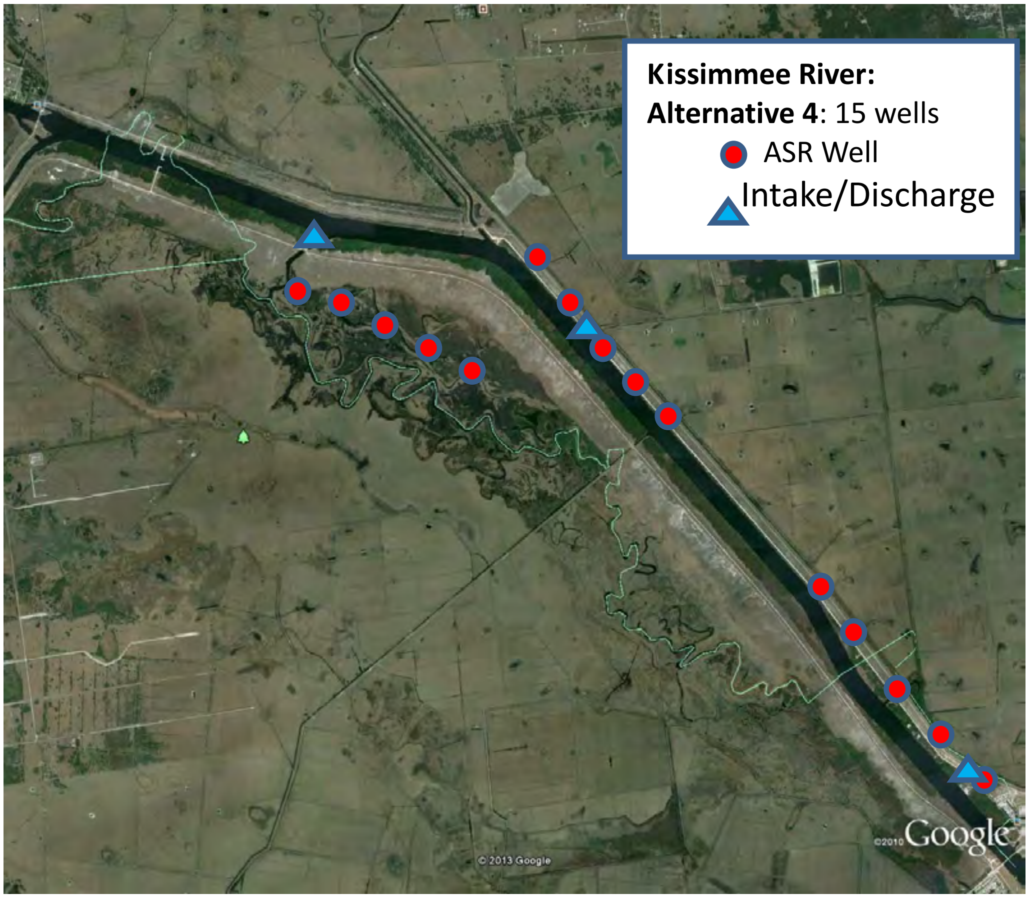


Figure 4.5. Conceptual Layout for ALT4 and ALT4-S11. These alternatives have 15 wells in Kissimmee Basin. All wells are located below S-65E.

4.4.7.4 Greater Everglades ASR Scenarios

The ASR scenarios developed for Lake Okeechobee are applicable to the Greater Everglades because this basin is downstream of the Lake and no ASR facilities are planned that would discharge to or within the Greater Everglades. Potential CERP ASR impacts to the Greater Everglades are not expected to be as significant as those that might occur within the Kissimmee River or Lake Okeechobee because this basin is geographically distant from CERP ASR facilities described in the evaluated CERP implementation scenarios. Ecologic receptors within the Greater Everglades are expected to experience smaller changes in water quality since ASR flows and loads are diluted first by Lake Okeechobee and then by other hydrologic flows and processes in the Everglades agricultural Area prior to entering the Water Conservation Areas located at the northern end of the Everglades Protection Area.

5.0 ANALYSIS PHASE

The analysis phase evaluates the two primary components of risk: exposure and effects. The relationship between these two components and the ecosystem characteristics are the basis for the ERA. **Figure 5.1** presents the components of the Analysis Phase.

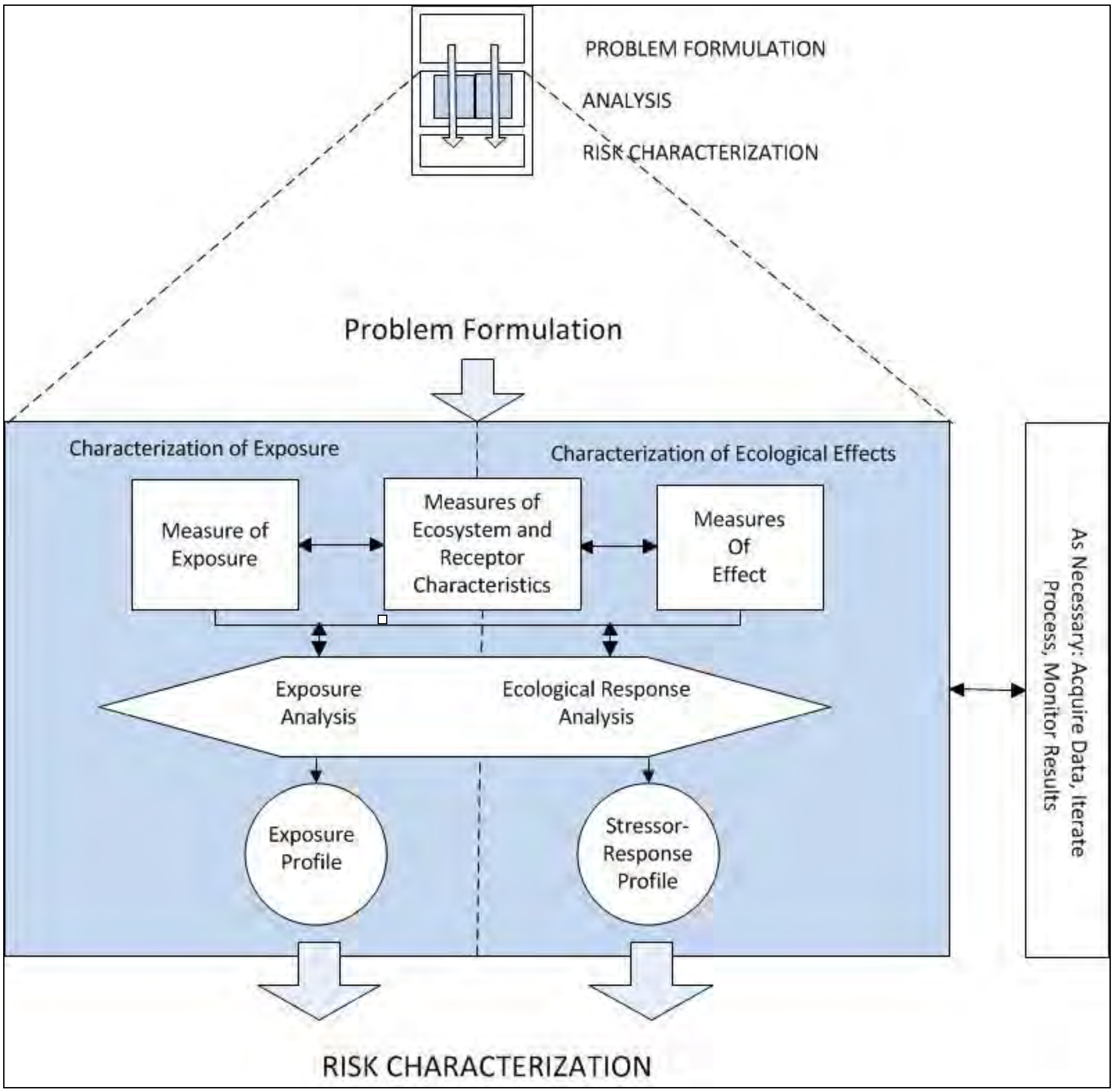


Figure 5.1. Analysis Phase (USEPA, 1998)

The objective of the Analysis Phase is to provide the materials needed for determining or predicting ecological responses to stressors under the exposure scenarios selected. The focus and structure of the analysis are provided by the assessment endpoints selected and the conceptual model developed.

Through the analysis of information and modeling, the following final assessment endpoints were defined for this regional ERA:

- Reproducing Populations (Fecundity) of Native Fish;
- Survival of Fish, Aquatic Invertebrates, and Manatees;
- Diversity and Abundance of SAV, Periphyton and Algae Species; and
- Protection from Methylmercury Accumulation in Wildlife and Humans.

The final ERA CEM is presented in **Figure 5.2**.

The Analysis Phase outputs are summary profiles that describe exposure and the relationship between the stressors and the ecological responses. During this phase of the ERA:

- the data that were be used to evaluate the risk hypothesis selected;
- exposure analysis were carried out by examining the sources of the stressors, their distribution in the environment, and the co-occurrence or contact between the stressors and the valued ecological attributes (receptors);
- effects were evaluated by developing stressor-response relationships, evidence for causality, and the relationship between the measures of effect and assessment endpoints; and
- the exposure and effects conclusions were summarized.

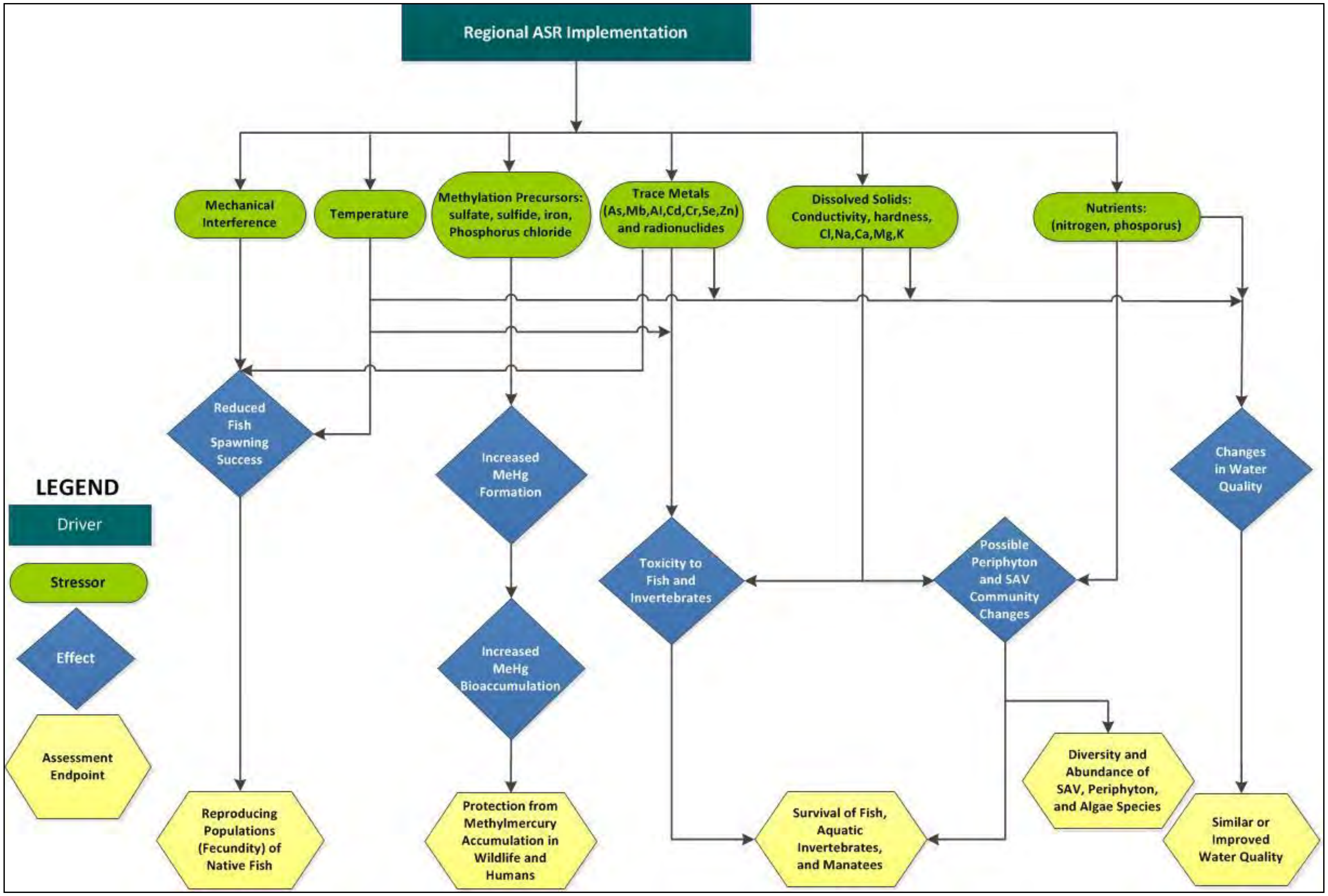


Figure 5.2. Regional ASR ERA Conceptual Ecological Model

The Analysis Phase is iterative and builds on substantial interaction between exposure and effects characterizations as shown in **Figure 5.1**. This is the case in this regional ERA that addresses primary (e.g., water quality changes, mechanical interference) and secondary stressors and effects of concern (i.e., methylation precursors) requiring a phased approach to the analysis. Based on the nature of the multiple stressors being addressed, the results of the analysis range from highly quantitative to qualitative.

A significant volume of ecotoxicological data was developed for ASRs in south Florida in order to establish the stressor response profiles and document the causality applicable to regional ASR implementation. Due to its broad spatial application, an exposure scenario-consequence approach was taken to develop measures of exposure and exposure profiles, and this process is described in the next section, Characterization of Exposure.

5.1 CHARACTERIZATION OF EXPOSURE

Exposure characterization describes potential and predicted co-occurrence or contact of stressors with receptors. This characterization was based on: measures of exposure and ecosystem and receptor characteristics; the stressor sources; distribution of stressors in the environment; and the extent and pattern of potential contact or co-occurrence in several aquatic ecosystems in south Florida.

The exposure profiles identify the exposed receptors, describe the course the stressors are expected to take from the source to the receptor (exposure pathway), and describe the intensity and spatial/temporal extent of co-occurrence or contact. The exposure variability and uncertainty of exposure estimates are described, and the likelihood that the exposure will occur is discussed.

An exposure pathway is the physical connection between the ASR related stressors and the receptors. It defines the timing, duration, quantity, intensity and spatial distribution of stressors as potentially experienced by the receptors of interest.

For this ERA, the source of the stressors is the operation of ASR facilities in the Lake Okeechobee Basin which includes the following regional ecosystems: Kissimmee River, Lake Okeechobee, and Greater Everglades. ASR related stressors are present during both the recharge and discharge phases of ASR well operations. The timing, duration, quantity, intensity, and spatial distribution of Lake Okeechobee Basin ASR implementation have been developed for the alternatives (ALT2, ALT3, ALT4, and ALT4-S11). These alternatives were described in detail in Section 4.4.7. **Figures 5.3** and **5.4** show the timing and magnitude of ASR recharge and recovery for all ASR facilities contemplated for the Lake Okeechobee Basin.

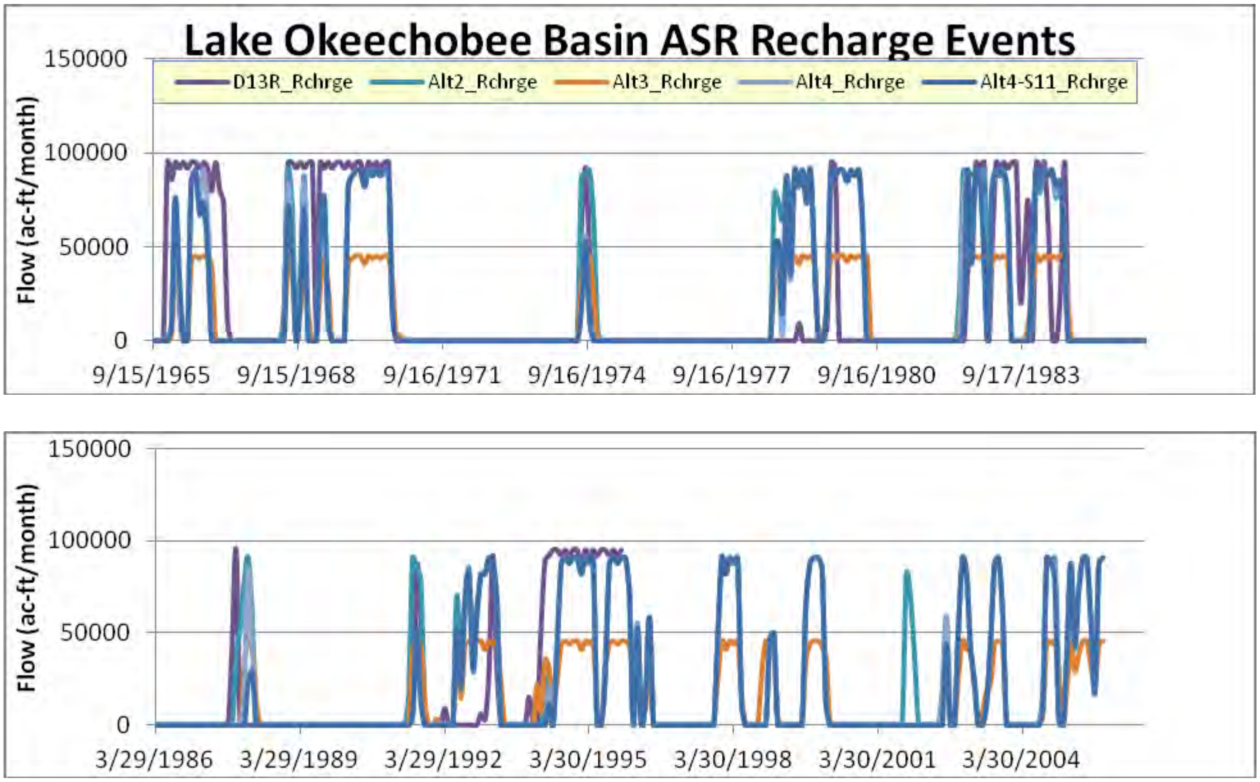
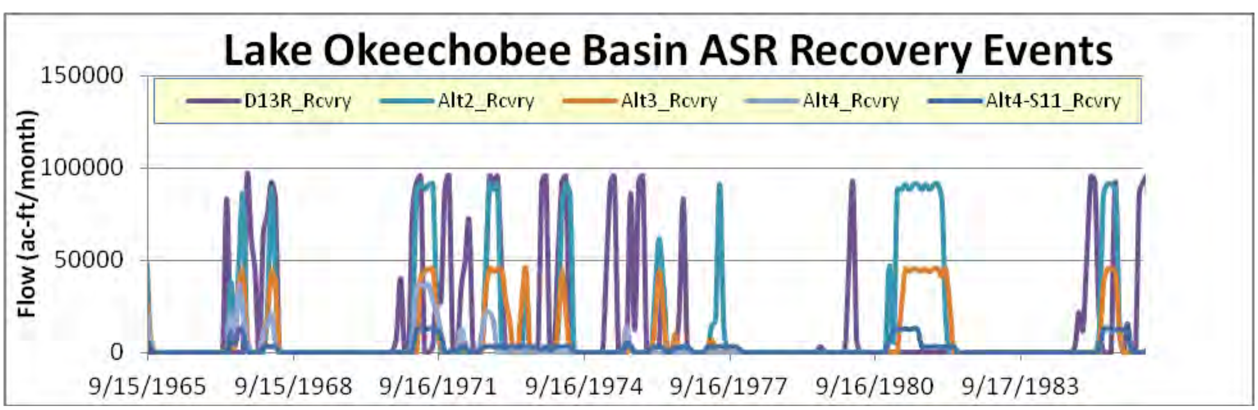


Figure 5.3. Lake Okeechobee Basin Recharge Events as Predicted Using SFWMM (D13R) and LOOPS.



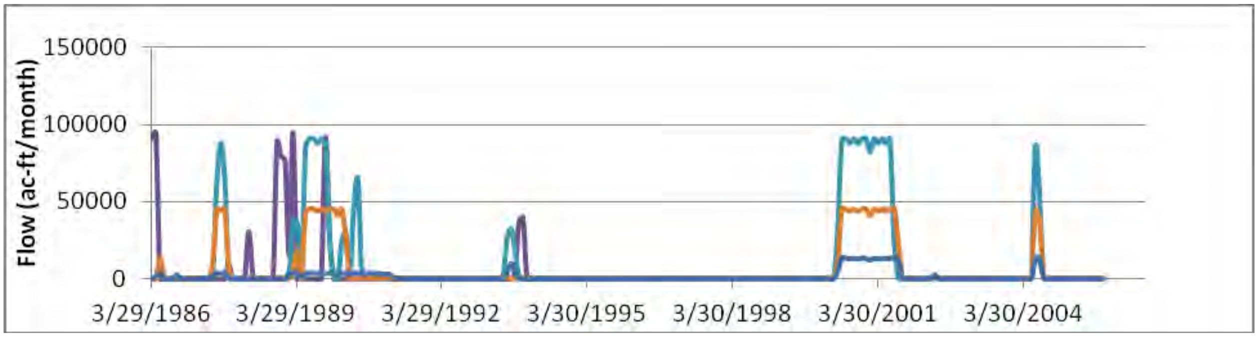


Figure 5.4. Lake Okeechobee Basin Recovery Events as Predicted Using SFWMM (D13R) and LOOPS

The spatial distribution for Lake Okeechobee and the Kissimmee River of the implementation scenarios matches the geographical distribution of wells for each alternative as described in Section 4.7.7. No ASR wells are planned for the Greater Everglades; the spatial component of the pathway in this ecosystem is the result of the surface water distribution from the upstream basin (Lake Okeechobee).

The timing, duration, and quantity of ASR flows for each of the alternatives have been estimated using surface water hydrology models such as the SFWMM 2x2 and LOOPS. This information has been organized by regional ecosystem: Kissimmee River, Lake Okeechobee and Greater Everglades. The intensity of ASR flows, which equate to potential changes in water quality associated with ASR discharges, have been estimated based upon existing surface and groundwater data, data collected during operations at the KRASR, the LOEM model, and the ELM-Sulfate model.

5.1.1 Kissimmee River Exposure Pathway

5.1.1.1 Timing, Duration, and Magnitude of Kissimmee River ASR Water Quantity and Flows

The timing, duration and magnitude of Kissimmee River ASR flows is determined by Lake Okeechobee (Lake) stage conditions, so recharge and recovery event statistics for the Kissimmee River ASRs are the same as all other ASR installations planned around the lake. The daily volume of Kissimmee Basin ASR Recharge and Recovery flows is shown in **Table 5.1**.

Recharge rates for the Kissimmee Basin are expected to vary from 1,150 to 230 ac-ft/day, corresponding to the number of ASR wells sited in the basin (60, 30, or 15 wells). Recovery rates for the Kissimmee ASR facilities match the recharge rate (5 mgd) for

D13R, ALT2, ALT3, and ALT4. For ALT4-S11, recovery is only 25% of the recharge rate due to hydrogeological constraints. The percent of time Kissimmee ASR facilities are operated in either the recharge or recovery mode is shown in **Table 5.2** for all the alternatives evaluated. Recharge event statistics are shown in **Table 5.3** and recovery event statistics are shown in **Table 5.4**. Inter-event statistics are based on the number of days that ASRs are not operated between recharge or recovery events.

Table 5.1. Modeled ASR Recharge and Recovery Rates for the Kissimmee River Basin.

Alternative	Recharge Rate in Kissimmee Basin	Recovery Rate in Kissimmee Basin
	(ac-ft/day)	(ac-ft/day)
D13R	1150	1150
ALT2	1150	1150
ALT3	460	460
ALT4	230	230
ALT4-S11	230	58

Table 5.2. Percent of Time ASR Operations Would Occur in the Lake Okeechobee Basin based on Model Simulation Output.

	Recharge	Recovery	Idle
Alternative	**Percent of Time ASR Operates in Recharge Mode**	**Percent of Time ASR Operates in Recovery Mode**	**Percent of Time ASR Facilities are Idle**
D13R*	**23%**	**12%**	**65%**
ALT2	**26%**	**13%**	**61%**
ALT3	**29%**	**14%**	**38%**
ALT4	**23%**	**12%**	**65%**
ALT4-S11	**22%**	**27%**	**51%**
***Covers 1965-1995 period. All other Alternatives cover 1965-2005 period.**			

Table 5.3. Lake Okeechobee ASR Recharge Event and Inter-Event Statistics Predicted by SFWMM2x2 and LOOPS Models

Recharge Event Statistics					
Metric	**D13R ***	**Alt2**	**Alt3**	**Alt4**	**Alt4-S11**
Number of Event > 30 days	**14**	**33**	**30**	**28**	**26**
Average Duration of Events > 30 days (days)	**177**	**107**	**138**	**109**	**113**
Median Duration of Events > 30 days (days)	**80**	**86**	**109**	**83**	**88**
Max Duration of Events > 30 Days (days)	**578**	**337**	**352**	**337**	**337**
Total Number of Days With Recharge (days)	**2657**	**3806**	**4337**	**3393**	**3305**
Recharge Inter-Event Statistics					
Metric	**D13R * (Days)**	**Alt2 (Days)**	**Alt3 (Days)**	**Alt4 (Days)**	**Alt4-S11 (Days)**
Number of Inter-Event > 30 days	**16**	**32**	**29**	**33**	**33**
Average Duration of Inter-Events > 30 Days (days)	**474**	**339**	**357**	**343**	**346**
Median Duration of Inter-Events > 30 days (days)	**237**	**139**	**145**	**104**	**106**
Max Duration of Inter-Events > 30 Days (days)	**1571**	**1427**	**1375**	**1451**	**1451**
Total Number of Days With No Recharge (days)	**8699**	**11165**	**10624**	**11575**	**11662**
*** D13R Time period 1965-1995, other ALTs Time Period is 1965-2005**					

Table 5.4. Lake Okeechobee ASR Recovery Event and Inter-Event Statistics Predicted by SFWMM2x2 and LOOPS Models

Recovery Event Statistics					
Duration of Recovery	**D13R * (Days)**	**Alt2 (Days)**	**Alt3 (Days)**	**Alt4 (Days)**	**Alt4-S11 (Days)**
Total Number of Recovery Days	1374	1963	2122	1852	4024
Average Duration of Recovery Event Lasting 30 days	50	119	135	117	188
Number of Recovery Events Lasting 30 Days	15	12	13	11	20
Maximum Duration of Recovery Events	117	415	450	459	615
Inter-Event Duration between Recovery Events					
Frequency and Duration	**D13R* (months)**	**Alt2 (months)**	**Alt3 (months)**	**Alt4 (months)**	**Alt4-S11 (months)**
Minimum Inter-Event Duration	2	2	2	4	2
Average Inter-event Duration	11	19	20	27	25
Maximum Inter-event Duration	54	80	122	80	80

* D13R simulation period is 1965-1995. Other alternatives have simulation periods of 1965-2005.
Notes: Inter-event duration is the period of time in months between the end of one recovery event and the beginning of the following recovery event.
Minimum inter-event period excludes durations less than 1 month.
Maximum inter-event period excludes inter-events that conclude at end of simulation period.

From an ecological perspective the potential impact to receptors in the lower Kissimmee Basin will depend upon the quantity of flow that occurs in river during both recharge and recovery. In the Lower Kissimmee Basin, flows at the S-65E structure define the availability of water for ASR recharge and the capacity to dilute ASR recovered water discharged into the Kissimmee River. **Figure 5.5** shows the monthly average S-65E flows that occur for days with ASR recharge for each alternative as well as the average monthly flows at S-65E for all days. The average monthly S-65E flows for days with ASR recharge generally exceed the overall average monthly S-65E flows presumably because days with ASR recharge correspond to wet periods with higher than average S-65E flows. **Figure 5.6** shows the percent of average daily S-65E flows that is diverted to the ASR system during recharge events.

ALT4 and ALT4S-11 pump a smaller percentage of average S-65E flows because these two alternatives have only 15 ASR wells in the Kissimmee Basin while ALT3 has 30 wells and ALT2 has 75 wells. **Figure 5.7** shows the percent of days in each month that ASR recharge occurs for each alternative. Generally, most alternatives show that recharge does not occur for more than 25 percent of the days in any month.

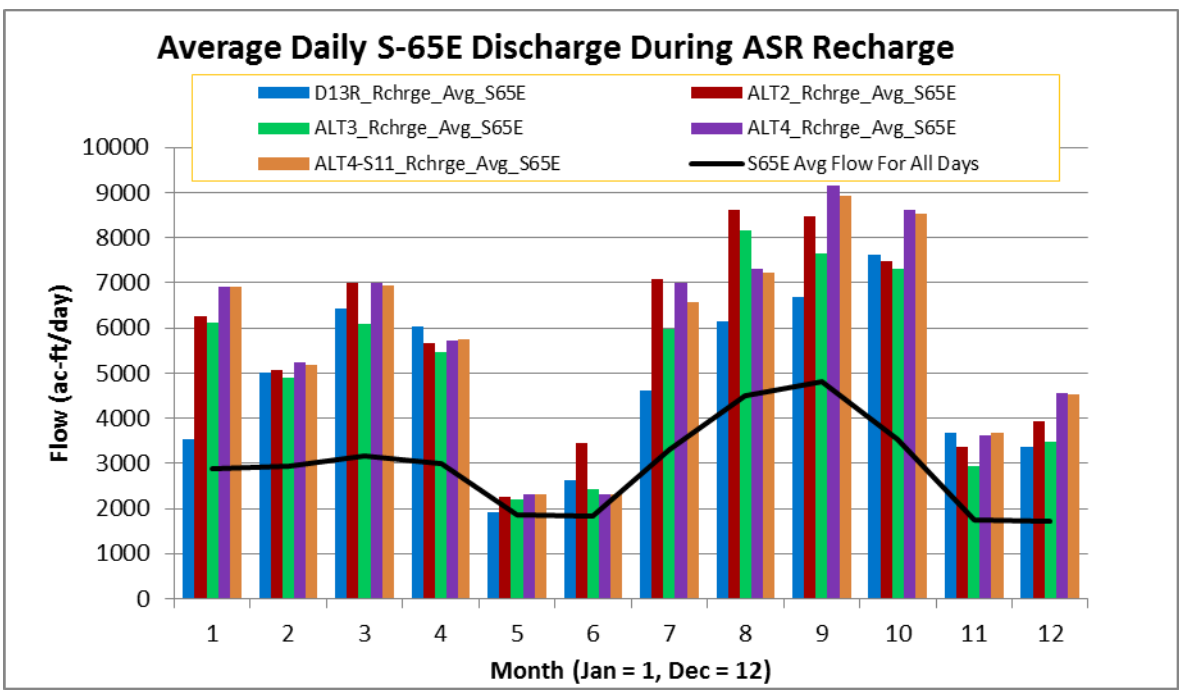


Figure 5.5. Average Daily S-65E Discharge During ASR Recharge Flows.

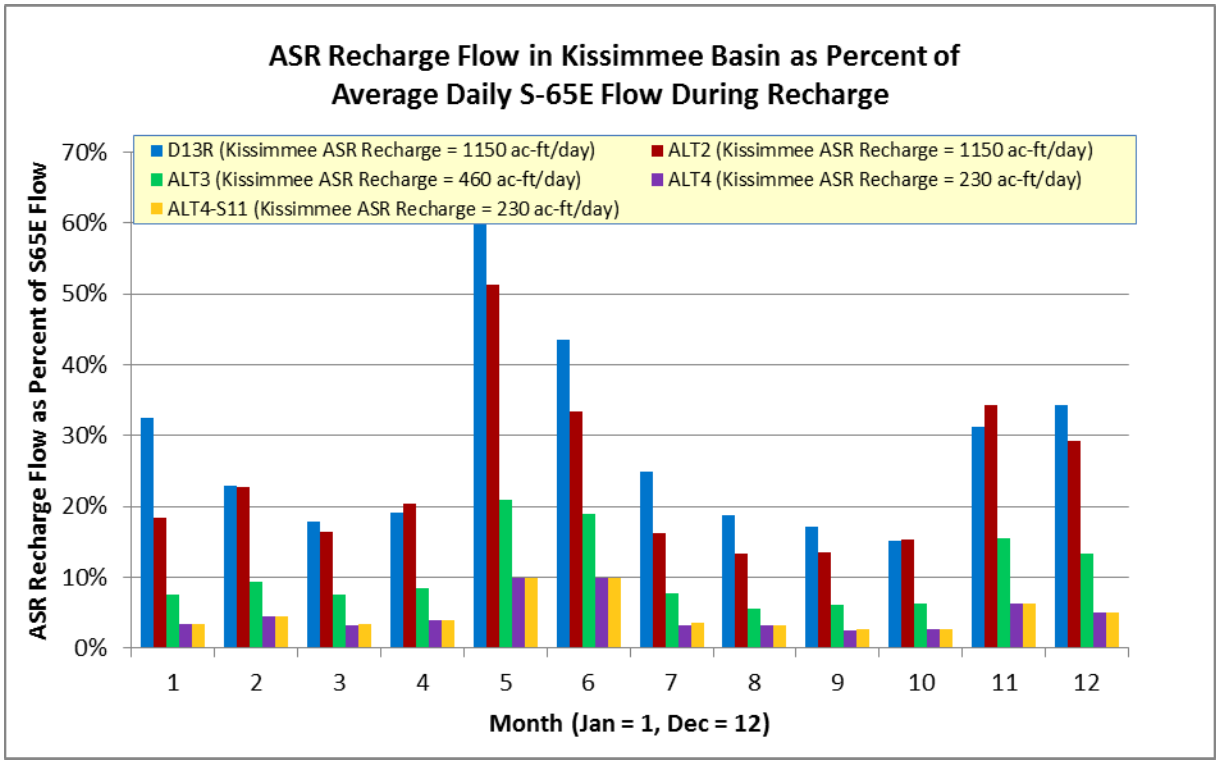


Figure 5.6. Kissimmee Basin ASR Recharge Flow as Percent of Average Daily S-65E Flow During Recharge.

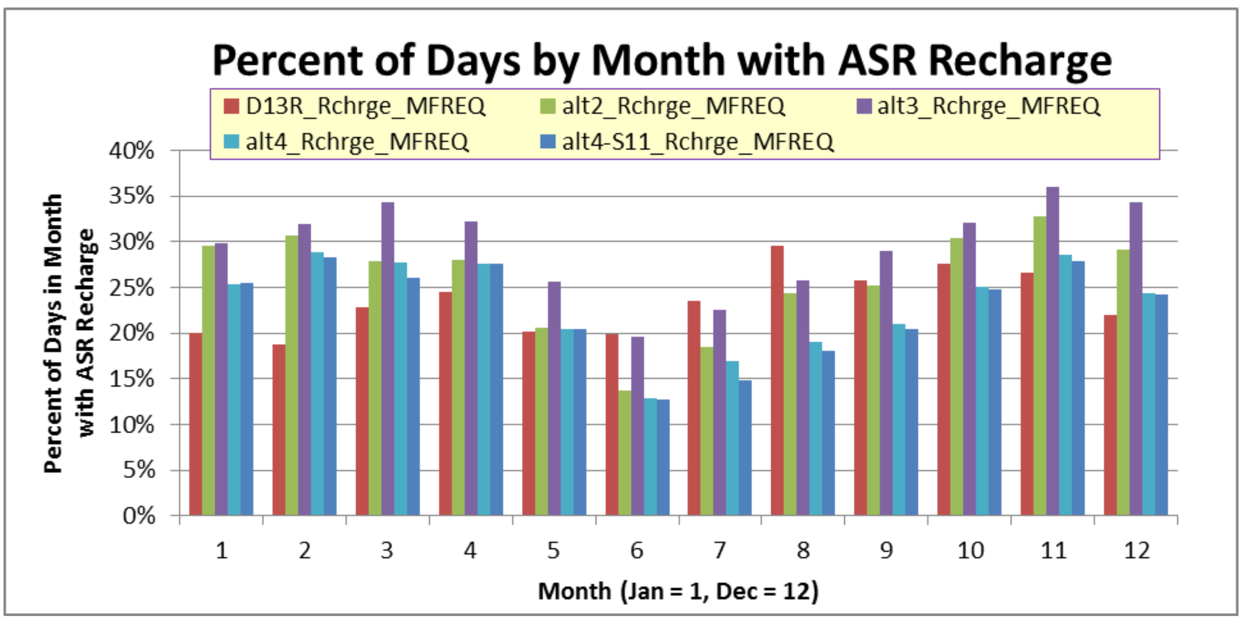


Figure 5.7. Percent of Days in Each Month with ASR Recharge

Figure 5.8 shows the average S-65E discharge during recovery events and the overall monthly average S-65E flows for the period of record (POR). It is expected that the average S-65E flows for the POR will exceed the average S-65E flows that occur during recovery events since recovery events are scheduled during periods of reduced water availability.

Figure 5.9 shows the recovered ASR flow volume as a percentage of the average S-65E monthly discharge during recovery events. This figure indicates that for most of the alternatives, recovered ASR discharge volumes during December and January would dominate flow in the Kissimmee River even for ALT4-S11. In comparison to the Kissimmee River ASR Pilot Project NPDES permit mixing zone requirement (3.9 to 1 ratio for river flow to ASR flow) for discharge into the river, ALT4-S11 would meet this standard with the exception of the discharges in January, May, and December which have ASR recovered flow exceeding 50 percent of the average S-65E flows. The other alternatives would generally not meet the 3.9 to 1 mixing flow requirement; however, future NPDES permits might not include such a requirement or the specified ratio may be different.

Figure 5.10 shows the percent of days in each month that ASR recovery occurs. Note that ALT4-S11 has significantly more recovery flow days than the other alternative as a result of the limited daily discharge rate of this alternative which extends the duration of recovery events.

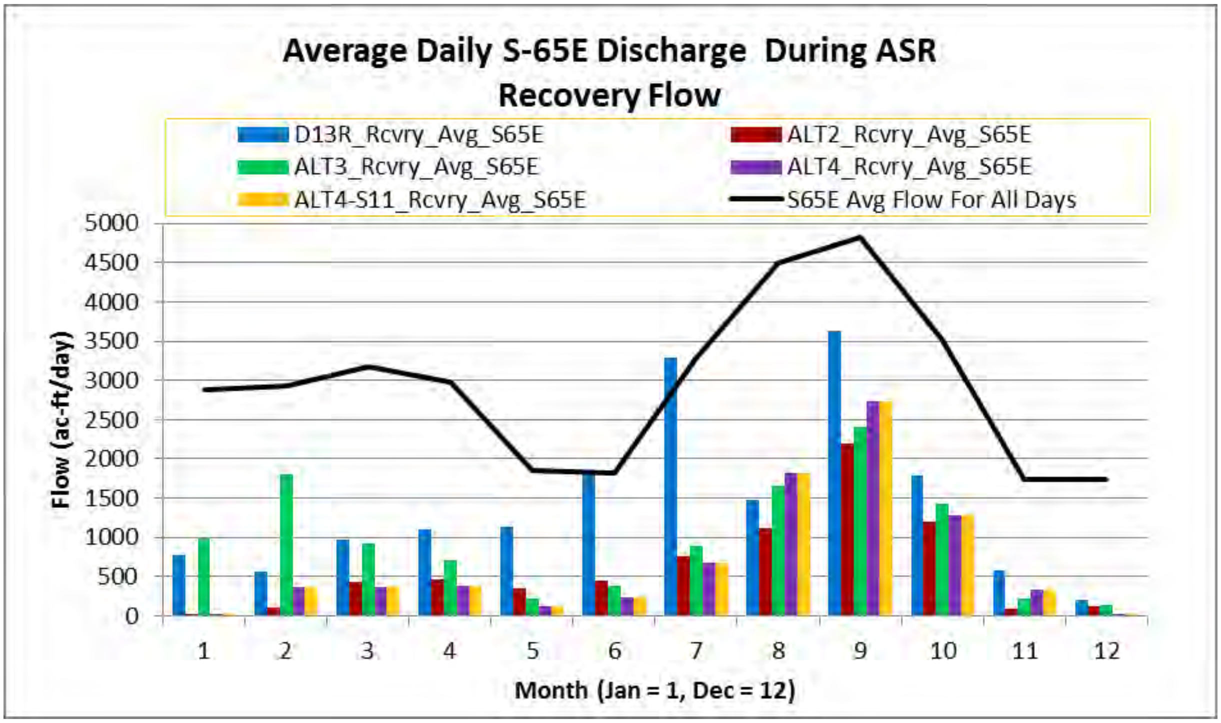


Figure 5.8. Average Daily S-65E Discharge by Month for Days with ASR Recovery Flow

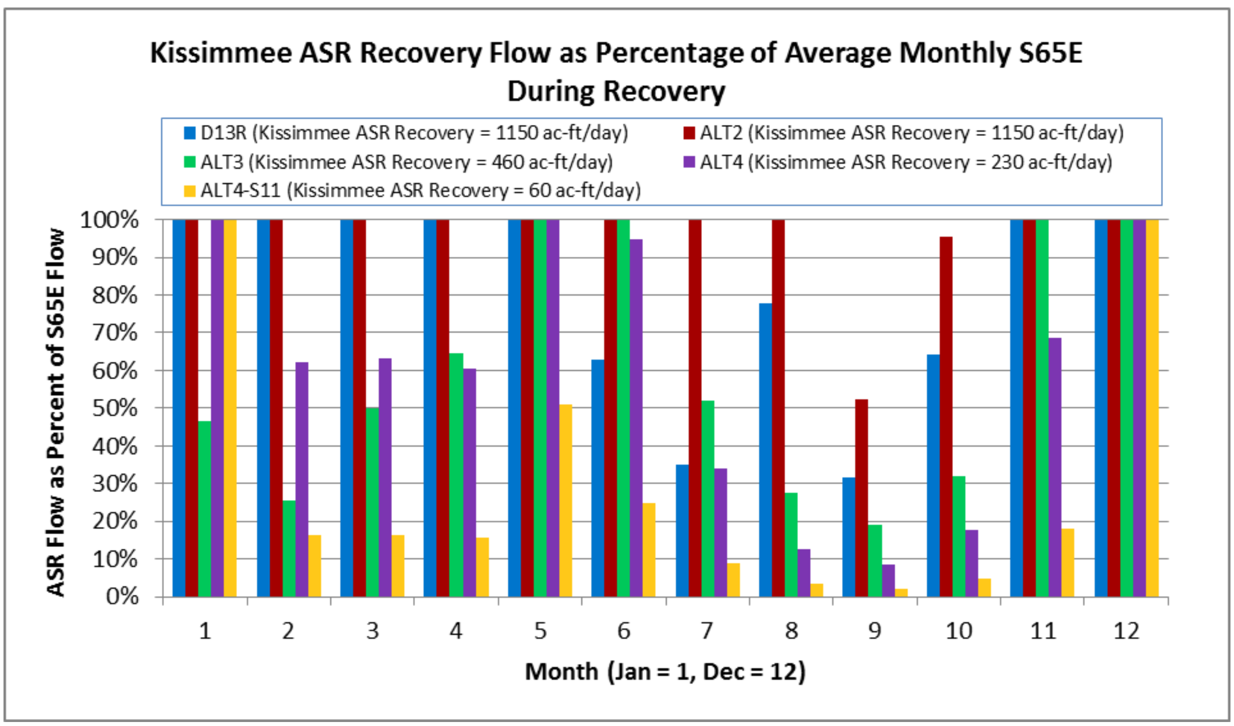


Figure 5.9. Kissimmee ASR Recovery Flow as Percentage of Average Monthly S-65E Flows that Occur During Recovery Events (Note: In this figure, percentages greater than 100 are not depicted).

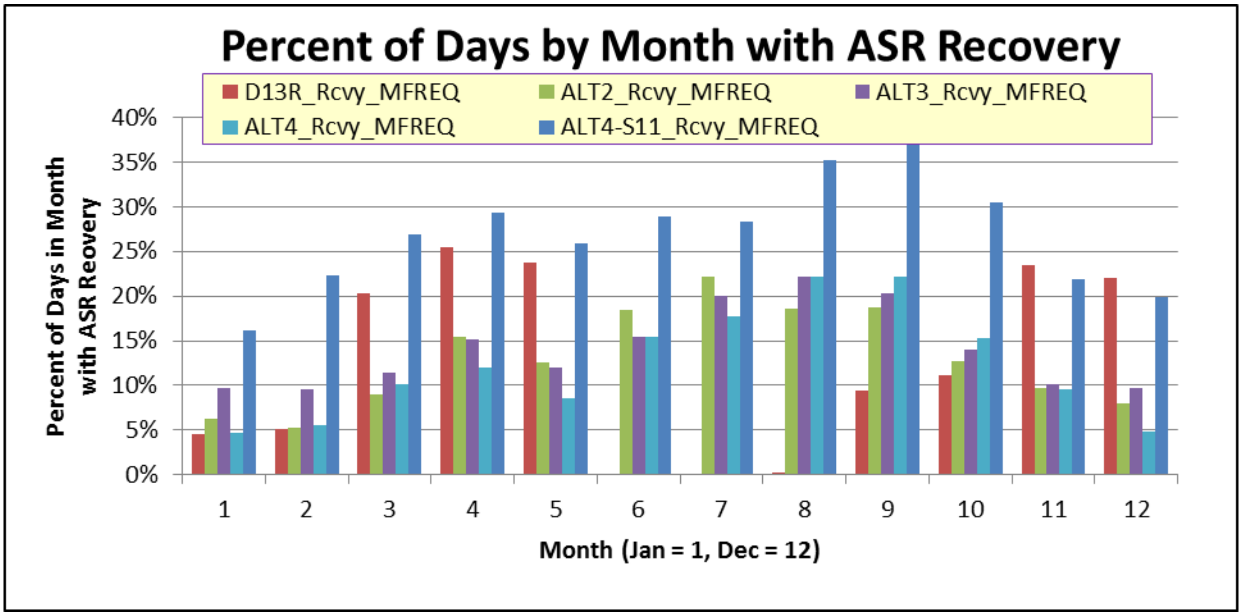


Figure 5.10. Percent of Days in Each Month With ASR Recovery

The timing and duration of recharge events is fairly consistent across the alternatives. For exposure of Kissimmee River basin receptors to ASR recharge conditions, the most significant difference between the alternatives is in the volume of water extracted from the Kissimmee River as a percentage of the available water. ALT4 and ALT4-S11 extract the least amount of water from the Kissimmee Basin (230 ac-ft/day) in comparison to ALT2 and ALT3 which extract two to four times as much water.

The timing and duration of recovery events is consistent across ALT2, ALT3, and ALT4; however, ALT4-S11 generally has more recovery events that last longer due to the reduced rate of recovery for this alternative. Relative to the other alternatives, ALT4-S11 has much lower recovered water flows in proportion to S-65E flows which would result in greater dilution of ASR recovery flows with Kissimmee River surface water than other alternatives.

5.1.1.2 Kissimmee River Water Quality (Exposure Intensity)

5.1.1.2.1 General Water Quality Impacts

Surface water quality in the Kissimmee River is potentially affected by the timing and duration of these ASR flows (as discussed in the section above) and by the quality of the recovered water. During cycle testing of the KRASR facility recovered water quality measurements were collected at the discharge structure. **Table 5.5** shows the minimum and maximum water quality concentrations measured during Cycle 4 (January 2012-July 2013) at the wellhead (post-treatment) during recharge and at the point of discharge during recovery. Cycle 4 was chosen as the most representative dataset since the earlier test cycles served to condition the aquifer to ASR storage and recovery operations. The results in this table indicate that recovered water met applicable surface water quality criteria during this cycle. In general, the concentrations of most of the constituents closely matched the surface water baseline concentrations during the initial period of recovery and generally trended towards the baseline groundwater concentrations as recovery proceeded. Earlier cycle tests results showed elevated arsenic concentrations in the recovered water; however, maximum concentrations trended lower with each successive cycle test.

For many of the water quality constituents such as color, sulfate, and chloride (shown in **Table 5.5**), long-term operation of the wells is likely to result in recovered water concentrations trending toward surface water baseline concentrations as more of the recharged surface water is not recovered during successive recovery events. Concentrations of other constituents such as arsenic and phosphorus may continue to be attenuated through the recharge/storage/recovery process; however, it is possible that the aquifer's ability to sequester these constituents will diminish over time.

Table 5.5 Minimum and Maximum Concentrations Observed at KRASR during Cycle 4 Testing in Comparison to State of Florida Class III Surface Water Criteria.

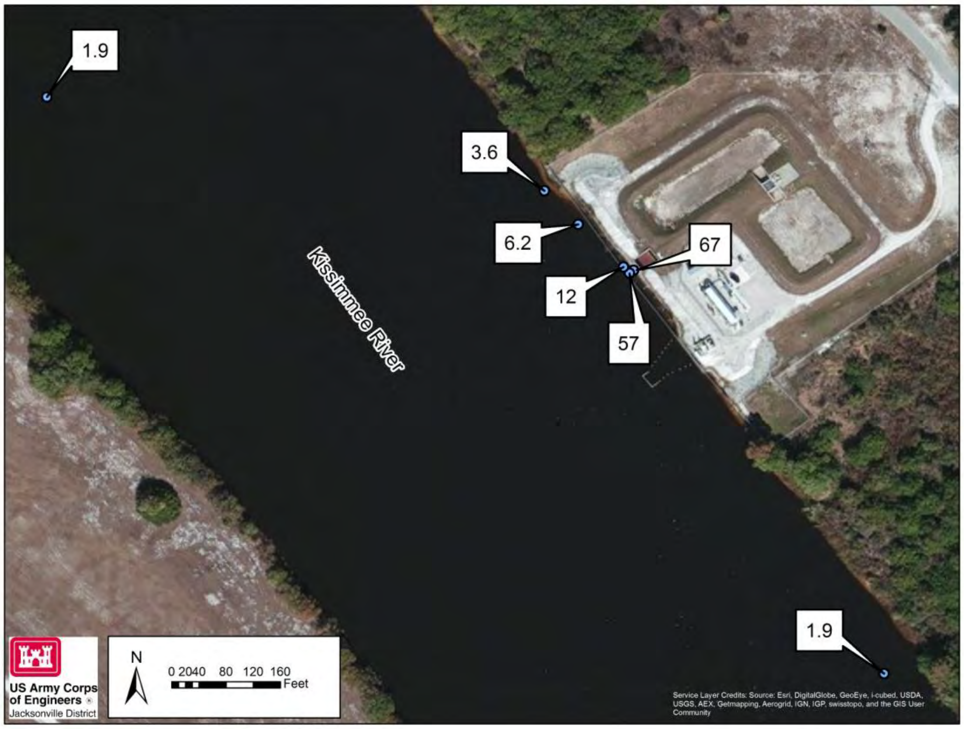
Parameter	**Recharge Water Quality**		**Recovered Water Quality**		**Florida Class III Water Quality Standard**
	Minimum	**Maximum**	**Minimum**	**Maximum**	
Temperature, in ° C	**18.5**	**31.3**	**23.7**	**25.2**	
Specific Conductance in µS/cm	**167**	**365**	**417**	**944**	**1,275**
pH	**6.21**	**7.09**	**7.12**	**8.07**	**Not < or > 1 unit from background**
Dissolved Oxygen, in mg/L	**0.83**	**7.94**	**6.52**	**8.25**	**> 5**
Turbidity, in NTU	**0.9**	**2.83**	**0.46**	**1.3**	**< 29 above background**
Total dissolved solids, in mg/L	**110**	**200**	**300**	**570**	
Total Suspended Solids, in mg/L	**5**	**6.5**	**5**	**5**	
Color, in PCU	**60**	**900**	**25**	**50**	

Hardness (calculated), in mg/L	**51**	**96**	**130**	**210**	
Calcium, in mg/L	**14**	**25**	**31**	**43**	
Magnesium, in mg/L	**3.5**	**84**	**11**	**25**	
Sodium, in mg/L	**12**	**25**	**29**	**90**	
Potassium, in mg/L	**2.9**	**6.1**	**4**	**6.3**	
Sulfate, in mg/L	**9.7**	**43**	**32**	**250**	
Sulfide, in mg/L	**0.007**	**0.019**	**0.021**	**0.89**	
Chloride, in mg/L	**21**	**58**	**46**	**300**	
Total Alkalinity, in mg/L as CaCO3	**31**	**47**	**70**	**90**	**> 20**
Total Organic Carbon, in mg/L	**16**	**27**	**4**	**9.5**	
Arsenic, in µg/L	**0.53**	**1.3**	**0.78**	**10**	**< 50**
Iron, in µg/L	**78**	**1000**	**43**	**390**	**<1000**
Manganese, in µg/L	**9.3**	**9.3**	**3.4**	**3.4**	
Molybdenum, in µg/L	**0.45**	**40**	**21**	**44**	
Mercury (Ultra-trace), in ng/L	**1.0**	**5.7**	**0.2**	**0.2**	**12**
Methyl Mercury, in ng/L	**0.13**	**2.69**	**0.02**	**0.02**	
Nitrate N, in mg/L	**0.015**	**0.47**	**0.015**	**0.069**	
Nitrite N, in mg/L	**0.015**	**0.031**	**0.015**	**0.025**	
Total Kjeldahl Nitrogen, in mg/L	**0.95**	**2.4**	**0.43**	**1.2**	
Ammonia, in mg/L	**0.026**	**0.41**	**0.13**	**0.67**	
Phosphorus, Total as P, in ug/L	**4.4**	**250**	**2.2**	**52**	
Gross Alpha, in pCi/L	**0.037**	**1.31**	**1.16**	**2.71**	**< 15**

Field parameter sampling was conducted in the Kissimmee River adjacent to the ASR outfall during discharges from KRASR required by the NPDES discharge permit. The measurements of temperature and specific conductivity showed that the water quality signal from the ASR flows were undetectable within 30 to 50 meters in any direction of the outfall.

Recovered water concentrations of mercury and methylmercury measured at the KRASR outfall were consistently lower than recharge water concentrations. The median concentrations of mercury and methylmercury in recharge water measured during all cycle tests at the KRASR wellhead were: 1.83 +/- 0.94 ng/L (n=54), with concentrations ranging between 0.99 ng/L and 5.65 ng/L (for mercury); and 0.24 ng/L -/+ 0.53 ng/L (n=54), with concentrations ranging between <0.020 ng/L (the MDL) and 3.02 ng/L (for methylmercury). All recharge water mercury analyses were less than the 12 ng/L surface water quality criterion; there is no surface water quality criterion for methylmercury. Mercury and methylmercury concentrations in recovered water during all cycle tests at the ASR wellhead or POD were nearly at their respective minimum detection limits (0.15 ng/L and 0.020 ng/L, respectively). The median concentrations were: 0.15 +/- 0.08 ng/L (n= 42), with concentrations ranging between < 0.15 ng/L and 0.68 ng/L (for mercury); and 0.020 +/- 0.005 ng/L (n=42), with concentrations ranging between 0.054 ng/L and <0.019 ng/L (for methylmercury). The t-test statistic (Mann-Whitney rank sum test) indicates that the difference in median mercury and methylmercury concentrations between recharge and recovered water is statistically significant (P <0.001). Declining mercury and methylmercury concentrations, even during prolonged cycles, indicate that additional mercury methylation does not occur during storage in the UFA, and ASR will not increase the load of methylmercury to receiving water bodies.

Figure 5.11 shows the dilution of the ASR related arsenic plume on two dates at the KRASR facility during Cycle 1 recovery in March of 2009. During the two weeks between these measurements, the flow in the river averaged 130 cfs. This is an indication that mixing of ASR effluent with river flows occurs in close proximity to the outfall at least for low volume discharges (<5 mgd) and that the area where potential impacts from changed water quality from similar discharge volumes would be localized. The discharge plume for a multi-well ASR facility would be larger though it should not exceed 800 meters since this is the maximum dimension of a discharge plume allowed by FDEP.



Arsenic 3/10/2009 at KRASR

Arsenic 3/19/2009 at KRASR

Figure 5.11. Arsenic Plume Measured at KRASR on Two Dates in March 2009.

The results shown in **Table 5.5** are considered to be representative of the recovered water quality expected from UFA ASR storage wells in the Kissimmee River Basin. None of the ASR scenarios analyzed here include APPZ wells in the Kissimmee Basin. If APPZ wells were widely installed for ASR in the Kissimmee Basin and these wells provided significant contributions of recovered ASR water, then the maximum recovered concentrations for parameters such as TDS, chloride, sulfate, sulfide, alkalinity, and hardness would be higher since the APPZ wells generally have higher concentrations of these constituents.

Near-field water quality conditions just downstream of the ASR outfalls are likely to be dominated by recovered water quality during recovery events. Far-field water quality conditions in the Kissimmee River will depend upon the number of wells installed in the basin and how they are operated. Implementation of cluster ASR facilities in the Kissimmee Basin would result in greater flows at discharge sites and larger mixing zones than that observed at the KRASR pilot facility.

Multiple ASR cluster facilities in the Kissimmee Basin such as that called for in ALT2 and ALT3 would likely result in large mixing zones such that downstream water quality in the river during recovery events would likely be very similar to the ASR recovered water quality since ASR recovery flows would dominate river flows during periods with low to no flow at S-65E. For ALT4-S11, the maximum ASR discharge rate for the 15 wells in the Kissimmee Basin is limited to 25 percent of the design flow capacity or 18.75 MGD. These 15 wells would likely be placed in three five well clusters. The mixing zones at the outfall from each of these clusters would not be significantly larger than that measured at KRASR and the potential exposure mixing zone area in the vicinity of these cluster outfalls would be limited.

While recovered water at KRASR met surface water quality criteria, there is still a potential to impact receptors that are sensitive to the changes in water quality. For example, there is no Class I or III standard for sulfide in Florida waters; however, concentrations above 0.2 mg/L are considered by USEPA to be potentially toxic to freshwater aquatic life. This potential exposure could be mitigated by designing the re-aeration facilities at ASR discharge sites to take into account de-gassing of sulfide as well as entrainment of DO. Exposures associated with reduced nutrient concentrations in the recovered water might prove beneficial to the Kissimmee River and Lake Okeechobee since these systems are considered to be eutrophic. Discharge of ASR water with reduced color and turbidity may also provide some ecological benefit associated with improved light transmittance.

5.1.1.2.2 Thermal

ASR recovery discharges are likely to have higher water temperatures than receiving waters during the winter months and lower temperatures than the receiving waters during the summer months. At the immediate location of discharge, the maximum predicted temperature increase could be as high as 12^{o}C assuming average groundwater temperature for recovered water and a receiving water temperature near the lowest recorded measurement of 13^{o}C. Assuming average flow and temperature conditions in the receiving water, the average maximum water temperature increase is predicted to be up to 5^{o}C and average maximum temperature decreases is predicted to be 3^{o}C. Based on hydrologic modeling, recovery events are likely to occur on an annual basis and last on average more than 100 days. However, inter-event periods may be as long as 6-7 years which may allow affected resources to recover. Assuming a maximum plume length of 800 meters as determined by FDEP requirements, the near-field mixing zones for the Kissimmee River Basin ASR scenarios such as ALT2 would result in approximately 1/3rd of the shoreline habitat potentially impacted with the greatest change in surface water temperature conditions.

The frequency and duration are important factors to consider in evaluating the effect of ASR related surface water temperature changes on fish and wildlife receptors. **Table 5.6** shows the percent of time that Kissimmee ASR facilities will operate in the recovery mode and the percent of that time that the ASR flows exceed S-65E flow volumes. From this table, it appears that ASR recovery operations will occur between 12 and 27 percent of the time with ALT4-S11 having a longer recovery period due to the reduced rate of recovery. The availability of sufficient flows at S-65E for blending with ASR recovery flows is also important. The percent of time during recovery that the volume of recovery exceeds historic S-65E flows varies from 31 percent for ALT4-S11 to 74 percent for ALT3. When considering the entire simulation period, not just the time during recovery events, the percent of time that ASR recharge flows exceed S-65E Flows is 10 percent or less for all of the alternatives.

Using a simplified mixing model, average thermal exposures were estimated for the ASR scenarios contemplated for the Kissimmee Basin. **Table 5.7** shows the average change in temperature by month for each of the ASR scenarios. The estimated change in water temperatures shown in this table are based upon full mixing of ASR flow with the average available S-65E flow (during ASR recovery) for each month. Increases in average water temperature are most significant in December and January. Decreases in temperature are projected to occur if ASR discharge occurs in the late spring through summer period. Larger ASR flows (ALT2) provide greater average changes in temperature in comparison to ASR scenarios with fewer wells (ALT3) and reduced recovery volume (ALT3, ALT4, ALT4-S11).

Table 5.6. Percent of Time Kissimmee ASR Operations Occur and Exceed Monthly Average S-65E Flows During Either Recharge or Recovery Mode.

	Recovery		
Alternative	**Percent of Time ASR Operates in Recovery Mode**	**Percent of Time During Recovery That ASR Flows Exceed S-65E Flows**	**Percent of Total Time Recovery Exceeds S-65E Flows**
ALT2	**13%**	**74%**	**10%**
ALT3	**14%**	**55%**	**8%**
ALT4	**12%**	**43%**	**5%**
ALT4-S11	**27%**	**31%**	**8%**

Table 5.7. Average Change in Kissimmee River Water Temperature (^{o}C) Due to ASR Implementation Scenarios.

		Change in Water Temp Assuming Fully Mixed Conditions and no thermal input/output			
Month	No ASR Temperature (° C)	ALT2 (Kissimmee ASR Recovery = 880 ac-ft/day) (° C)	ALT3 (Kissimmee ASR Recovery = 440 ac-ft/day) (° C)	ALT4 (Kissimmee ASR Recovery = 220 ac-ft/day) (° C)	ALT4-S11 (Kissimmee ASR Recovery = 58 ac-ft/day) (° C)
Jan	18.4	6.5	2.1	6.1	0.5
Feb	19.6	5.0	1.1	2.1	0.2
Mar	21.6	2.5	1.1	1.3	0.2
Apr	24.6	0.3	0.2	0.2	0.0
May	27.3	-1.8	-1.6	-1.5	-0.1
Jun	29.4	-3.2	-2.4	-2.1	-0.4
July	30.3	-3.2	-1.8	-1.3	-0.2
Aug	30.2	-2.6	-1.1	-0.6	-0.1
Sep	28.9	-1.4	-0.6	-0.3	-0.1
Oct	26.4	-0.7	-0.3	-0.2	-0.1
Nov	22.9	1.9	1.4	0.8	0.3
Dec	20.1	4.5	3.8	4.9	0.9

5.1.2 Lake Okeechobee Exposure Pathway

5.1.2.1 Timing, Duration, and Quantity of Lake Okeechobee ASR Flows

The timing, duration and quantity of Lake Okeechobee ASR flows were estimated from SFWMM 2x2 and LOOPS model output. Lake Okeechobee stage conditions determine the timing and duration of ASR recharge and recovery at all nine ASR installations within the Lake Okeechobee Basin. During periods of high lake stages, the ASR system would be used to store excess surface water which would result in lower peak Lake stages. During periods of low Lake stages, stored ASR water would be recovered and discharged into the Lake. These recharge and recovery events might typically be scheduled during the wet and dry seasons though it is possible that recovery does not occur for several years during long-duration wet periods. **Figure 5.12** shows the locations of potential ASR installations considered in this ERA for the Lake Okeechobee Basin.

Figure 5.12. Lake Okeechobee Basin Proposed ASR Sites

Figure 5.3 and Figure 5.4 show histograms of recharge and recovery events predicted by the SFWMM and the LOOPS models for the 1965-2005 time period. (**Appendix B** has more detailed hydrographs of recharge and recovery). The timing and duration of the recharge and recovery events predicted for the D13R and ALT2 scenarios are very similar indicating that the LOOPS model provides results that are comparable to SFWMM results. This is an indication that the SFWMM and the LOOPS models used similar lake stage elevations and operations rules to trigger either ASR recharge or recovery events. **Table 5.8** shows the maximum Lake Okeechobee Basin ASR recharge and recovery flow in ac-ft/day for each of the scenarios. Note that D13R, ALT2, ALT4, and ALT4-S11 all have the same recharge rate. This means that for Lake Okeechobee, they each have the same capacity to bring down high Lake stages with ASR operations. D13R and ALT2 have the greatest capacity to augment low Lake stages since they have a recovery capacity of 2,940 ac-ft/day. ALT3 has half of this capacity since it has only 100 wells. The recovery capacity of ALT4 is limited because more than half of its 200 wells are anticipated to be completed in the BZ aquifer, which is assumed to have no recovery. The recovery capacity of ALT4-S11 is further reduced from ALT4 due to the rate adjustment factors listed in **Table 4.10**.

Table 5.8 ASR Recharge and Recovery Rates for the Lake Okeechobee Basin.

Alternative	Maximum ASR Recharge Flow in Lake O Basin	Maximum ASR Recovery Flow in Lake O Basin
	(ac-ft/day)	(ac-ft/day)
D13R	2940	2940

ALT2	2940	2940
ALT3	1470	1470
ALT4	2940	1170
ALT4-S11	2940	460

Table 5.2 shows the percent of the time that Lake Okeechobee Basin ASR facilities are planned to be operated in either the recharge or the recovery model. For D13R, ALT2, ALT3, and ALT4, the ASR facilities operate in recharge mode about 23 to 29 percent of the time and in recovery mode around 12 to 14 percent of the time. For ALT4-S11, the facilities are expected to operate in recharge mode 22 percent of the time which is similar to the other alternatives; however, recovery mode operations last about twice as long (27 percent of the time versus 13 percent) relative to the other alternatives. ALT4-S11 has reduced recovery flows, thus a less rapid increase in Lake stage which would results in longer recovery event durations.

Table 5.3 is a summary of Recharge duration and inter-event statistics. The maximum duration of ASR recharge events varies from about 330 to more than 570 days. The median duration is around 100 days and the average duration of recharge events varies from 107 to 177 days. Excluding D13R, which does not cover the period from 1996 to 2005, the number of recharge events is around 30. The average duration of recharge inter-event periods (time between recharge events) varies from 339 to 474 days while the median duration of inter-event periods varies from around 100 to 250 days.

Table 5.4 includes statistics regarding the number of recovery events, the average, median, and maximum duration of recovery events and similar statistics regarding periods between discharge events. The average duration of recovery events varies from 50 to 188 days depending upon the ASR alternative. ALT4-S11 has a maximum recovery rate that is 456 ac-ft/day and an average duration of 188 days while ALT2 has a maximum recovery rate of 2936 ac-ft/day and an average duration of 119 days. The shorter average recovery duration for ALT2 relative to ALT4-S11 has to do with the lake stage reaching the shut off trigger stage for ASR discharges quicker as a result of higher recovery rates specified for ALT2.

The recovery inter-event duration information can be used to evaluate whether ecological resources have sufficient time to recovery between ASR related exposure events. The average inter-event duration between recovery discharges varies from 19 to 27 months for alternatives simulated for the 1965-2005 period. The D13R alternative has an average inter-event period of 11 months; however, it is not comparable to the other alternative since the simulation period for this alternative is 1965-1995.

5.1.2.2 Lake Okeechobee Water Quality (Exposure Intensity)

ASR impacts to Lake Okeechobee water quality were evaluated using the LOEM and by using a simple mass balance approach to evaluate constituent loading. The mass balance approach was used to address water quality constituents such as hardness and alkalinity which were not modeled in the LOEM as well as to provide estimated water quality conditions for ALT4-S11 which was not simulated with LOEM.

5.1.2.2.1 Lake Okeechobee Environmental Modeling Results

The LOEM model was modified in 2011 specifically for this ERA to incorporate sulfate, chloride, and SAV. Additional details of the LOEM modeling assumptions and results are found in **Appendix B**. Estimating recovered water quality concentrations to establish boundary conditions is difficult given the limited available field data. The concentration of chemical constituents in discharged ASR water depends upon the volume of surface water stored in the aquifer, percent of stored water recovered, and the quality of the groundwater in the storage zone and the surface water. During recovery, the quality of water changes as the recovery proceeds and the apparent blend of surface and groundwater changes as shown in **Figure 5.13** for the KRASR pilot site**.** Not only does the quality of the recovered water change as a recovery event proceeds, the quality of the groundwater varies geographically as well as vertically within the three primary Floridan Aquifer storage zones (UF, APPZ, BZ).

To develop the most plausible scenarios for ASR related impacts to Lake Okeechobee water quality, specific water quality boundary conditions were developed for each ASR well cluster location by ASR scenario. The assumptions for the simulated LOEM scenarios are shown in **Table 5.9**. To address the uncertainty inherent to varying recovered water quality concentrations, ASR scenarios were simulated assuming constant recovered water quality concentrations set to baseline groundwater values (model runs designated with a “C”) and assuming varying recovered water quality concentrations (model runs designated with a “V”). The ALT1 scenario includes no ASR wells but is used to establish the baseline water quality and SAV conditions in the Lake during the simulation period. Note that the ALT4-S11 was not simulated using LOEM because this scenario was developed by the hydrogeologic modeling team in 2012 after the LOEM modeling study was completed in 2011.

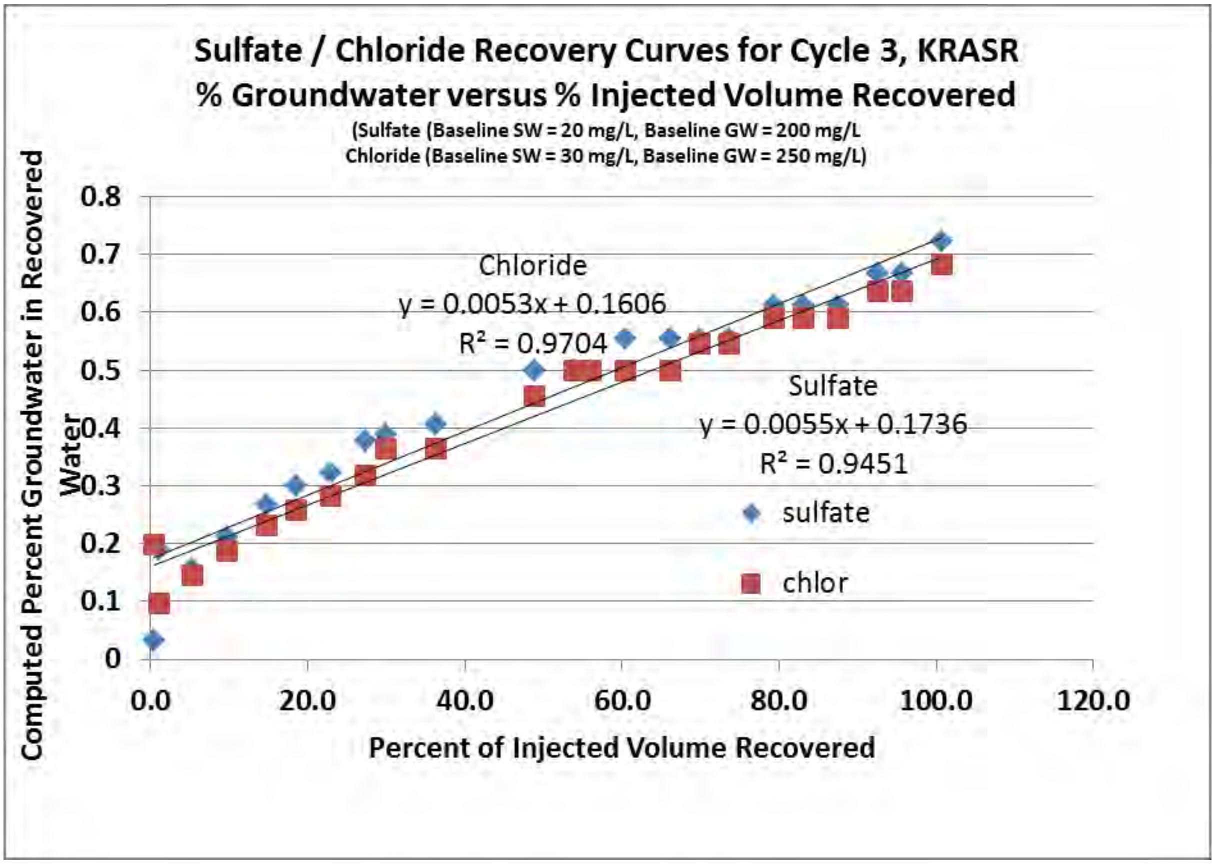


Figure 5.13. Sulfate / Chloride Recovery Curves for Cycle 3 at Kissimmee River ASR Pilot Site.

Table 5.9. Recovered Water Quality Concentration Assumption for LOEM Simulated Alternatives

Alternative	Recovered Water Quality Concentration Assumption	Number of Wells			
		UF	APPZ	BZ	Total
ALT1	Not applicable	0	0	0	0
ALT2C	Set to GW Baseline	200	0	0	200
ALT2V	Varies from SW to GW Baselines	200	0	0	200
ALT3C	Set to GW Baseline	100	0	0	100
ALT4V	Varies from SW to GW Baselines	48	32	120	200
ALT4C	Set to GW Baseline	48	32	120	200

DBHYDRO data were used as the source of baseline Lake Okeechobee water quality. **Figure 5.14** shows the LOEM model grid and water quality sampling locations used to calibrate the LOEM model and review model predictions. Concentrations of dissolved solids in Lake Okeechobee surface water are generally inversely related to lake stage and volume since years with above average rainfall conditions tend to result in reduced dissolved solids concentrations.

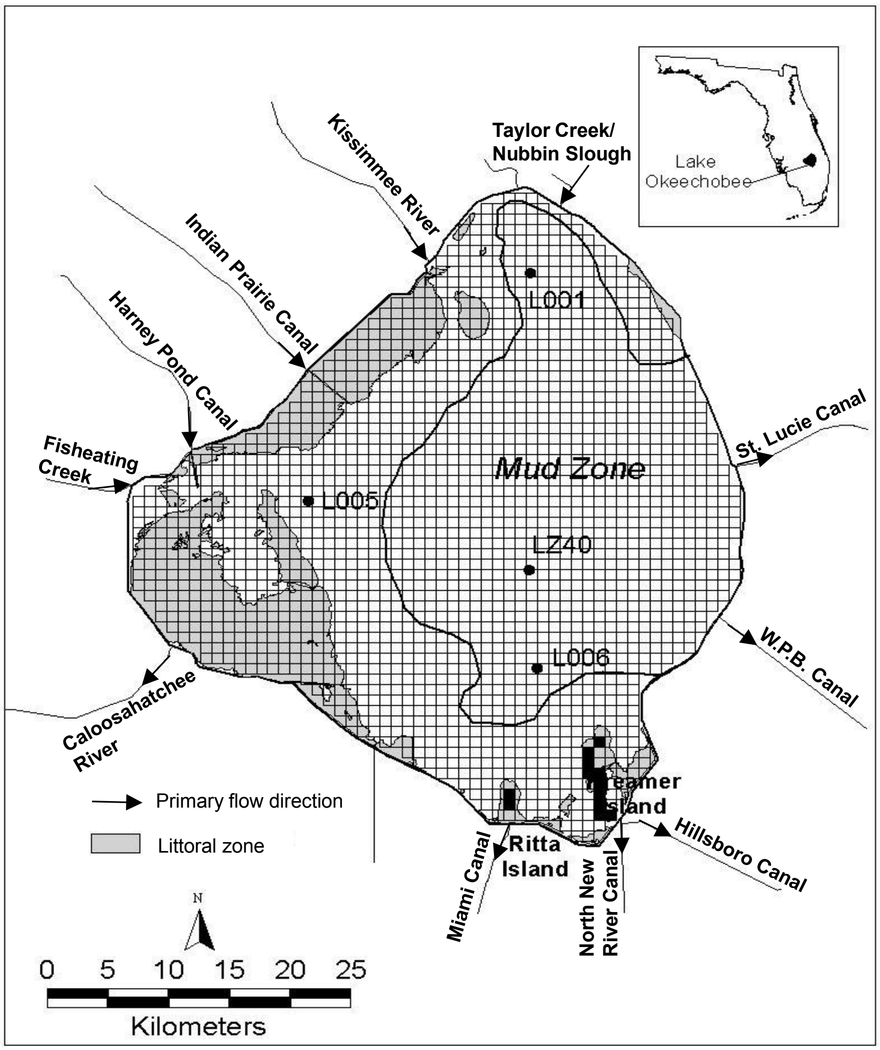


Figure 5.14. LOEM Model Grid and Water Quality Monitoring Stations in Lake Okeechobee

The average predicted water quality concentrations for the baseline (ALT1) and ASR scenarios that assume constant water quality in the recovered water are shown in **Table 5.10**. The average TSS concentration with the ALT2 scenario is shown to be somewhat lower than the baseline prediction. This is likely due to a combination of discharging recovered water with limited TSS as well as the impact of the ALT2 ASR discharges on increasing lake stage which reduces the ability of wind driven waves to re-entrain settled solids back into the water column. ALT3 and ALT4 show less difference in TSS relative to ALT1, this may be a reflection of the reduced volume of ASR discharges and lesser ability to modify Lake stage conditions.

The modeled results indicate that for the nutrients (nitrogen and phosphorus species) the ASR scenarios would not significantly increase or decrease average Lake concentrations for these constituents. For instance, though the recovered water TP concentration for ALT2C is 0.01 mg/L which is significantly lower than the recharge water TP concentration of 0.10 mg/L, there is no change in Lake TP concentration. Based on these results, it appears that the ability to sequester phosphorus load in the aquifer through ASR operations will not result in a measurable change to water column concentration of phosphorus in the Lake. This may be due to internal cycling of legacy phosphorus between the water column and the sediment bed.

Sulfate and chloride concentrations appear to be significantly impacted by the ASR scenarios that have the most wells discharging to the lake. Since **Table 5.10** shows only the predictions for the ASR scenarios with recovered water concentrations reflect the baseline groundwater concentrations. These concentrations are generally conservative relative to concentrations predicted under the more likely scenario that recovered water quality varies from near surface water conditions to nearly groundwater conditions over recovery events. Since the ALT4-S11 scenario has less than ½ of the recovered water flow in comparison to ALT4, it is likely that changes in water quality for ALT4-S11 will be significantly less than that predicted for ALT4.

Table 5.10. Average Lake Okeechobee Water Quality Concentrations Predicted at LZ40 by LOEM for Observed and Predicted Historical and ASR Scenarios assuming constant, "C", (non-varying) recovered water quality concentrations (Jin, et al, 2014).

Parameter	Number of Data Points (1999-2009)	Observed Historical	Predicted Baseline (ALT1)	ALT2C (200-well)	ALT3C (100-well)	ALT4C (~50-well)

DO (mg/l)	**121**	**8.1**	**8.6**	**8.6**	**8.6**	**8.6**
Chlorophyll (mg/l)	**122**	**16**	**17**	**19**	**19**	**19**
Total Phosphorus (mg/l)	**127**	**0.19**	**0.130**	**0.129**	**0.131**	**0.131**
SRP (mg/l)	**126**	**0.06**	**0.07**	**0.065**	**0.065**	**0.065**
TKN (mg/l)	**127**	**1.5**	**1.3**	**1.4**	**1.4**	**1.4**
NOx (mg/l)	**117**	**0.29**	**0.05**	**0.04**	**0.04**	**0.04**
TSS (mg/l)	**127**	**51**	**36**	**29**	**31**	**33**
T (^{o}C)	**126**	**24**	**25**	**25**	**25**	**25**
Cl (mg/l)	**125**	**58**	**59**	**89**	**77**	**68**
Ca (mg/l)	**37**	**41**	**41**	**41**	**42**	**42**
SO4 (mg/l)	**36**	**36**	**33**	**53**	**44**	**39**

Graphs of the water quality modeling results for several parameters at monitoring station L001 are presented in **Figures 5.15** through **5.18**. The L001 station is located in the northern portion of Lake Okeechobee and the predicted results at this station are representative of the predicted changes in water quality for most of the Lake. (Additional LOEM water quality results at other monitoring stations are included in **Appendix B**.)

Figure 5.15 shows the predicted sulfate concentration at L001. Periods of high sulfate concentration in this figure are coincident with low lake stage since sulfate concentrations are inversely correlated to lake stage. Relative to other alternatives, the sulfate concentration at LOO1 for ALT2C results in the largest increase in sulfate concentrations over baseline conditions. This is due to two factors: ALT2C has the maximum number of ASR wells discharging to the Lake, and the recovered water quality concentrations are assumed to match the baseline groundwater concentration during the entire recovery period. The assumption that recovered water quality matches groundwater baseline conditions is not realistic as demonstrated by water quality data collected during recovery events at the KRASR pilot site as well as at other ASR facilities throughout Florida. For this reason, ALT2C is considered to be a conservative estimate of the potential for CERP ASR to alter Lake Okeechobee water quality. ALT3C with half of the wells as ALT2C increases the maximum sulfate concentration from around 60 mg/L to nearly 80 mg/L. Since ALT3C assumes that recovered water concentrations match the baseline GW concentrations for the entire recovery period, the estimates of peak sulfate concentration shown here are likely high and also conservative for this 100 well scenario. ALT2V provides a more realistic prediction of the impact of 200 Upper Floridan ASR wells on Lake Okeechobee sulfate concentrations. For ALT2V, the maximum sulfate concentration in the Lake appears to increase from around 60 mg/L to 75 mg/L during periods when ASR water is recovered and discharged to the Lake.

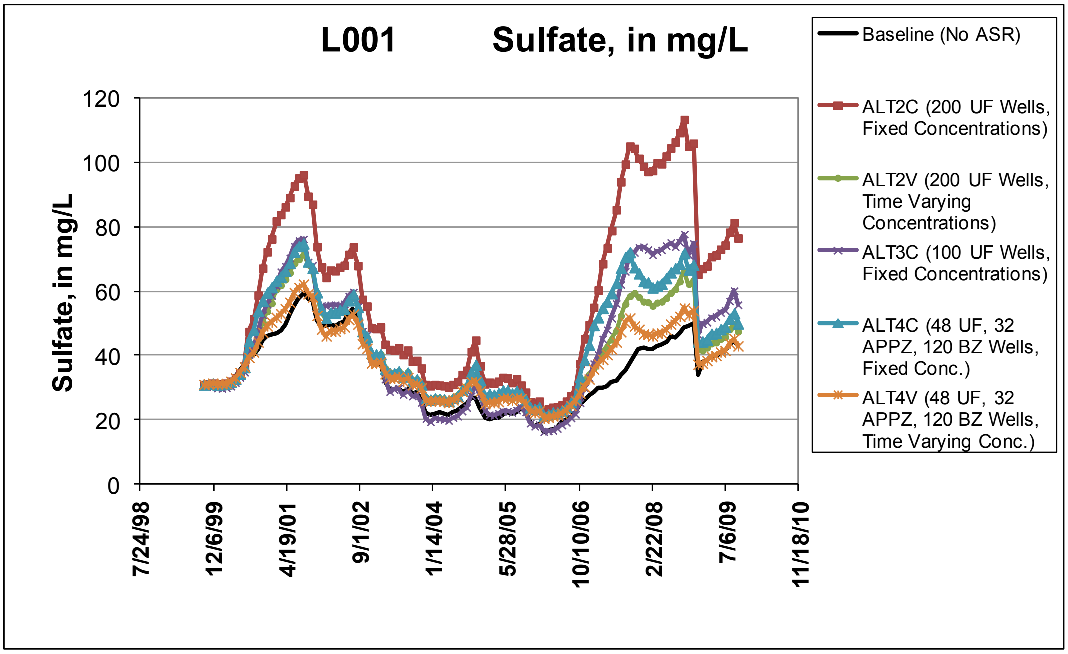


Figure 5.15. Predicted Sulfate at L001 (Northern Lake Okeechobee).

Maximum sulfate concentrations for ALT4V increase only moderately at L001 from around 60 mg/L to a peak of approximately 62 mg/L. The maximum increase at any one time of sulfate for ALT4V appears to be approximately 20 mg/L which occurs in 2007. ALT4-S11 was not simulated using the LOEM model since this alternative was created after the LOEM modeling project was completed. However, since ALT4-S11 has approximately 50 percent of the recovered water in comparison to ALT4, it is likely that the maximum increase in sulfate concentration for ALT4-S11 is on the order of 10 mg/L. This is due to the combined effect of reduced ASR discharges in ALT4S-11 with a recovery rate of only 1.25 MGD for the wells located in the high efficiency UF aquifer zone and the 2.5 MGD recovery rate for the APPZ wells.

These modeled results show that several ASR scenarios could cause increased sulfate concentrations in Lake Okeechobee during and immediately after ASR recovery events; however, shortly after the recovery events end, the sulfate concentrations return almost to the baseline (no-ASR) concentration. The strong inverse correlation between Lake stage and sulfate concentrations effectively limits the duration of ASR related exposure to elevated sulfate concentrations since increased Lake stages that result from rainfall runoff naturally dilute sulfate concentrations. Also, the initiation of rainfall and higher lake stages can trigger the end of ASR discharge events that contribute sulfate to the lake.

Figure 5.16 shows the impact of ASR scenarios on Lake chloride concentrations. Like sulfate, the ALT2C alternative results in the greatest increase in lake chloride from a maximum near 100 mg/L to nearly 200 mg/L. For the more realistic ALT2V and ALT4V, the maximum chloride concentration is around 120 mg/L. Similar to sulfate, chloride concentrations return to near the baseline concentration conditions for all of the alternatives shortly after recovery ceases.

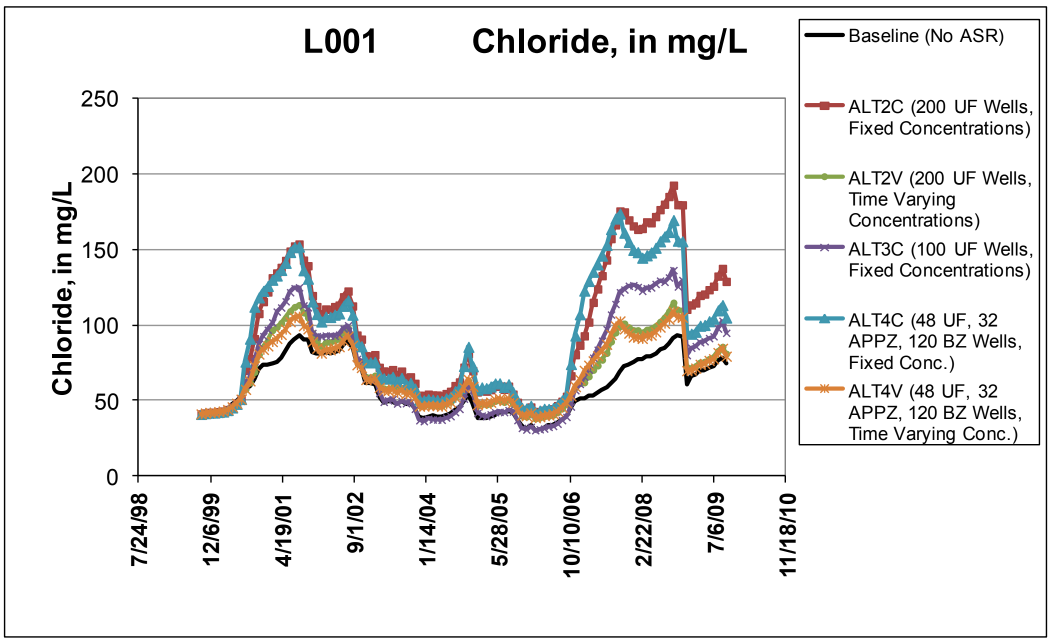


Figure 5.16. Predicted Chloride at L001 (Northern Lake Okeechobee).

Figure 5.17 shows that there is little to no impact from ASR on lake temperature at L001. This is likely due to the fact that the recovered water from ASR wells is near the ambient surface water temperature and this ASR water relatively quickly reaches thermal equilibrium with the lake water. However, there may be areas in close proximity to ASR discharge locations where there is some impact to ambient Lake water temperature. However due to mixing from wind and other environmental drivers such as solar input, the main portion of the Lake (at L001 for instance) is not exposed to thermal impacts from ASR discharges.

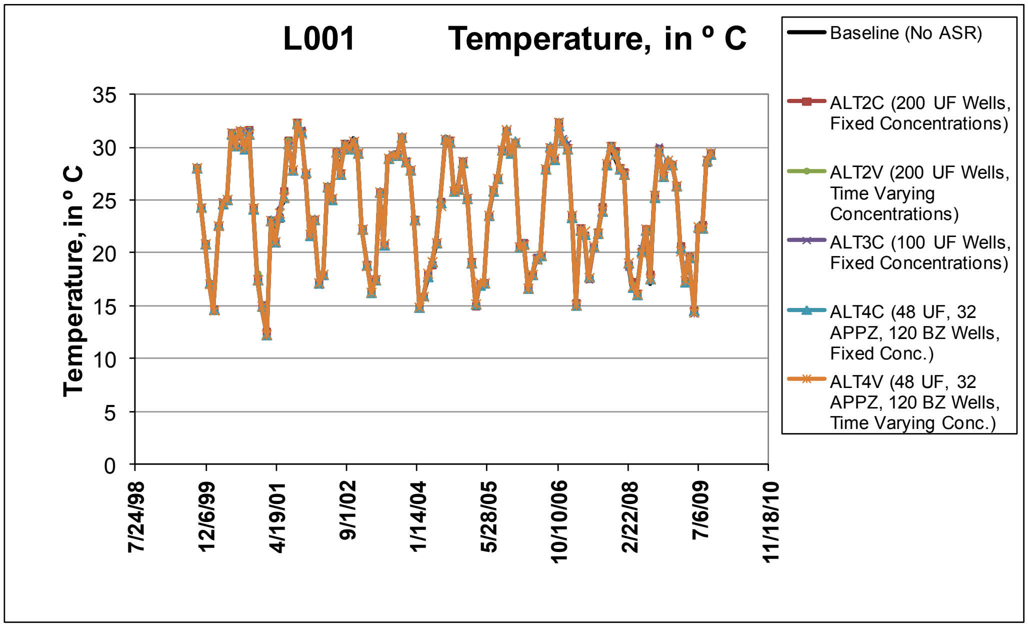


Figure 5.17. Predicted Temperature at L001 (Northern Lake Okeechobee).

Figure 5.18 shows the impact of the ASR scenarios on DO at LOO1. In general, there are no significant changes to Lake DO concentrations due to the assumption that the recovered water is discharged into the Lake with a concentration at 5 mg/L which is likely very close to the ambient Lake DO concentration.

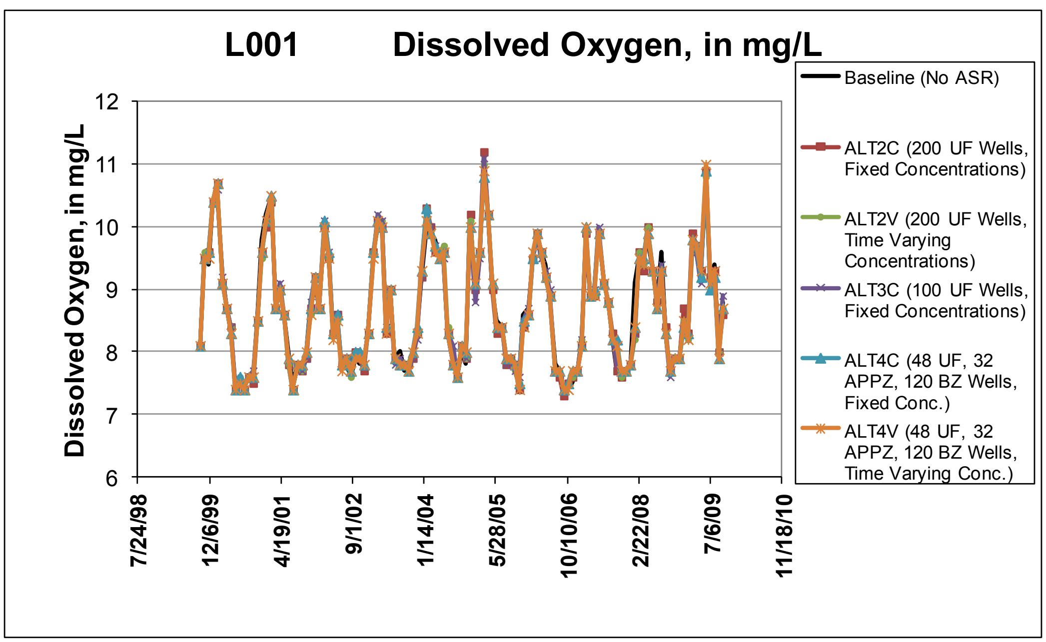


Figure 5.18. Predicted Dissolved Oxygen at L001 (Northern Lake Okeechobee).

The results for other monitoring locations (see **Appendix B**) are similar to those presented here. This is an indication that the Lake is well mixed and that locating ASR well clusters around the perimeter of the Lake rather than at a single location is a good strategy to limit water quality changes associated with ASR discharges. However, given the circulation patterns predicted by the LOEM, it is possible that large volume ASR discharges from Kissimmee River ASR facilities might be pushed into the ecologically significant littoral zone along the southwest shore of the Lake.

The water quality predictions shown here for the ASR scenarios cover only some of the potential ASR water quality stressors; however, these results can be used to infer the potential changes to other generally conservative constituents such as calcium, sodium, magnesium, etc.

5.1.2.2.2 Lake Okeechobee Water Quality Mass Balance

The annual ASR loads for each constituent were computed for each year of the 1965-2005 simulation period using LOOPS predicted ASR recovered volumes and time varying recovered water quality concentrations incorporated into the LOEM boundary condition datasets. The average annual Lake load was estimated for each year by using the assumed baseline concentrations in **Table 5.11** and the average Lake stage volume predicted by LOOPS for each year. **Table 5.12** shows the results of the rough order of magnitude mass balance assessment in terms of the maximum annual ASR load relative to the annual average lake load for each year. The maximum percentage of annual ASR flow relative to average annual lake storage is 38 percent under ALT2. The equivalent flow percentages for ALT3, ALT4, and ALT4-S11 are 15, 12, and 4 percent, respectively.

Table 5.11. Assumed Baseline Constituent Concentrations in Lake Okeechobee.

Chloride	Sulfate	Alkalinity	Hardness	TDS
(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)
58	25	113	157	355

Table 5.12. Maximum Annual ASR Load as a Percentage of Annual Average Lake Load.

	ALT2	ALT3	ALT4	ALT4-S11
ASR Recovery Flow	38%	15%	12%	4%
Hardness	69%	27%	35%	16%
Alkalinity	29%	12%	11%	4%

Chloride	171%	65%	144%	74%
Sulfate	223%	85%	128%	59%
TDS	85%	33%	50%	25%
Total Phosphorus	6%	3%	2%	1%
TSS	16%	7%	5%	2%

The maximum annual ratios of ASR load to Lake load shown in **Table 5.12** are an indication of the potential increase in concentration; however, they cannot be directly equated to concentration change since these load percentage estimates do not account for the fact that the ASR releases are actually delivered over the entire year when other lake inflows/outflow such as rainfall, evapotranspiration and water supply and other releases occur.

Dissolved Solids

ASR discharges to Lake Okeechobee are likely to result in increased dissolved solids concentrations, increased chloride concentrations, increased sulfate concentrations, and increased hardness/alkalinity. ALT2 with 200 ASR wells discharging may potentially increase the load of chloride and sulfate in the lake by more than 200 percent and in the case of alkalinity by around 30 percent. Changes to the alkalinity load of the Lake are less than that predicted for sulfate because the average surface water alkalinity concentration of around 40 mg/L is much closer to the predicted maximum alkalinity concentration of recovered water at 80 mg/L than the difference in equivalent surface and groundwater concentrations for sulfate which are 30 mg/L and 250 mg/L, respectively. ALT4-S11 which is the hydrogeologically preferred alternative will result in a maximum annual sulfate load equivalent to about 75 percent of the baseline Lake load. The maximum increase in water column concentrations will be lower than the average increase in annual load shown in **Table 5.12** due to dilution and exchange that occurs over a given year. LOEM modeling shows that increased dissolved solids (chloride, sulfate) concentrations occur during and immediately after ASR recovery events but that shortly after the end of the recovery event, the water column concentrations revert to the baseline (no-ASR) concentrations. The effect of ALT4-S11 ASR discharges on Lake water quality should be approximately 50 percent of the change observed for ALT4 since recovered water volume for ALT4-S11 is 50 percent of the volume estimated for ALT4. Given the significantly reduced volume of recovered water, the ALT4S-11 predicted Lake concentrations for constituents such as hardness and alkalinity should not increase substantially over the baseline condition and should remain within the normal range of variability experienced over the last 20 years given that this alternative would only contribute as much as 4 percent of the annual alkalinity load to the Lake during dry periods.

From **Table 5.12** it is evident that ALT2, ALT3, and ALT4 may result in ecologically significant increases in chloride, sulfate, and TDS load to the lake during low lake periods. While ALT4S-11 shows more moderate impacts to chloride, sulfate, and TDS, it is possible that loading during dry periods for these constituents would also be ecologically significant.

Total Phosphorus

The use of ASR to store and recover water to Lake Okeechobee has the potential benefit of reducing the total phosphorus (TP) load into the Lake. **Table 5.13** includes a comparison of the net average annual reduction in TP delivered to the Lake as a result of the operation of different ASR scenarios within the Lake Okeechobee basin. The TP concentrations assumed for this assessment are: 0.10 mg/L for recharge water which is approximately the current Lake Okeechobee and Kissimmee River background concentration and 0.01 mg/L for recovered water which is roughly the average concentration in recovered water measured at the KRASR site. The average annual reduction in TP load varies from around 30 mTons/yr for ALT2, ALT4, and ALT4-S11 and around 20 mTons/yr for ALT3. All of the alternatives discharge less than 2 mTons/yr. Much of the reduction in load is the result of recovering much less water than is recharged. For ALT2 and ALT3, total recovery volumes are approximately one half of recharge volumes. The use of BZ wells with zero recovery efficiency results in average recovery of about 15 percent of the stored volume for ALT4 and less than 10 percent for ALT4-S11 due to the addition of operational recovery rate constraints.

The current annual Lake TP load is between 400 to 500 mTons/yr. The TP Total Maximum Daily Load (TMDL) for the Lake is approximately 150 mTons/yr. The predicted average annual reduction of 30 mTons/yr of TP due to ASR represents about 10 percent of the required total reduction required to achieve the TMDL for inflow TP load to the Lake. During wet years, the ASR related reduction in TP load to the Lake would be greater than this; however, during dry years the recovered ASR water would add a relatively small phosphorus load to the Lake. Due to the significant storage of legacy phosphorus in the Lake sediments, the reduction in TP load to the lake due to ASR operations is not likely to have a measurable effects on overall Lake water column TP concentrations until such time that those sediments are flushed out of the Lake or are buried with cleaner sediments.

Table 5.13. Average Annual Total Phosphorus Load Reduction to Lake Okeechobee

Alternative	Average Annual Recharge Volume	Average Annual Recharge TP Load	Average Annual Recovery Volume	Average Annual Recovery TP Load	Average Annual Reduction in TP Load
	(ac-ft/yr)	(mTons/yr)	(ac-ft/yr)	(mTons/yr)	(mTons/yr)
ALT2	277,301	34	140,548	1.7	32
ALT3	157,767	19	75,966	0.9	19
ALT4	247,731	31	42,810	0.5	30
ALT4-S11	241,502	30	21,693	0.3	30

5.1.3 Greater Everglades Exposure Pathways

5.1.3.1 Timing, Duration, and Magnitude of Greater Everglades ASR Flows Water Quantity

CERP ASR flows from Lake Okeechobee do enter the Greater Everglades; however, since there are no CERP ASR systems within or directly adjacent to this basin, there are limited direct impacts to receptors resulting from discharge of ASR flows into this basin. Indirect exposures to receptors within the Greater Everglades due to ASR flows are expected to be limited to changes in the quality of water received from Lake Okeechobee. The hydrology from the D13R version of the SFWMM 2x2 model was used to define the CERP flows to the Greater Everglades for all of the ASR scenarios evaluated in this ERA. Since only ALT2 has the same number of ASR wells (200) and operations as assumed in the original CERP plan, the implicit assumption that results from using D13R flows for this ERA is that other CERP projects will make up the difference between the CERP ASR contributions to flows and the lesser ASR flows that would result from ALT3, ALT4, or ALT4-S11. An updated series of CERP regional hydrologic modeling results would be necessary to comprehensively evaluate effects to the Greater Everglades for ASR scenarios implementation other than D13R/ALT2.

5.1.3.2 Greater Everglades Water Quality (Exposure Intensity)

Lake flows contribute 30 percent of total flows entering the northern end of WCA-3A with the balance coming from rainfall and runoff processes in the Everglades Agricultural Area. The alkalinity and hardness of water entering STA-3/4 at the S-370 pump station should be indicative of the quality of water that eventually reaches the northern Water Conservation Areas. At the S-370 pump station, the average alkalinity and hardness for the 2005 through 2012 period (SFWMD, DBHYDRO database) are 300 mg/L, and 362 mg/L, respectively. The standard deviations at the S-370 pump station are 60 mg/L for alkalinity and 74 mg/L for hardness. The corresponding average concentrations for these three parameters in Lake Okeechobee (L001/L007 monitoring stations) for the same period are 100 mg/L, and 152 mg/L. Assuming that under the worse case ASR flows double the average Lake Okeechobee hardness and alkalinity to 200 mg/L and 300 mg/L, respectively, the average ASR impacted alkalinity concentration would rise to approximately 330 mg/L and the average ASR impacted hardness concentration would rise to approximately 410 mg/L. Both of these increases are less than the standard deviation of the present measurements indicating that the northern WCA-3A system already experiences similar concentrations.

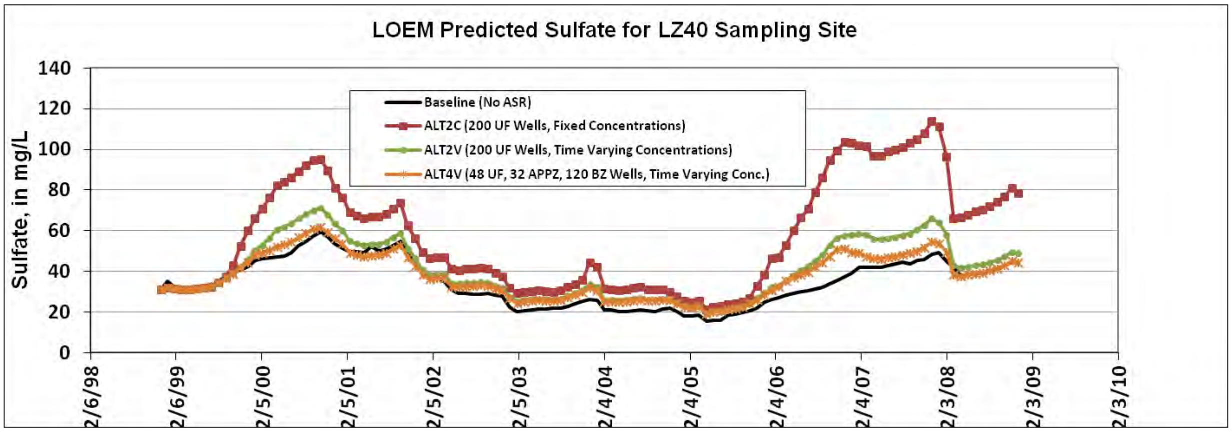
The ERA study team reviewed the ASR well placement scenarios and LOEM modeling output and determined that potential changes to sulfate loads delivered to the Greater Everglades was the most important exposure to evaluate for this region. Sulfate has been identified by the USGS and other parties as playing a significant role in regulating mercury methylation within the Greater Everglades. ASR-related sulfate loads could potentially alter the location of methylmercury hotspots and the rate of mercury methylation could result in increased mercury bioaccumulation in fish. To address ASR related sulfate loading, the team developed and linked a series of models culminating in the development of the ELM-Sulfate model by Fitz (2013). Details regarding this modeling effort are included in **Appendix B**.

The hydrologic boundary conditions used for most ELM modeling come from the South Florida Water Management Model (SFWMM). In this case, SFWMM v5.4 hydrologic simulations of the 2050 future base (2050B2) and the CERP plan (CERP0) were used to drive the hydrology for all ELM simulations. The estimates for sulfate boundary conditions were derived from LOEM model outputs and taking into account sulfate addition and loss that occurs as water travels from Lake Okeechobee through the EAA to the northern water conservation areas. The BASE (ALT1), ALT2C, ALT2V, and ALT4V simulation results from the LOEM model were carried forward to develop ASR exposure scenarios for the Greater Everglades. The ALT2C and ALT2V model runs were selected as the upper boundary of potential ASR-related increases in sulfate loads to the Greater Everglades while the ALT4V was selected to represent a more likely implementation scenario. ALT3 was not simulated since the expected impact on Lake water quality and Everglades water quality was considered to be bounded by the ALT2 and ALT4 simulation results. Since ALT4-S11 was developed as a viable alternative by the Hydrogeologic modeling team after the LOEM modeling was completed, this alternative was not simulated using LOEM or the ELM-Sulfate model.

To translate the predicted sulfate concentrations from the LOEM timeframe (1999-2009) into the ELM-Sulfate timeframe (1965-2000), linear regression equations were developed and applied to adjust the historic sulfate data for the 1974-2000 period to reflect ASR discharges for several scenarios. This was done by: 1) computing the difference between the predicted sulfate concentrations and Lake stages for the baseline and ASR scenarios using the LOEM simulated data for the 1999 to 2009 period; and 2) creating regression equations for each alternative using the change in stage, change in sulfate, and ASR signal. **Figure 5-19** shows the predicted Lake Okeechobee ASR concentrations for the 1974-2000 period for ALT2C, ALT2V, and ALT4V.

Three spatial performance metrics were developed to evaluate the ELM-Sulfate simulation output. The first performance metric, Sulfate Loss, measures the rate of marsh uptake of sulfate from the water column over the simulation period. This metric provides an integrated perspective of the exposure of additional sulfate load on the landscape; however, since it is a long-term average it tends to mask short-term impulses which may be critical to the mercury methylation and bio-uptake processes. The second metric is SO_4 period of record spatial average concentration. This metric provides a long-term perspective of the areas that are subjected to additional sulfate loading; however, again it does not capture short-term exposure. The third metric is the short-term average water column SO_4 concentration mapping. This metric captures short-term increases in sulfate concentrations that potentially could result in changes to methylmercury dynamics and subsequent bioaccumulation in fish. All of these metrics are presented in the ELM-Sulfate papers included in **Appendix B**.

Figure 5.20 shows the water column sulfate concentration in WCA-3A in the vicinity of the L-29 Interceptor canal for a 1982 period that represents a worst case scenario. This time period was selected because ASR operations before and after this date would result in the highest Lake sulfate concentrations for the 1974-1999 period as shown in **Figure 5.19**. **Figures 5.21, 5.22,** and **5.23** show the results for the third performance metric for 05/19/1982 which follows an extended ASR recovery event. For ALT2C, **Figure 5.21** shows that there are more than 36,000 ha with an increase in water column sulfate of more than 5 mg/L. For ALT2V, **Figure 5.22** shows that there are slightly less than 1,700 ha with an increase in water column sulfate of more than 5 mg/L. **Figure 5.23** shows that for ALT4V there is no area with an increase or decrease of water column sulfate of + - 5 mg/L.



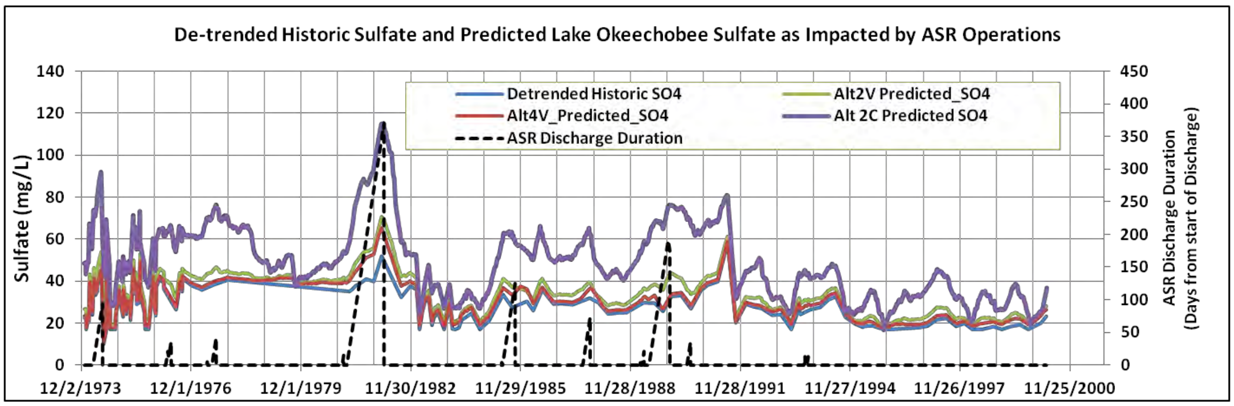


Figure 5-19. Predicted SO_4 Concentrations in Lake Okeechobee from LOEM for the 1999-2009 period (top graph) and Estimated ASR Related SO_4 Concentrations During the 1974-2000 Time Period (bottom graph).

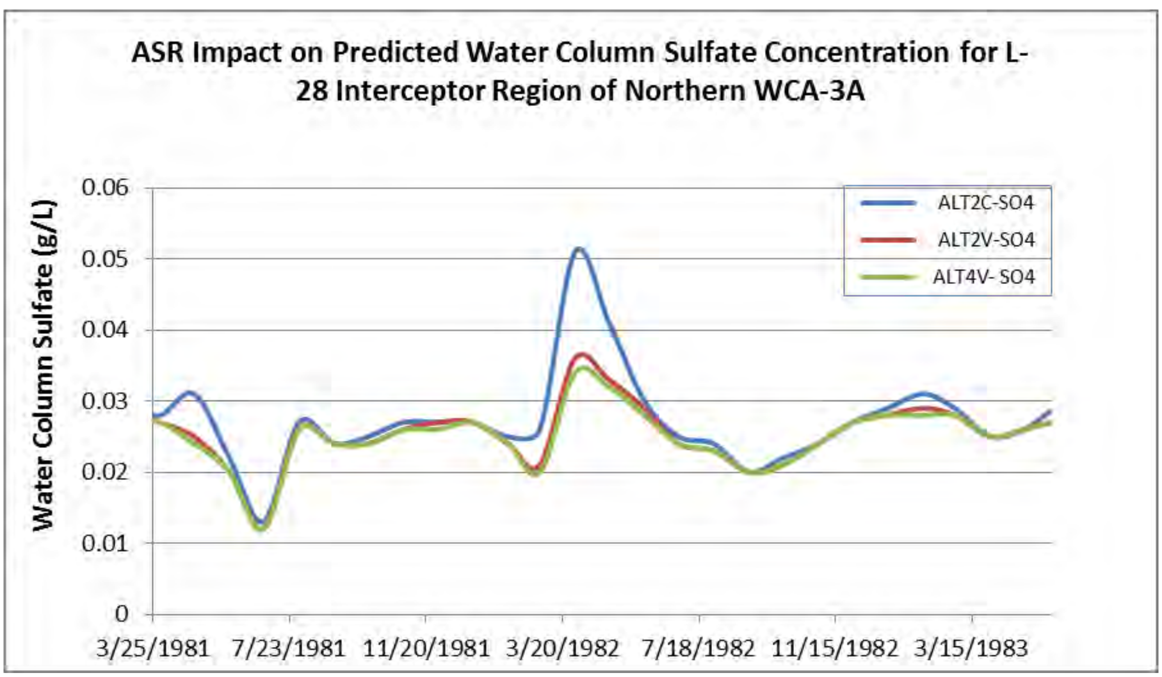


Figure 5.20. ELM-Sulfate Predicted SO4 Concentrations in WCA-3A Near the L-29 Interceptor Canal.

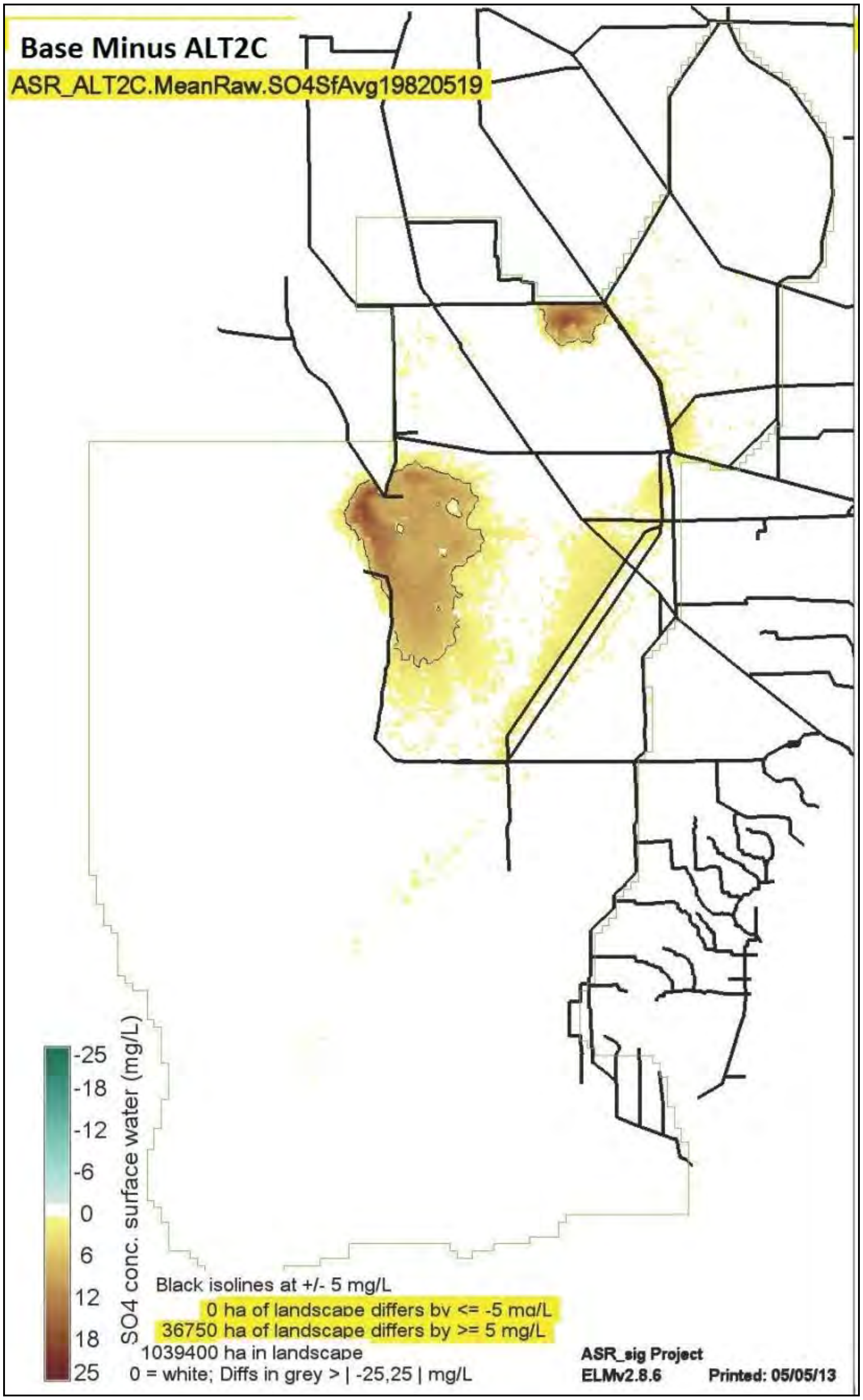


Figure 5-21. Predicted Impact of ALT2C on SO4 Concentration in the Everglades Protection Area on 05-19-1982.

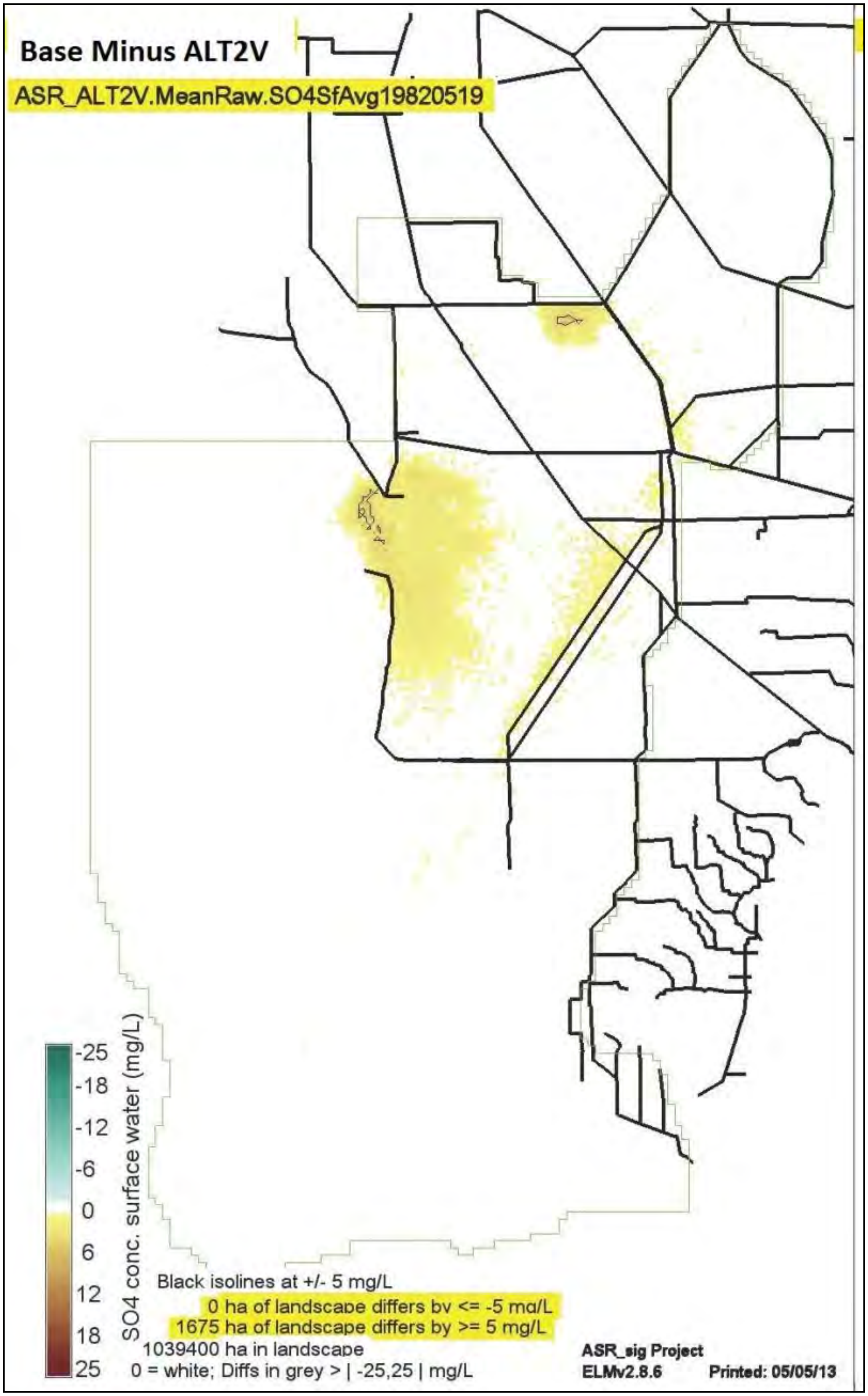


Figure 5-22. Predicted Impact of ALT2V on SO4 Concentration in the Everglades Protection Area on 05-19-1982.

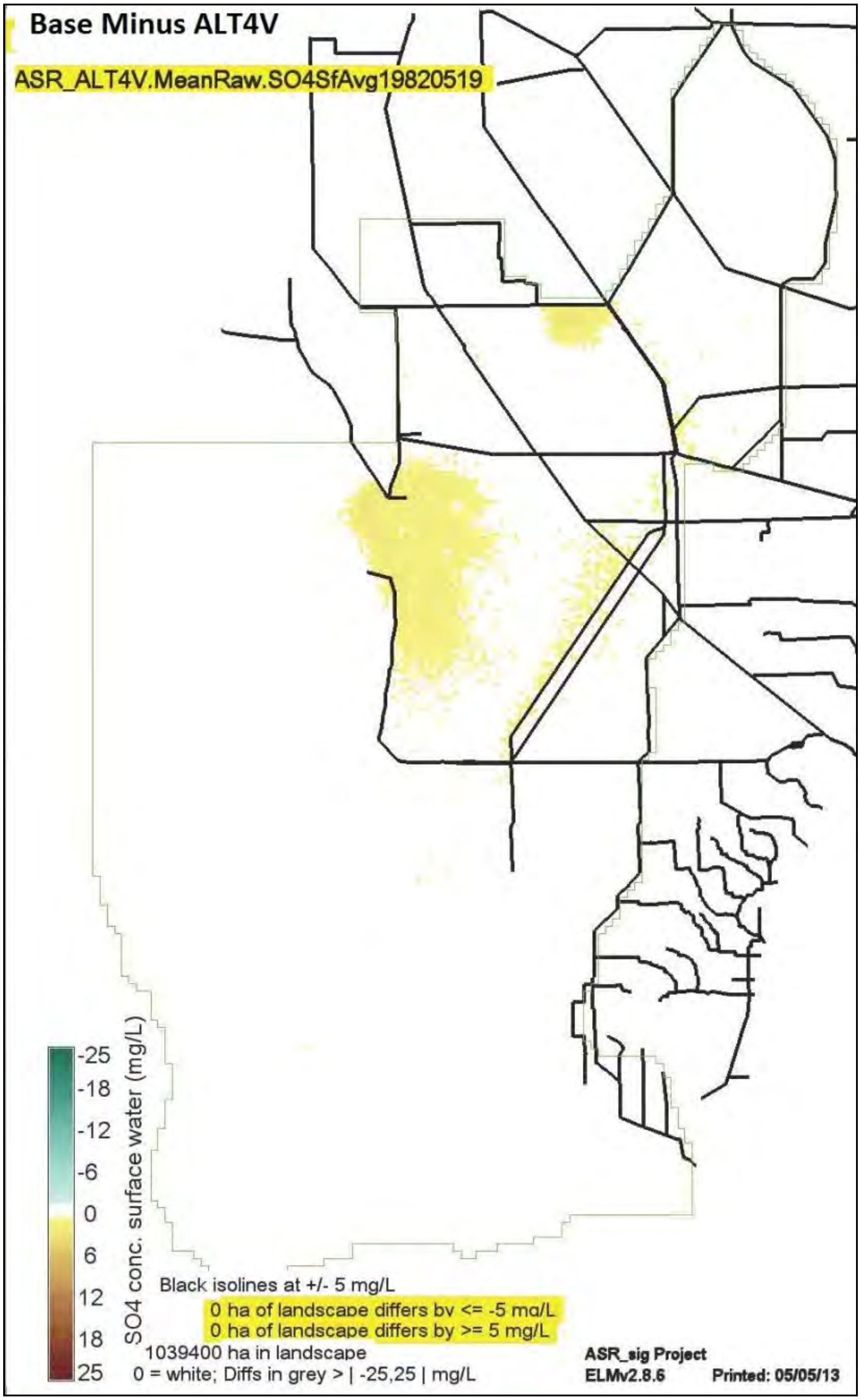


Figure 5-23. Predicted Impact of ALT4V on SO4 Concentration in the Everglades Protection Area on 05-19-1982.

5.1.4 Exposure Profiles

The exposure profiles identify the receptors and describe the exposure pathways and intensity, spatial, and temporal extent of co-occurrence or contact. The exposure profile also addresses the variability and uncertainty of exposure estimates (EPA 1998).

5.1.4.1 Kissimmee River Basin

The co-occurrence of stressors and receptors of interest by ASR operation mode for the Kissimmee River Basin ASR installation is shown in **Table 5.14**. The exposure profile for each of the receptors is described below.

Table 5.14. Exposure Profile by ASR Operation Mode for Selected Receptors in Kissimmee River Basin

Receptor	ASR Operation Mode	ASR Related Stresses					
		Mechanical	Thermal	Methylation Precursors	Trace Metals	Dissolved Solids	Nutrients
Fish	Recharge	X					
	Recovery		X	X	X	X	
Manatee	Recharge						
	Recovery		X				
Periphyton /SAV	Recharge						
	Recovery				X	X	X
Aquatic Invertebrates	Recharge	X					
	Recovery				X	X	X
Human Health/Wildlife	Recharge						
	Recovery			X	X		

Fish and Invertebrates

Juvenile and larval stage fish and aquatic invertebrates are present in the Kissimmee River year round. During recharge, these organisms in the lower Kissimmee River will be exposed to physical mechanical stress if they are drawn into the ASR well system intakes during the roughly 25 percent of the time that the ASR system will be operating in recharge mode. These organisms will be lost from the ecosystem (not returned). It is difficult to estimate the number of small biota that may be drawn into ASR intakes; however, relative differences between ASR scenarios can be qualitatively assessed based upon the number of ASR wells in the Kissimmee Basin for each Alternative. ALT2 has 75 wells and ALT3 has 30 wells while both ALT4 and ALT4S-11 have 15 wells within the Kissimmee River Basin. For ALT2, it would take 12 days of recharge to displace a volume of water equivalent to the storage capacity of the lower portion of the Kissimmee River. For ALT3, this would take approximately 30 days of recharge to displace the storage volume in the lower Kissimmee River. For ALT4 and ALT4-S11 it would take approximately 60 days.

Fish are also susceptible to thermal changes that can potentially occur during recovery operations. Fish spawning in the Kissimmee River occurs during most months of the year so it is likely that ASR discharges would be co-incident with spawning. Fish occupying 25 percent of the stream channel may be exposed to ASR impacts given that the length of the Kissimmee River from Lake Kissimmee to Lake Okeechobee is approximately 60 miles and ASR installations are likely to be placed in only the southern 15 miles of the river. The temperature of recovered water is typically around 25°C while the average monthly surface water temperature varies from 18°C to 30°C degrees. It should be noted that recovered water temperature varies somewhat depending upon the duration of storage and monthly water temperatures don't reflect the possibility of stratification in the receiving water body. Accounting for average S-65E flows and recovery volumes by alternative, **Table 5.7** shows that the average potential difference in no-ASR surface water temperature and fully mixed receiving water temperature is as much as plus 6.5°C in December through February and as low as -3°C during June and July for ALT2, ALT3, and ALT4. For ALT4-S11 with its significantly reduced recovery volume, the maximum difference between the no-ASR receiving water temperatures and the fully mixed receiving water temperature is less than plus/minus 1°C.

The estimates provided in **Table 5.7** don't take into account environmental heat gain or loss that occurs once the recovered water is discharged into the receiving stream. The estimates were computed assuming complete mixing and not the possibility that thermal stratification of discharges may occur that increases or decreases the co-occurrence of thermal stress and affected receptors. The average duration of recovery events is more than 130 days (from **Table 5.4**) which means that on average, the recovery events would last long enough to cover the entire spawning to larval stage reproductive cycle of typical Kissimmee fish species.

Water quality changes that will be observed by fish and invertebrates are associated with ASR recovery flows which are likely to be limited; it is expected that recovery discharges will cease when the recovered water potentially exceeds surface water quality standards. There are approximately 15,000 meters between the S-65E structure and Lake Okeechobee. Discharge of recovered water will occur less than 15 percent of the time for ALT2, ALT3, and ALT4 and more than 27 percent of the time for ALT4S-11. It is difficult to predict the size of the discharge plume for the ASR alternatives; however, the worse-case situation would have no flow at S-65E and the lower river completely filled with recovered water under the ALT2 and potentially ALT3 scenarios.

<u>Manatees</u>

Manatees have been observed in the lower Kissimmee River primarily during the winter months. Recovery of ASR water occurs during all months of the year for all of the alternatives. Discharges in December through February result in the greatest increase in water temperature which might result in an attractive nuisance to manatees during periods when surface water temperatures fall below 20°C. As well, the average duration of recovery events would extend through the length of the cold season meaning that thermal refuges created by ASR recovery flow would likely extend through the period with the coldest river water temperature as long as the initiation of recovery begins after November 1st.

<u>Periphyton/SAV</u>

SAV are not a significant ecological receptor in the Kissimmee River due to its low abundance. Periphyton in the lower river would be concentrated along the river bank. There are approximately 20 miles of stream bank between the S-65E structure and Lake Okeechobee. Discharge of recovered water will occur less than 15 percent of the time for ALT2, ALT3, and ALT4 and more than 27 percent of the time for ALT4S-11. It is difficult to predict the size of the discharge plume for the ASR alternatives; however, the worse-case situation would have no flow at S-65E and the lower river completely filled with recovered water under the ALT2 and potentially ALT3 scenarios. Discharge plumes for ALT4 and ALT4S-11 are less likely to completely fill the river between S-65E and the Lake due to the reduced volume of recovered water. If one assumes a maximum plume length of 800 meters for each well cluster, as established by FDEP regulation, then ALT4 with six well clusters of five wells apiece would generate a 5,000 meter plume which is approximately 1/3rd of the total distance between S-65E and the Lake. This means that about 1/3rd of the attached periphyton would potentially be exposed to recovered water during discharge events. If the plume size is proportional to flow quantity, then ALT4-S11 which has 5 times less recovered flow relative to ALT4 would result in exposing approximately 1/15th of the attached periphyton to recovered water. The spatial extent of the discharge plumes will vary over the course of a recovery event as the concentrations of recovered water change as more water is discharged. Additionally, plume dimensions for each water quality constituent will be unique since plumes are defined by the relative differences in recovered water quality concentrations and receiving surface water quality concentrations.

5.1.4.2 Lake Okeechobee

The co-occurrence of stressors and receptors of interest by ASR operation mode for the Lake Okeechobee Basin ASR installation is shown in **Table 5.15**. The exposure profiles for fish, periphyton/SAV, and human health/wildlife are described below. Exposure of other receptors such as manatees and aquatic invertebrates were considered to be non-significant given the dilution of ASR water that occurs as these discharges mix with the much larger Lake volume.

Table 5.15. Exposure Profile by ASR Operation Mode for Critical Receptors in Lake Okeechobee

Receptor	ASR Operation Mode	ASR Related Stresses					
		Mechanical	Thermal	Methylation Precursors	Trace Metals	Dissolved Solids	Nutrients
Fish	Recharge	X	X				
	Recovery						
SAV	Recharge						
	Recovery				X	X	
Human Health/Wildlife	Recharge						
	Recovery			X			

SAV

SAV exposures are primarily driven by ASR changes to hydrologic conditions and less so by changes in water quality since ASR impact to nutrient concentrations and light transmittance are not considered significant. ASR discharges into the Lake can potentially affect SAV by increasing the area available for SAV growth through inundating more of the lake bottom during periods of extreme low stage and by increasing the depth of the water which reduces the ability of waves to re-suspend bottom sediments and thus improve light conditions which are key to SAV growth and survival. Alternatives with more ASR wells that recharge and recover are likely to have the greatest impact on SAV biomass and coverage.

ALT2 has the greatest potential to affect SAV because it has 200 wells that will discharge back to the Lake. ALT4 would likely have limited impact on SAV because while it has more than 200 wells operating at full capacity in recharge mode, it has less than ½ of the capacity to recover water since many of the wells in this alternative are placed into the APPZ or the BZ and have lower recovery efficiency. The inability to recover stored water from the ASR system would limit the ability of ASR to augment low Lake stage conditions. ALT4-S11 has even less ability to recover water so its ability to improve conditions for SAV is less likely since overall, this alternative actually results in lower low condition Lake stages than any other alternatives, including the Base scenario (ALT1) without ASRs.

<u>Fish and Human Health / Wildlife</u>

In addition to the indirect effects from mechanical and thermal stresses in upstream basins, fish populations within Lake Okeechobee may potentially be exposed to ASR-driven changes in mercury methylation dynamics due to the addition of sulfate load from ASRs. Increased methylation may increase the potential for bioaccumulation of methylmercury in fish; this could adversely affect wildlife and humans who eat fish from Lake Okeechobee. The LOEM model indicates that ALT2 could temporarily increase Lake sulfate concentrations by 15 to 60 mg/L while ALT4 would likely increase these concentrations by 10 to 30 mg/L. The long-term average sulfate concentration in the lake would increase from around 30 mg/L to 50 mg/L with ALT2 and to around 31 mg/L with ALT4. Though ALT4-S11 was not modeled using LOEM, based on the fact that recovery for this alternative is less than 50 percent of the volume provided by ALT4, it is likely that ALT4-S11 would result in temporary increases in sulfate concentrations by no more than 5 to 15 mg/L. ALT4-S11 is unlikely to increase the long-term sulfate concentration in the

Lake. The duration of increased ASR related sulfate concentrations in the Lake is not likely to be permanent since the LOEM model predicts that sulfate concentrations revert to near baseline concentration conditions after one or two wet seasons.

5.1.4.3 Greater Everglades

The co-occurrence of stressors and receptors of interest by ASR operation mode for the Greater Everglades is shown in **Table 5.16**. The exposure profile for fish and human health/wildlife are described below. Exposure of other receptors such as manatees, periphyton/SAV, and aquatic invertebrates were considered to be less significant given the dilution of ASR water that occurs as the ASR discharges mix first with Lake Okeechobee water and then with Everglades Agricultural Area runoff before entering the northern water conservation areas.

Table 5.16. Exposure Profile by ASR Operation Mode for Critical Receptors in the Greater Everglades

Receptor	ASR Operation Mode	ASR Related Stresses					
		Mechanical	Thermal	Methylation Precursors	Trace Metals	Dissolved Solids	Nutrients
Fish	Recharge						
	Recovery			X			
Human Health/Wildlife	Recharge						
	Recovery			X			

Fish and Human Health / Wildlife

Fish populations within the Greater Everglades may potentially be exposed to ASR-related changes in mercury methylation dynamics due to the addition of ASR related sulfate load. Increased mercury methylation rates in the ecosystem may increase bioaccumulation of mercury in fish. If these fish are consumed by consumers positioned at higher trophic levels, the methylmercury can accumulate in wildlife and humans who eat fish in from the Greater Everglades. The ELM-Sulfate model results indicate that as a result of an extended ASR recovery event predicted for May of 1982, 36,750 hectares of Greater Everglades habitat could experience an increase in sulfate concentrations of more than 5 mg/L for ALT2C. Under the assumption that sulfate concentrations vary over the duration of a recovery event (ALT2V), the ELM-Sulfate model results indicate that 1,675 hectares of the Greater Everglades habitat could experience an increase in sulfate concentrations of more than 5 mg/l. For ALT4V, the ELM-Sulfate model predicted no increase in area where the sulfate concentration increased by more than 5 mg/L. Given that ALT4-S11 contributes much less recovered water to Lake Okeechobee, if modeled in ELM-Sulfate, this alternative would also show no areas where sulfate increases by more than 5 mg/L. A review of the LOEM and ELM-Sulfate modeling output shows that increased sulfate concentrations from ASR operations are ephemeral and may last only a few months before reverting to the baseline concentrations.

5.2 ECOSYSTEM AND RECEPTOR CHARACTERISTICS

This risk assessment will consider ASR discharge volumes, timing, and concentrations, as well as channel morphology, dilution from upstream flows, and in-stream habitat in our assessment of ASR stressors on the fishery, periphyton, SAV, aquatic invertebrates, and manatee receptors. The following sections present general ecological descriptions of these receptors.

The Kissimmee Basin includes more than 20 lakes in the Kissimmee Chain of Lakes, their tributary streams and associated marshes, the Kissimmee River and floodplain. The basin forms the headwaters of Lake Okeechobee and the Everglades. Lake Okeechobee is the largest lake in the southeastern United States. It is shallow, frequently turbid, eutrophic, and a central component of the hydrology and environment in south Florida.

The Greater Everglades encompass a mosaic of inter-connected freshwater wetlands and estuaries located primarily south of the Everglades Agricultural Area (EAA). The characteristics of the Everglades, as described in the Total System Conceptual Ecological Model (Ogden et al. 2005), that together distinguish the Everglades ecosystem from other large wetland systems are: sheet flow; multi-year hydroperiods; oligotrophic nutrient status; patterned peatland landscape of sloughs, ridges, tree islands and marl prairies; highly productive mangrove estuaries; large breeding populations of wading birds that depend on an aquatic prey forage base; and the American alligator.

The following subsections present additional information regarding the ecosystem characterization and its components.

5.2.1 Fisheries

5.2.1.1 Kissimmee River

The fishery community of the Kissimmee River prior to channelization was dominated by lotic (flowing water) species. Channelization began in 1962 and ended in 1971. There is documentation of at least 39 native fish species in the river under pre-channelization conditions, but there were probably more. During June and July, 1957, the Florida Game and Fresh Water Fish Commission (FGFWFC) found approximately 30 native fish species in an adjacent floodplain marsh and the river channel (SFWMD 2005). The resulting hydrologic and habitat changes probably greatly reduced populations of some species (e.g., pirate perch, redbreast sunfish, coastal shiner, pugnose minnow, tadpole madtom) and greatly increased the abundance of channel-tolerant species (e.g., bowfin and gar). It is also likely that some lacustrine (i.e., predominantly lake-dwelling) species such as bluegill became more abundant under post-channelization conditions.

More recent fisheries sampling was conducted from 2004 to 2006 as part of baseline data collection for the ASR project (FGFWFC 2007). This data is tabulated in **Section 3 of Appendix B**. A total of 33 fish species were collected. The samples were numerically dominated in all years by bluegill and largemouth bass, with moderate numbers of redear sunfish and Florida gar. In the summer 2005 and spring 2006 samples, adult white catfish were especially abundant. In the winter 2005 and 2006 samples, adult black crappies were very abundant. The trends for biomass were similar - largemouth bass were generally highest and gar was second highest. Surprisingly, Orinoco sailfin catfish (an exotic species) had the highest biomass in two of the samples.

Larval fish are likely the most susceptible to ASR operations. A total of 23 different larval fish taxa were collected during the Spring of 1997 and 1998 (combined) in Pool A and Pool C of the Kissimmee River by FWC and tabulated by the Water Management District (SFWMD 2005). Sampling was conducted in remnant river channels (Control sites) and the C-38 channel (Impacted sites); however, no statistical differences in abundance or species composition were reported between Control and Impacted sites. Sunfishes (*Lepomis* spp.) and shad (*Dorosoma* spp.) were most abundant and comprised 69.1 percent and 80.9 percent of larval fishes collected in Control and Impact pools, respectively.

The USACE and SFWMD began an ecological restoration project for the Kissimmee River (authorized in 1992) within the middle third of the river (i.e., S-65D upstream to the S-65A structure). The intent was to reconnect the floodplain and channel habitats and to fill in portions of the previously dredged channel to allow for higher river velocities. It is anticipated to benefit native fish populations in addition to other native flora and fauna. Construction is on-going. Improved native fish populations above the S-65E structure due to the Kissimmee River Restoration should result in additional fish in the Lower Kissimmee and Lake Okeechobee as some of this population migrates downstream. As a result of this upstream restoration project a greater number of fish than that demonstrated by recent fishery surveys will potentially be impacted by ASR in the lower Kissimmee and Lake Okeechobee.

5.2.1.2 Lake Okeechobee

The abundance and diversity of Lake Okeechobee's native fish population varies from year-to-year, depending on submerged aquatic vegetation, prey, lake levels, and water quality. Extremely high or low lake stage may negatively affect emergent and SAV coverage reducing the amount of available fish habitat. Excessive nutrient loading may indirectly negatively impact the fish communities by shifting their macroinvertebrate prey base from preferred taxa such as chironomids (non-biting midges) to one dominated by less utilized oligochaete (annelid worm) taxa. Three hurricanes in 2004 and 2005 negatively affected the fish community health.

In 2008, electrofishing resulted in the capture of 4,974 fish with a combined biomass of 361 kilograms (kg) (RECOVER 2009). Thirty fish species were represented. Four species collectively comprised 82 percent of the catch by number and were, in order of abundance: threadfin shad (*Dorosoma petenense*), gizzard shad (*Dorosoma cepedianum*), eastern mosquitofish (*Gambusia holbrooki*), and bluegill (*Lepomis macrochirus*). Six species collectively comprised 78 percent of the catch by weight and were, in order of biomass: Florida gar (*Lepisosteus platyrhincus*) gizzard shad, bluegill, Largemouth bass (*Micropterus salmoides*), bowfin (*Amia calva*), and redear sunfish (*Lepomis microlophus*).

Trawl sampling in 2008 resulted in the capture of 2,816 fish with a combined biomass of 221 kilograms (kg) (RECOVER 2009). Seventeen fish species were represented. Three species collectively comprised 84 percent of the catch by number and were, in order of abundance: threadfin shad , white catfish (*Ameiurus catus*), and bluegill. Three species collectively comprised 79 percent of the catch by weight and were, in order of biomass: white catfish, Florida gar, and bluegill. Comparison of lake wide trawl sampling data for selected dominant species shows an increase in abundance of threadfin shad and white catfish, while black crappie (*Pomaxis nigromaculatus*) showed a continued decline in abundance.

5.2.1.2.1 Trends and Trophic Structure

The decline in black crappie relative abundance is due to extremely poor recruitment since 2002 and the short-lived nature of the species. A majority of both threadfin and gizzard shad captured in 2008 were young-of-year fish. Threadfin shad abundances have increased since 2005 but remain well below levels observed during 1988 to 1991, a period when black crappie abundances were high. Food habitat analyses have shown that young-of-year shad are primary forage of adult black crappie in Lake Okeechobee. Low shad numbers are a major contributing factor to extremely low relative abundance of crappie; thus, the increase in shad observed in 2008 is an important indicator for the potential to rebuild crappie stock levels. This, along with the large number of eastern mosquito fish, are key in the recovery of the largemouth bass populations of Lake Okeechobee because without prey, predatory fish populations would continue to decline.

Chironomid larvae are the primary food source of juvenile black crappie and the decline in the former is another causative factor explaining the decline of black crappie. Bluegill feed on very small fish and invertebrates. In 2005 and 2006, bluegill abundance decreased in comparison to the 1987 to 1991 data by 94 and 92 percent, respectively, which mirrors the decline in invertebrates as their direct prey and that of many of the smaller fish upon which they feed (RECOVER 2009).

In summary, ASR could potentially influence fish populations directly through mechanical impingement or indirectly through water quality changes.

5.2.2 Periphyton

Periphyton abundance and community composition in lakes and rivers are influenced by both abiotic and biotic factors. Abiotic factors include light, nutrients, toxic substances, wave energy, water current velocity and the amount of colonizable surface. Grazing activity by macroinvertebrates and fish constitute the primary biotic factor influence on periphyton growth.

Periphyton is an important food source for herbivorous macroinvertebrates and fish and its biovolume, biomass and community structure is being monitored as part of the Lake restoration program. In general, Lake stage as it relates to light availability and host substrate areal coverage (e.g., SAV) in the near shore regions appears to be the most influential factors affecting periphyton biomass.

5.2.2.1 Nutrients

A broad array of mostly inorganic nutrients, such as carbon, phosphorus, nitrogen, silicon, calcium, iron, manganese, oxygen, copper and other trace metals are required for periphytic growth (Lowe, 1996). Nutrient concentrations in the water column and upper portion of the sediments can play a significant role in spatial and temporal periphyton abundance. Several taxa have been identified by Fairchild et al. (1985) that dominate under high nitrate and phosphate concentrations (e.g. *Navicula*, *Stigeoclonium tenue*) or are considered to be superior competitors at obtaining sufficient nitrogen and phosphorus (*Achnanthidium minutissimum, Epithemia adnata*, *Gonphonema tenellum*) when it is in short supply, relative to other periphyton taxa. Previous research in the littoral marsh and near shore regions of Lake Okeechobee has indicated that that periphyton growth can be limited by either nitrogen, phosphorus or both, when light levels are sufficient (Havens et al., 1999; 1999, Hwang et al., 1998, Zimba, 1998, Rodusky et al., 2001). In the littoral marsh, periphyton nutrient limitation can occur year-round, while in the near shore region, it is usually limited to summer months, when light penetration into the water column is highest (Rodusky, 2010).

When nutrient concentrations are sufficiently high, indirect competition between periphyton and phytoplankton via nutrient uptake can occur. When periphyton and host submerged or emergent plants are abundant, nutrient uptake by periphyton and associated host plants can result in suppressed phytoplankton abundance, as has been suggested to occur during the summer in Lake Okeechobee (Phlips et al. 1993). Conversely, the relationship between water column nutrients and phytoplankton abundance is thought to be stronger than that between nutrients and periphyton (Cattaneo, 1987). Therefore, when phytoplankton becomes abundant, it can indirectly suppress periphyton abundance by reducing water column light levels.

5.2.2.2 Metals

Elevated metal concentrations have been shown in streams to have negative impacts on periphyton biomass and community richness, although very low concentrations of some trace metals (e.g. silica) have been shown to limit periphyton growth in the same manner as nutrients (Zimba, 1998). Many of the studies examining elevated metal concentrations, typically cadmium, copper, nickel, silver and zinc, have been conducted in acid mining drainage streams or in polluted waterways near industrial discharges. For example, the reduction in number of periphyton taxa and biomass at New Zealand mining drainage stream sites was associated with elevated metal oxide deposition (Bray et al., 2008). At a polluted site in southwestern France, elevated cadmium and zinc concentrations coincided with a shift among diatom taxa, from reference site dominated *Nitzschia dissipata* and *Gomphoneis minuta*, to *Gomphonema parvulum*, *Pinnularia* sp. or *Fragilaria crotonensis*. This study suggests that as little as two weeks of exposure to low-level metal concentrations can result in dominance by diatom taxa indicative of metal pollution (Gold et al. 2002). Conversely, increased tolerance to elevated copper and co-tolerance to elevated nickel, silver and zinc levels and a switch from cyanobacteria dominance to chlorophyte dominance was reported in an outdoor flow-through aquaria system (Soldo & Behra, 2000). Bioaccumulation of these metals in periphyton can then be transferred to invertebrate grazers, as was noted in a study of mayflies grazing on periphyton which bio-concentrated cadmium (Lingtian et al., 2010).

5.2.3 Submerged Aquatic Vegetation

SAV is not monitored in the Kissimmee River and it is considered ephemeral. SAV abundance is a key indicator of the Lake's overall ecological health and has been monitored since 1999. SAV are an important component in the Lake ecosystem, and its areal coverage shifts with Lake stage. It is unclear what these shifts in the areal coverage of emergent vegetation, vascular SAV, and nonvascular SAV are having on habitat values in the littoral and near shore zones of the Lake. But recent studies show that recent conditions with lower Lake stages are substantially better than they were during the generally higher Lake stages that characterized the mid- to late 1990s, and following the 2004-2005 hurricanes (South Florida Environmental Report, 2013). SAVs also provide habitat for fish and invertebrates.

5.2.4 Aquatic Invertebrates

In July 2012, December 2012, and May 2013, AMEC Environment & Infrastructure, Inc. conducted benthic invertebrate and habitat assessments in the river near the KRASR. Overall, the invertebrate community was characterized as “impaired” (using the Stream Condition Index) and indicated that the river habitat was degraded due to channelization. The July 2012 sample had the highest diversity (30 taxa); however, 9 of these taxa are considered very pollution tolerant. No pollution sensitive taxa were found. The overall abundance was very poor (less than 10 individuals collected per taxon) except for amphipod *Hyalella azteca* (> 100 individuals in each sample). In general, the organisms collected are considered representative of lentic and depositional habitats rather than flowing water habitats. Other taxa collected included midges, damselflies, leeches, beetles, and snails. The December 2012 sample had 25 different taxa, and the May 2013 sample had 18 different taxa. Otherwise, the samples from these two dates were very similar to the July 2012 sample.

5.2.5 Manatees

The federally endangered West Indian manatee (*Trichechus manatus*) lives in freshwater, brackish and marine habitats. Submerged, emergent, and floating vegetation are their preferred food. Manatees exhibit opportunistic, as well as predictable patterns in their distribution and movement. They are able to undertake extensive north-south migrations with seasonal distribution determined by water temperature. When ambient water temperatures drop below 20° C (68°F) in autumn and winter, manatees aggregate within the confines of natural and artificial warm-water refuges or move to the southern tip of Florida.

As water temperatures rise, manatees disperse from winter aggregation areas. While some remain near their winter refuges, others undertake extensive travels along the coast and far up rivers and canals. On the east coast, summer sightings drop off rapidly north of Georgia. On the west coast, sightings drop off sharply west of the Suwannee River in Florida. During summer, manatees may be commonly found almost anywhere in Florida where water depths and access channels are greater than 1 to 2 m (3.3 to 6.6 ft) including some locations proposed for ASR (i.e., Kissimmee River, C-40, C-41, C-44, and C-43). Manatees do have access to the Hillsboro Canal, but not near the HASR; only downstream of the G-56 structure. Shallow grass beds with ready access to deep channels are preferred feeding areas in coastal and riverine habitats. Manatees often use secluded canals, creeks, embayments, and lagoons, particularly near the mouths of coastal rivers and sloughs, for feeding, resting, cavorting, mating, and calving.

The most significant problem presently faced by manatees in Florida is death or injury from boat strikes. The long-term availability of warm-water refuges for manatees is uncertain if minimum flows and levels are not established for the natural springs on which many manatees depend, and as deregulation of the power industry in Florida occurs. Their survival will depend on maintaining the integrity of ecosystems and habitat sufficient to support a viable manatee population.

5.2.6 Wildlife and Humans

The Kissimmee River, Lake Okeechobee, other tributaries, and the Greater Everglades provide habitat for a large number of wildlife species that co-exist in a complex ecosystem food web linking aquatic and terrestrial habitats. The potential risk of an increase in methylation of naturally occurring mercury is an effect that is addressed as part of this ERA. If methylation was to increase, methylmercury could concentrate in the tissues of organisms from all trophic levels. Human and wildlife (e.g., birds, raccoons, deer, etc.) that consume these potentially contaminated food sources can also be impacted and could be at risk should this occur. This aspect of the ERA is also addressed in detail in a later section.

5.3 CHARACTERIZATION OF ECOLOGICAL EFFECTS

The previous sections have presented the stressors being addressed by this ERA and their potential distribution (exposure profiles) in the environment. The biological characteristics of the potential receptors (and ecosystems) were also described in order to provide the ecological setting. This section describes the measured effects of ASR recovered water on a broad set of aquatic organisms. These data were developed through the use of laboratory toxicological tests, onsite studies, and field assessments.

Toxicological data was developed by exposing test organisms to control water and increasing dilutions of recovered waters (up to full strength recovered water). These data allowed the evaluation of effects with varying stressor levels. Ecotoxicological data were not available for south Florida ASRs, but there was a good understanding of the aquatic ecosystems and receptors to be protected.

In addition to direct chemical stressor effects, physical effects were also assessed. Thermal and physical effects of ASR implementation were also evaluated using data collected. This was focused primarily on the ASR Pilot intakes and their potential to impinge and entrain aquatic organisms. The effect of thermal discharges from the ASRs was another physical stressor evaluated on the assessment endpoints (reproduction of fisheries and protection of manatees). The physical effect of the "first flush" was evaluated and minimized by requiring initial recovery flows to be discharged to on-site holding ponds.

Secondary effects related to the potential development of mercury methylation precursors in Lake Okeechobee and/or the Greater Everglades were characterized. The potential effect on assessment endpoints (fish, wildlife and humans) of this exposure pathway could be significant; therefore this aspect of the ERA was thoroughly modeled and studied.

Benefits of ASR implementation were also evaluated, and the focus was primarily on the potential reduction of nutrients and the increased clarity of the discharged recovered water. Localized improvement in DO was also evaluated as a potential benefit of ASRs. The regional water management benefits provided by regional ASR implementation are partly addressed in this report through the use of existing performance measures developed for the Restudy report.

5.3.1 Stressor-Response Analysis

An ecological response analysis evaluates the relationship between the stressor levels and the ecological effects, the plausibility that effects may occur as a result of exposure to stressors, and the linkages between measurable ecological effects and assessment endpoints. Several lines of information were developed for this ERA including direct measurement of effects (point estimates such as LC_{50} and IC_{25}), field studies (e.g., in situ effects exposures, periphytometers, bioaccumulation studies, stream condition studies), and modeled effects (e.g., as estimates of methylmercury precursor distribution). "No effect" levels were also included in this analysis, and they typically apply to chronic toxicity tests evaluating multiple endpoints (e.g., No Observed Effect Level, Lowest Adverse Effect Level). Development of effects thresholds is important if toxicity is found; stressor-response curves can be used to describe incremental risks or can be used as inputs to effects models. Quantitative and qualitative stressor-response relationships were described based on the effects data available. Their intensity, time (exposure duration) and spatial dimension (e.g., thermal plume size) are descriptors of stressor-response analyses.

Establishing Cause-and-Effects Relationships

Multiple ecotoxicology and field studies were conducted to reduce uncertainty. Evidence of causality was developed through experimental data (laboratory and field tests). Cause and effect associations were documented to demonstrate stressor-response relationships. Some of the field studies did not provide a clear causality due to natural variability in aquatic systems, but these studies were used as additional lines of evidence and to evaluate potential measures of effects for the assessment endpoints.

As previously stated, assessment endpoints are the environmental values of concern for the ERA, but they can't always be measured directly. In this case, measures of effect are selected. For example, the assessment endpoint "reproducing populations of native fish" would be assessed in the future through a measure of effect such as "reproducing populations of black crappie in the Kissimmee River."

A summary profile for the stressor-response information is the final step in the development of the ecological response analysis. The initial question in this ERA was the identification of ecological entities potentially affected by regional ASR implementation. Aquatic ecosystems in south Florida including canals (e.g., Kissimmee River, Hillsboro Canal), Lake Okeechobee, and estuaries (i.e., Caloosahatchee, St. Lucie, and Lake Worth Lagoon) were identified as environments potentially at risk. Based on known surface water flows, the Greater Everglades was also identified as an ecological entity to be included in this ERA.

The next question was related to the nature of the anticipated effects. Acute and chronic effects were anticipated in these aquatic ecosystems; including effects on reproduction.

Both aquatic plants and animals were included in the effects tests. Tests using frog embryos were included in data development as representatives for amphibians, an important group of aquatic vertebrates. The potential for bioconcentration of metals (arsenic, mercury) and radionuclides (radium) in aquatic species were also anticipated based on toxicological data available for these stressors. Physical effects to planktonic species (and early life stages of fish and invertebrates) due to entrainment and impingement by the water intakes were also considered as a potential effect to be evaluated.

Subtle changes in water quality (e.g., water hardness, conductivity, nutrient concentrations) were anticipated based on the data collected, therefore field studies using periphyton biological communities were included to assess potential effects on these key water quality indicators. Benthic communities were evaluated in some of the potential receiving water bodies; however, the team realized that this assessment tool might be unsuitable for determining minor effects from ASR discharges to impaired aquatic systems.

In order to evaluate the intensity of the effects, a series of laboratory, onsite and in situ studies were developed and conducted during Cycles 1 and 2 at KRASR. The effects included mortality, growth, reproduction, and bioaccumulation potential. Acute and chronic studies were conducted with algae, invertebrates, fish and frogs. The studies conducted and modeling outputs were used to document the linkages and exposure pathways between the stressors and the predicted effects.

5.3.2 Effects Information

5.3.2.1 Toxicology

An ecotoxicology research program was conducted to identify a set of aquatic tests to evaluate the ecotoxicity and bioconcentration potential of ASR recovered waters discharged to aquatic ecosystems (Johnson, 2005; Johnson et al., 2007). All toxicity tests conducted at KRASR are summarized in **Table 5.17** for all cycles. Over 80 acute and chronic toxicity tests were conducted as part of this effects characterization at KRASR. Most likely this is the largest development of acute and chronic toxicity dataset for ASR systems. **Appendix A** includes the full KRASR results including supporting data from HASR and data developed at the Palm Beach County Water Utilities Department (Johnson et al., 2007).

An effect on reproduction of *C. dubia* was observed during Cycle 1 in two of the tests using recovered water. The March 10, 2009 test showed a statistically significant difference between the 12.5 percent recovered water and the controls. This data point is considered a test anomaly since no effects on reproduction were observed at higher recovered water concentrations up to 100 percent. The March 24, 2009 sample of recovered water showed an **IC_{25} of 95.52 percent**, indicating a minor but measurable reduction in reproduction of the water flea in 95.52 percent recovered water. Cycle 2 showed an effect on reproduction on two tests. The November sample showed a decrease in reproduction in **100 percent** recovered water and the last sample near the completion of the cycle showed an **IC_{25} of 76.4 percent.**

Table 5.17 Summary of acute and chronic toxicity test results for all KRASR cycle

			Selenastrum capricornutum 96-hr (Green Algae)	*Ceriodaphnia dubia* 7-day (Water Flea)		Pimephales promelas 7-day (Fathead Minnow)	*Daphnia magna* 21-day (Water Flea)		FETAX (Frog – *Xenopus*)			*C. dubia* 96-hr (Water Flea)	*C. leedsi* 96-hr (Bannerfin Shiner)
Cycle	**Phase**	Test Initiation Date	96-hr growth test (NOEC)	Survival test (NOEC)	Reproduction test (NOEC/IC_{25})	Embryo-larval survival and teratogenesis test (NOEC)	Chronic survival test (NOEC)	Chronic reproduction test (NOEC/ IC_{25})	Mortality sig. diff. from control	Malformation sig. from. than control	Growth sig. diff. from control	Acute survival test (LC_{50})	Acute survival test (LC_{50})
Cycle 1	RCG[1]	Jan 13-15, 2009	100%	100%	100%/ >100%	>100%	100%	100%/>100%	No	No	No	>100%	>100%
		Feb 2-3, 2009	25%	100%	100%/ >100%	>100%			No	No	No		
	Recovered water (RCV)	Mar 10-12, 2009	100%	100%	>100%		100%	100%/>100%	No	No	No	>100%	>100%
		Mar 16-20, 2009	100%	100%	100%/ >100%				No	No	No	>100%	>100%
		Mar 23-26, 2009	100%	100%	100%/ **IC_{25}95.5%**	>100%			No	No	No		
		Mar 31–Apr 2, 2009	100%	100%	100%/ >100%	>100%						>100%	>100%
		7-Apr-09				>100%							
		17-Apr-09										>100%	>100%
Cycle 2	RCV	Oct 28-29, 2009	100%	100%	100%/ >100%	>100%			No	No	No	>100%	>100%
		Nov 17-19, 2009	100%	100%	50% / >100%	>100%						>100%	>100%
		Dec 7-10, 2009	100%	100%	100%/ >100%	>100%			No	No	No		
		22-Dec-09			50% / **IC_{25} 76.4%**							>100%	>100%
		31-Dec-09				>100%							
		Jan 2-4, 2010							No	No	No	>100%	>100%

Cycle	Phase	Test Initiation Date	*Selenastrum capricornutum 96-hour (Green Algae)*	*Ceriodaphnia dubia 7-day (Water Flea)*		Pimephales promelas 7-day (Flathead Minnow)	*Daphnia magna, 21 Day (Water Flea)*		FETAX (Frog – *Xenopus*)			*C. dubia* 96-hr (Water Flea)	*C. leedsi 96-hr (Bannerfin Shiner)*
Cycle	**Phase**	Test Initiation Date	96-hr growth test (NOEC)	Survival test (NOEC)	Reproduction test ($NOEC/IC_{25}$)	Embryo-larval survival and teratogenesis test (NOEC)	Chronic survival test (NOEC)	Chronic reproduction test ($NOEC/IC_{25}$)	Mortality sig. diff. from control	Malformation sig. from. than control	Growth sig. diff. from control	Acute survival test (LC_{50})	Acute survival test (LC_{50})
Cycle 3	RCV	Jan-11			100% / 100%	>100%						>100%	>100%
		Feb-11			No test	No test						>100%	>100%
		Mar-11			No test	No test						>100%	>100%
		May-11		--	**IC_{25} 7.2%**	>100%						**83.92%**	>100%
		Jun-11		--	>100%/100%	>100%						>100%	>100%
Cycle 4	RCV	Jan-13			>100%/100%	>100%						>100%	>100%
		Feb-13		--	>100 / **IC_{25} 83.9**	>100%							
		Mar-13			>100% / **IC_{25} 76.2**	>100%						>100%	>100%
		Apr-13		>100%	>100%/>100 %	>100%						>100%	>100%
		May-13		>100%	>100%/>100 %	>100%						>100%	>100%
		Jun-13		>100%	>100%/>100 %	>100%						>100%	>100%

RCG = Recharge water (source water) , RCV = Recovered water

Cycle 3 had one sampling event (May 2011) that showed effects on the survival (96-hour LC50 of 83.92 %) and reduced reproduction (**IC_{25} of 7.2%**), also near the end of the cycle. Two of the mid-cycle samples during Cycle 4 also showed chronic effects on *C. dubia* reproduction with **IC_{25}** of **83.9** and **76.2** percent. But the following three monthly tests did not show this effect.

There appears to be a change in recovered water quality that occurs during the mid to late period in the recovery cycles that results in a slight reduction in reproduction of this sensitive invertebrate species. Except for the May 2011 test, all other chronic test results show a minor, but measurable, reduction in reproduction. These chronic tests also show that a recovered water dilution greater than 50 percent would not be expected to elicit this effect on reproduction. The May 2011 showed the highest effect (IC_{25} of 7.2 percent) and these results appear to be valid a separate acute test also showed acute toxicity to *C. dubia* with that sample. This effect observed on this sample during Cycle 3 was not apparent in the subsequent samples taken in May 2011. Similar results were observed during Cycle 4, slight chronic toxicity in the second and third month, but no further toxicity later in the recovery cycle.

Frog Embryo Teratogenesis Assay – *Xenopus* (FETAX) tests were conducted three times during Cycle 1 and three times during Cycle 2 using recovered water. These tests did not show a quantifiable effect of the recovered water on the survival, malformations, or growth.

Overall, the recovered water from KRASR did not show quantifiable acute or chronic effects on any species tested with the exception of the sensitive cladoceran *C. dubia*. The effect observed was on reproduction of this sensitive cladoceran species, showing that at times during mid- to late- cycle the recovered water at concentrations greater than 50 percent had an inhibitory effect on the reproduction of this species. The cause for this chronic effect is not known. Toxicological testing at HASR did not identify any chronic or acute toxicity associated with recovered ASR water.

5.3.2.2 Bioconcentration Studies at KRASR

Bioconcentration studies were conducted at the KRASR during the recharge and recovery periods of Cycle 1 (mobile laboratory exposures of fish and mussels) and the recovery period of Cycle 2 (field exposures using caged mussels). During Cycle 4 field collected mussels were evaluated for metal concentration in their tissues. A summary of these studies is provided here and in Appendix C.

During the mobile laboratory bioconcentration studies, the metals analyzed in the recharge/recovered waters and animal tissues were mercury (total and methylmercury), arsenic, molybdenum, antimony, aluminum, cadmium, chromium, nickel, selenium, and zinc. Radium-226 and -228 radionuclides were also analyzed in freshwater mussels. The recovered water bioconcentration study was conducted using a laboratory control and 3 treatments as follows:

- Laboratory control water prepared using reverse osmosis water
- RCV: Recovered ASR water, 100% unaltered
- BSW: Background surface water (receiving water), 100% unaltered
- MIX: 50/50 mixture of receiving water and recovered ASR water.

The objectives of these bioconcentration tests were to evaluate the potential accumulation of selected metals and radium in the tissues of the test organisms exposed to surface water and recovered water. Statistical comparisons were made to determine if there was a difference in metal concentrations in treatment types and tissue concentrations. Metal and radionuclide concentrations in fish and mussel tissues measured during the Cycle 1 and Cycle 2 tests are shown in **Table 5.18**. The water quality for these exposures is summarized in **Table 5.19**. Arsenic concentrations in the recovered ASR water and the 50/50 mix water exceed the SDWA MCL.

Table 5.18 -- Metal and radionuclide concentrations in fish and mussel tissues during KRASR Cycles 1 and 2

Cycle	Phase	Exposure Length	Tissue Type	Treatment	Aluminum (mg/Kg)	Antimony (mg/Kg)	Arsenic (mg/Kg)	Cadmium (mg/Kg)	Chromium (mg/Kg)	Mercury (ng/g)	Methyl Mercury (ng/g)	Molybdenum (mg/Kg)	Nickel (mg/Kg)	Ra-226 (pCi/L)	Ra-228 (pCi/L)	Selenium (mg/Kg)	Zinc (mg/Kg)
Cycle 1	e water (lab exposur		Muss	Background	7.2	<0.026	0.66	0.27	0.28	42.3	8.47	<0.06	0.17	3.09	1.25	<0.65	21.1
		28 days		Full strength	32.4	<0.026	0.65	0.24	0.17	36.9	5.70	0.05	0.20	1.36	.92	<0.66	27.9
			Fish	Background	<2.6	<0.026	<0.32	<0.013	0.70	20.67	21.77	0.11	0.44			<0.64	26.4
		28 days		Full strength	1.67	<0.025	0.46	<0.013	0.36	13.13	16.32	0.05	0.25			<0.64	21.0
	Recovered water (onsite lab exposure)		Muss	Background	5.11	<0.024	0.52	0.23	<0.24	38.3	8.05	0.04	0.05	1.47	0.98	<0.60	9.9
		28 days		BSW	55.50	<0.025	1.07	0.38	0.39	60.3	9.03	0.07	0.19	1.08	1.11	0.36	43.0
		28 days		MIX	51.1	<0.025	1.40	0.33	0.31	57.3	9.35	0.09	0.25	1.64	0.70	<0.62	37.3
		28 days		RCV	15.1	<0.025	2.18	0.29	0.25	50.0	8.20	0.12	0.4	1.57	1.00	<0.63	31.7
			Fish	Background	<2.5	<0.025	0.21	<0.012	<0.24	18.8	21.55	0.07	0.11			0.41	33.9
		28 days		BSW	1.9	0.019	0.44	0.01	0.34	16.7	10.72	0.04	0.23			<0.62	19.3
		28 days		MIX	15.2	<0.025	0.46	<0.012	0.17	16.1	10.63	0.10	0.19			<0.62	31.4
		28 days		RCV	<2.5	<0.025	0.41	0.01	0.18	17.6	21.93	0.13	0.10			0.36	26.6
Cycle 2	Recovery (Field Exposures)		Mussel	Background	7.10	0.026	0.53	0.21	0.14	39.2	7.13	0.04	0.06	2.02	0.62	0.28	16.77
		35 days	Mussel	Station 1	56.70	<0.012	0.86	0.25	0.53	69.7	11.67	0.07	0.17	0.76	0.45	<0.14	38.73
		35 days		Station 3A	50.80	<0.011	1.01	0.30	0.27	105.4	<0.80	0.09	0.16	0.86	0.58	0.48	46.00
		35 days		Station 3B	92.10	<0.012	1.03	0.21	0.49	74.3	<0.80	0.08	0.19	1.17	0.50	0.66	66.77
		35 days		Station 5	50.80	<0.011	0.93	0.16	0.28	57.7	9.00	0.06	0.15	0.73	0.54	<0.13	38.67
		69 days	Mussel	Station 1	96.47	0.017	0.70	0.15	0.13	64.5	10.33	0.06	0.06	0.86	1.03	0.19	18.70
		69 days		Station 3A	81.57	<0.012	0.72	0.16	0.18	85.1	0.60	0.07	0.09	1.36	1.06	0.40	23.20
		69 days		Station 3B	56.93	<0.012	0.83	0.20	0.21	73.8	0.93	0.07	0.12	0.81	0.71	0.37	24.63
		69 days		Station 5	112.70	<0.012	0.61	0.20	0.18	79.8	11.60	0.05	0.14	1.08	0.94	0.20	9.99

For 'Non-detects' a value equal to one-half the minimum detection limit (MDL) was used to determine the average concentration
If all replicates were 'Non-detects', then "<" highest sample-specific MDL is presented
mg/kg = milligrams per kilogram; ng/g = nanogram per gram.; pCi/g = picocuries per gram
BSW = Kissimmee River water collected from upstream of the ASR discharge
MIX = 50/50 mixture of BSW and recovered water
RCV = full strength recovered water

Table 5.19 -- Trace Metal Water Quality Data for Cycle 1 Recovered Water Bioconcentration Study
Samples obtained at the start (day 0) and finish (day 28) of the study. (Analyses in bold font exceed the SDWA MCL)

Test Treatment	Analyte	Day 0							Day 28						
		Fish Vessels			Mussel Vessels				Fish Vessels			Mussel Vessels			
		A	B	C	A	B	C	Average	A	B	C	A	B	C	Average
Background Surface Water	Aluminum (µg/L)	151	121	113	111	102	210	134.7	52	158	130	265	221	533	226.5
	Antimony (µg/L)	0.098	0.099	0.099	0.109	0.102	0.102	0.102	0.087	0.086	0.094	0.093	0.085	0.090	0.0892
	Arsenic (µg/L)	1.47	1.47	1.44	1.36	1.46	1.39	1.43	1.54	1.63	1.64	1.72	1.73	2.06	1.72
	Cadmium (µg/L)	0.008	0.007	0.01	0.008	0.008	0.009	<0.020	<0.004	0.004	0.006	0.008	0.008	0.017	0.0075
	Chromium (µg/L)	0.21	0.21	0.18	0.19	0.14	0.17	0.18	0.20	0.36	0.31	0.54	0.45	1.10	0.493
	Mercury (ng/L)	1.77	1.79	1.76	1.76	1.80	2.07	1.83	1.44	1.38	1.52	1.62	1.57	1.31	1.473
	Methyl Mercury (ng/L)	0.135	0.088	0.094	0.121	0.090	0.094	0.1037	0.121	0.140	0.121	0.137	0.095	0.105	0.1198
	Molybdenum (µg/L)	3.05	3.10	3.01	3.10	3.09	3.16	3.085	2.84	2.76	2.86	2.82	2.93	3.5	2.952
	Nickel (µg/L)	0.83	0.92	0.90	0.94	0.88	0.88	0.892	0.69	0.77	0.74	0.84	0.82	1.14	0.833
	Ra-226 (pCi/L)	-	-	-	0.41	-0.05	1.04	0.467	-	-	-	0.34	0.48	0.1	0.307
	Ra-228 (pCi/L)	-	-	-	0.46	0.4	0.83	0.5637	-	-	-	0.01	-0.09	0.48	0.133
	Selenium (µg/L)	1.04	1.11	1.16	1.11	1.19	1.06	1.112	0.73	0.69	0.68	0.75	0.70	0.79	0.723
	Zinc (µg/L)	2.85	1.66	1.91	1.99	1.30	1.67	1.897	0.66	1.49	1.23	2.46	2.55	4.68	2.178
50/50 Mixture of Background Surface Water and Recovered ASR Water	Aluminum (µg/L)	64.5	45.0	63.9	76.3	161	71.5	80.37	13.9	22.0	25.2	22.2	18.5	15.5	19.55
	Antimony (µg/L)	0.271	0.273	0.279	0.232	0.276	0.270	0.2668	0.089	0.083	0.086	0.091	0.091	0.092	0.08867
	Arsenic (µg/L)	36.5	36.7	36.4	29.3	38.6	36.2	35.62	25.3	19.7	16.2	16.9	18.0	20.9	**19.5**
	Cadmium (µg/L)	0.019	0.027	0.025	0.005	0.017	0.022	0.0192	<0.004	<0.004	<0.004	<0.004	<0.004	<0.004	<0.004
	Chromium (µg/L)	0.06	0.06	0.09	0.11	0.08	0.07	0.078	0.09	0.11	0.13	0.11	0.12	0.10	0.11
	Mercury (ng/L)	0.94	0.98	1.01	1.28	0.91	1.38	1.083	0.63	0.86	0.91	0.77	0.71	0.59	0.745
	Methyl Mercury (ng/L)	0.037	0.034	0.055	0.062	0.054	0.067	0.0515	0.077	0.067	0.079	0.106	0.090	0.066	0.0808
	Molybdenum (µg/L)	159	154	153	130	169	158	153.8	72.2	55.2	45.1	46.3	51.4	59.1	54.88
	Nickel (µg/L)	2.50	2.37	2.57	2.18	2.71	2.50	2.472	1.92	1.70	1.55	1.50	1.55	1.55	1.628
	Ra-226 (pCi/L)	-	-	-	0.5	0.43	0.44	0.457	-	-	-	1.17	0.91	0.94	1.007
	Ra-228 (pCi/L)	-	-	-	0.64	0.45	0.36	0.483	-	-	-	0.13	0.45	0.58	0.387
	Selenium (µg/L)	1.51	1.36	1.43	1.41	1.43	1.37	1.4183	1.93	1.68	1.47	1.32	1.56	1.63	1.598
	Zinc (µg/L)	1.53	1.46	1.12	2.03	1.71	1.26	1.518	0.75	0.90	0.87	0.70	0.59	0.72	0.755
Recovered ASR Water	Aluminum (µg/L)	3.8	3.1	4.2	8.9	6.8	7.5	5.7	4.2	2.7	3.1	2.6	2.4	2.4	2.9
	Antimony (µg/L)	0.442	0.444	0.440	0.447	0.460	0.454	0.4478	0.096	0.117	0.096	0.091	0.099	0.101	0.100
	Arsenic (µg/L)	**69.5**	**70.0**	**68.5**	**69.0**	**68.8**	**68.8**	**69.1**	**41.9**	**39.9**	**37.4**	**37.2**	**38.6**	**37.7**	**38.78**
	Cadmium (µg/L)	0.058	0.063	0.052	0.040	0.072	0.062	0.0578	0.174	0.177	0.178	0.182	0.186	0.194	0.1818
	Chromium (µg/L)	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	0.05	0.05	0.04	0.05	0.04	0.04	0.045
	Mercury (ng/L)	0.15	0.17	0.17	0.4	0.2	0.21	0.217	0.1	0.29	0.15	0.15	0.19	0.13	0.168
	Methyl Mercury	<0.019	<0.019	<0.019	0.021	<0.019	<0.019	0.0114	0.021	0.021	<0.019	<0.019	<0.019	0.023	0.0156

Table 5.19 -- Trace Metal Water Quality Data for Cycle 1 Recovered Water Bioconcentration Study
Samples obtained at the start (day 0) and finish (day 28) of the study. (Analyses in bold font exceed the SDWA MCL)

Test Treatment	Analyte	Day 0							Day 28						
		Fish Vessels			Mussel Vessels			Average	Fish Vessels			Mussel Vessels			Average
		A	B	C	A	B	C		A	B	C	A	B	C	
	(ng/L)														
	Molybdenum (µg/L)	296	306	316	287	302	269	296	101	99.0	100	101	95.9	98.9	99.3
	Nickel (µg/L)	4.02	3.96	3.86	3.99	4.00	4.06	3.982	2.37	2.33	2.19	2.34	2.25	2.18	2.277
	Ra-226 (pCi/L)	-	-	-	0.36	1.57	2.26	1.397	-	-	-	2.4	2.12	2.01	2.18
	Ra-228 (pCi/L)	-	-	-	0.16	0.17	0.33	0.22	-	-	-	0.65	-0.2	0.45	0.30
	Selenium (µg/L)	1.80	1.87	1.75	1.92	1.78	1.76	1.813	2.34	2.28	2.29	2.59	2.36	2.21	2.345
	Zinc (µg/L)	0.69	1.13	1.29	1.03	1.05	1.06	1.042	0.63	0.67	0.60	0.54	0.66	0.56	Z0.61

Bioconcentration Study – In situ Exposures of Caged Freshwater Mussels, Cycle 1

The bioconcentration or depuration of the metals/radionuclides was evaluated in fish and mussel tissues during Cycle 1 and are summarized below.

Cycle 1 recharge water:

- Mussels
  - The only statistically significant change over the 28-day study period was depuration of **Radium 226** (p=0.015).
- Fish
  - **Arsenic** accumulated in all fish tissues to an average concentration of **0.46 mg/kg** which was a statistically significant increase (p=<0.001) from background tissue concentrations (pre-exposure).

Cycle 1 recovered water:

- Mussels
  - **Arsenic** increased in all three treatment groups (p<0.001 for all treatments) and was significantly higher in the RCV treatment **(2.17 mg/kg**) than the BSW (1.07 mg/kg, p=0.005) and MIX (1.40 mg/kg, p=0.04).
  - **Nickel** was accumulated in all three treatment groups from a baseline concentration of 0.05 mg/kg to a level of 0.19 mg/kg for BSW (p=0.001), 0.25 mg/kg for MIX (p<0.001) and 0.40 mg/kg for RCV (P<0.001). The ending concentration of **0.40 mg/kg** for the RCV treatment was significantly higher than that for BSW (p=0.002) and MIX (p=0.011).
  - **Mercury** accumulated in mussels in both the BSW and MIX treatments (p=0.011 and p=0.037 respectively) but not in the RCV treatment.

Arsenic (2.17 mg/kg) and **nickel (40 mg/kg)** showed a significant bioaccumulation in mussel tissues exposed to recovered water for 28 days.

- Fish

- **Molybdenum** increased in the MIX (p=0.016) and RCV treatments (p=0.002).
-

Bioconcentration Study – In situ Exposures of Caged Freshwater Mussels, Cycle 2

The objective of the bioconcentration *in situ* exposures of caged mussels was to evaluate the potential uptake of metals and radium from recovered water, and its natural dilution in the receiving water body during the recovery period. This study was conducted using the freshwater mussel *E. buckleyi*, similar to the bioconcentration study conducted during cycle 1 recovery. Mussels were housed in cages, with individual compartments to maintain equal spacing and thus similar exposure for each mussel **(Figure 5.24)**. Three cages were deployed at each station location.

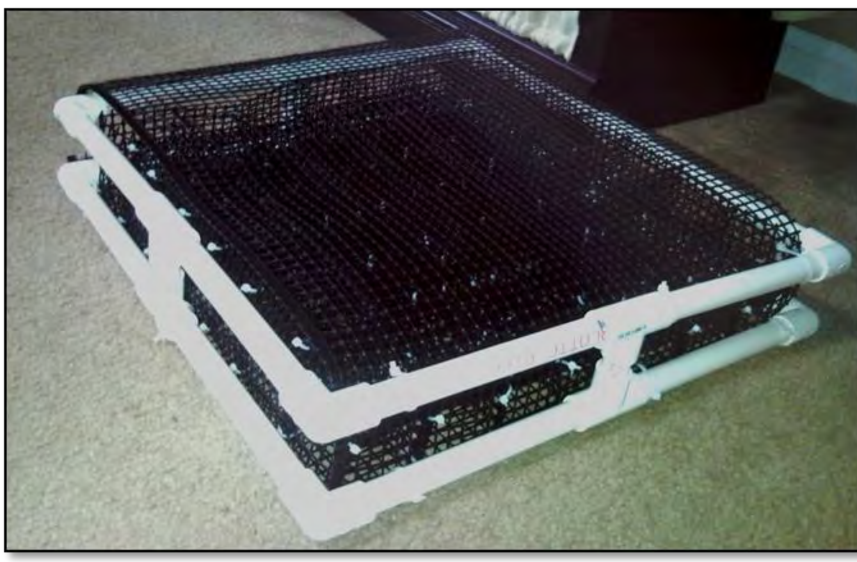


Figure 5.24- -- Cages for freshwater mussel exposures

The exposure locations for the in situ bioconcentration study are shown in **Figure 5.25**. Two sampling stations (ASR3A and ASR 3B) were placed directly in the mixing zone of the discharged recovered water. The other 2 stations were upstream (ASR 1) and downstream (ASR5) of the KRASR point of discharge.

Concentrations of metals was similar for stations ASR1 and ASR5 (away from the discharge) and between stations 3A and 3B (at the discharge). There was a marginally significant (p=0.045) difference in cadmium concentrations between stations ASR1 and ASR5 at day 35. Otherwise, there were no differences and stations were combined as either 'Control' or 'Discharge'. If no differences were observed between days 35 and 69 for each treatment, data was reduced further by combining across sampling periods for comparison between treatments and to the background concentrations.

Figure 5.25 -- Location of *insitu* exposure of caged mussels, periphytometers, and water quality sondes during the KRASR Cycle 2 recovery period

By virtue of no differences within the treatment groups or between sampling periods when grouped by treatments, six metals (Aluminum, Antimony, Mercury, Methylmercury, Molybdenum, and Nickel) and both radionuclides (Radium-226 and

Radium 228) were able to be consolidated for comparisons between background, discharge, and control concentrations.

Mercury was found to be significantly higher at the discharge stations than background conditions (p=0.004), while control stations were not significantly different from either background or discharge. **Methylmercury** concentrations, however, were found to be significantly lower at the discharge stations than background, and background was significantly lower than control stations (p<0.001). **Molybdenum** concentrations were higher at the discharge than either the background or control mussels (p<0.001).

Treatment was a significant factor (p=0.012) in determining **arsenic** concentration in mussels with higher concentrations observed at the discharge than control stations. A system-wide effect over time was also observed with significantly higher (p<0.001) concentrations on day 35 than day 0 (background) or day 69.

Field Collections of Mussels in the Vicinity of the KRASR During Cycle 4

Native mussels were collected in the vicinity of the KRASR during recharge and near completion of the KRASR cycle 4 recovery period. These data are summarized in **Table 5.20.** Stations SCI #1 and SCI #2 are located in front of the discharge area and Background is located across the river and slightly upstream. Statistical analysis could not be conducted on these samples due to insufficient replication. These data appear to show that radiation and mercury tissue concentrations in native river mussels were lower in the Kissimmee River near the end of the recovery period as compared to the recharge period. This is an unexpected result for radiation; however, the lower mercury tissue concentrations are consistent with reduced mercury concentration in the recovered water. There is insufficient data to be sure if these observations are related to the ASR discharges. Manganese and arsenic appear to be slightly higher in mussel tissue during May as compared to December and this could be related to the ASR discharge, but not confirmed through these data.

Table 5.20 -- Metal and radionuclide tissue concentration results from field collections of native mussels in the vicinity of the KRASR during Cycle 4

Cycle	Phase	Dates	Treatments	Aluminum (mg/Kg)	Arsenic (mg/Kg)	Manganese (mg/Kg)	Molybdenum (mg/Kg)	Mercury (mg/Kg)	Total Alpha Radiation (226, pCi/g)	Radium (228, pCi/g)
Cycle 4	Recharge	Dec 2012	BKGRD	8.5	0.49	140	<0.85	0.097	9.24	2.68
			SCI #1	11	0.41	340	<0.98	0.058	18.1	3.65
			SCI #2	<9.8	0.49	140	<0.98	0.053	13.0	4.11
	Recovery	May 2013	BKGRD	24	0.81	840	<0.88	0.045	2.08	0.76
			SCI #1	<9.7	0.70	450	<0.93	0.056	2.06	0.64
			SCI #2	22	0.78	81	<0.84	0.036	1.79	0.92

For 'Non-detects', "<" the MDL is presented
mg/kg = milligrams per kilogram.; pCi/g = picocuries per gram.

5.3.2.3 Periphyton Studies at KRASR

Periphyton baseline field studies were included in the ecotoxicology program in order to include plant communities in the assessment of potential risks and/or benefits of ASR implementation. Periphyton communities were sampled using periphytometers.

Periphytometers were deployed in the Kissimmee River concurrent with the Cycle 1 KRASR recharge and recovery periods at stations shown in **Figure 5.26.** Station ASR 1 is located near the flow control structure approximately 4,000-ft up-river of the KRASR. Periphytometers were also deployed in front of the KRASR discharge (ASR 3A and ASR 3B). The fourth station was on the west bank of the Kissimmee River, approximately 2,000-ft down-river from the KRASR (ASR 5).

Figure 5.26 -- Location of stations for periphytometer deployment during KRASR Cycle 1

The periphytometers before and after deployment are shown in **Figure 5.27**.

Figure 5.27-- Periphytometers during initial deployment (left), and after a 28-day deployment (right)

Table 5.21 shows the comparative diversity and evenness indices generated from these data for the cycle 1 recharge and recovery period.

Table 5.21 -- Diversity and Evenness Indices for the Periphyton Species Collected in the Kissimmee River in the Vicinity of the KRASR Pilot Project (Cycle 1)

Station ID	Recharge			Recovery		
	Shannon-Wiener Diversity Index	Pielou's Evenness Index	Hulbert Evenness Index	Shannon-Wiener Diversity Index	Pielou's Evenness Index	Hulbert Evenness Index
1	3.204	0.708	0.660	3.379	0.758	0.718
2	2.892	0.681	0.634	3.339	0.749	0.710
3	2.977	0.658	0.599	3.117	0.689	0.635
4	3.357	0.691	0.628	--	--	--
5	2.611	0.639	0.590	2.696	0.624	0.571
6	2.472	0.605	0.549	2.679	0.655	0.609
7	--	--	--	2.511	0.659	0.622
8	3.212	0.683	0.626	--	--	--
9	2.635	0.674	0.636	--	--	--
10	2.744	0.671	0.628	3.153	0.729	0.688

Periphyton communities were also evaluated during the Cycle 2 recovery. Two consecutive deployments were conducted to cover this recovery period. **Table 5.22** summarizes the results from these exposures.

Table 5.22 --Diversity and Evenness Indices for the Periphyton Species – Cycle 2 KRASR

		Recovery					
		11/23/2009			12/21/2009		
Station ID	Replicate	Shannon-Wiener Diversity Index	Pielou's Evenness Index	Hulbert Evenness Index	Shannon-Wiener Diversity Index	Pielou's Evenness Index	Hulbert Evenness Index
ASR 1	1	3.187	0.621	0.576	3.374	0.687	0.640
	2	3.580	0.745	0.689	3.060	0.643	0.590
	3	3.075	0.646	0.578	2.844	0.591	0.521
ASR 3A	1	3.643	0.750	0.719	3.224	0.713	0.662
	2	3.126	0.631	0.569	3.168	0.700	0.650
	3	3.533	0.720	0.675	3.316	0.676	0.616
ASR 3B	1	3.508	0.695	0.652	3.088	0.636	0.577
	2	3.523	0.657	0.608	2.804	0.629	0.574
	3	4.131	0.812	0.772	3.152	0.656	0.593
ASR 5	1	3.443	0.695	0.651	3.074	0.670	0.611
	2	3.377	0.688	0.653	2.876	0.627	0.581
	3	3.673	0.756	0.722	3.253	0.709	0.663

Diatom taxa were generally the most abundant and most of the dominant taxa in this data have species that are associated with nutrient-rich environments. Nutrients can influence periphyton abundance and community structure, but other factors (e.g. light availability, amount of colonizable substrate, water temperature, and grazer abundances) can weaken generally positive nutrient-periphyton abundance relationships. Dissolved metals, even at relatively low concentrations, also have been associated with reduced periphyton abundance and shifts in community composition after a few weeks of exposure. While there is no evidence that KRASR recovery water had a significant influence on periphyton communities compared to upstream and downstream sites, low level site repetition and variability in sites used for incubation precludes an in-depth statistical analysis of the periphyton data.

5.3.3 Stressor-Response Profiles / Risk Hypothesis Evaluation

The stressor-response profiles have been structured around a series of risk hypothesis developed as part of the Problem Formulation. Based on outputs from the exposure characterization, additional risk hypotheses were developed and are also discussed. The effects have been characterized in terms of high, moderate, low and minimal using the following definitions:

High – Short-term or long-term effects are probable and would result in substantially lower abundance, diversity, or health of receptor organisms. These effects could influence the decision about whether or not to proceed with an ASR implementation alternative in a given locality, regardless of any possible mitigation.

Moderate – Short-term or long-term effects are possible and may result in substantially lower abundance, diversity, or health of receptor organisms. These effects are sufficiently important to consider mitigation if ASR is implemented in that locality.

Low – Short-term or long-term effects are not expected that would result in substantially lower abundance, diversity, or health of receptor organisms. These effects probably would not require modification of ASR implementation beyond monitoring to validate the low risk characterization.

Minimal – Short-term or long-term effects are most likely not measurable.

The uncertainty of the effects characterizations are defined as the following:

High - The predicted risk is based upon limited information; therefore, additional information should be collected prior to implementation of ASR.

Moderate - The predicted risk is based upon likely sufficient information, but should be validated further prior to implementation of ASR.

Low - The predicted risk is based upon substantial information and likely does not need further verification.

5.3.3.1 Changes in Recovered Water Quality

The preliminary stressor-response hypothesis stated in the PMP was:

"If water quality characteristics of the recovered water affect surface water quality at the Pilot ASR projects, in the near field environment, and the Everglades, there is a potential for various effects on flora and fauna in these receiving waters."

In order to address this preliminary hypothesis, the ERA team re-worded the initial PMP hypotheses as this initial hypothesis, followed by a series of secondary stressor-effect hypotheses statements and questions.

Water quality of the recovered water does not negatively affect surface water quality downstream of the point of discharge to the level where negative effects on native flora and fauna are measurable at the local or regional level (Lake Okeechobee and Greater Everglades).

The secondary stressor-effect hypotheses will be addressed sequentially.

5.3.3.2 Effects to Surface Water Quality

1. **Would extended contact of recharge water with aquifer material change the chemistry of the recovered water? Would recovered water meet applicable surface water quality standards during discharge? The pH, alkalinity and hardness of the recovered water are likely to be greater than the surface water, especially in certain areas of the Greater Everglades.**

Section 5.1 Exposure Characterization and the ASR pilot data results showed that the recovered water quality did change during the period of storage. These water quality changes and the exposure pathways modeled indicate that these changes could be promulgated throughout the canals, Lake Okeechobee, and possibly the Greater Everglades. **Table 5.5** showed KRASR cycle 4 data as the most representative recovered water dataset (since earlier cycles condition the aquifer to ASR storage and recovery operations). The results in this table indicate that recovered water generally will meet surface water quality standards as long as discharges are stopped in the event that specific conductivity exceeds the 1,275 uS/cm criteria. Earlier cycle test results at KRASR showed elevated arsenic concentrations in the recovered water; however, maximum concentrations trended lower with each successive cycle test. The recovered water overall did not show acute effects. However, some chronic toxicity was detected using the sensitive *C. dubia* and this effect on reduced reproduction was observed near the end of the cycles. This effect was seen during Cycles 2, 3, and 4 at KRASR. Testing at HASR did not detect any toxicity.

Since toxicity and water quality sampling is available from only two CERP ASR pilot wells, there is uncertainty inherent with applying these results to regional ASR implementation.

5.3.3.2.1 Acute and Chronic Effects

2. Would trace metals and radionuclides leach from the aquifer material during the storage period? Increased trace metal concentrations could impact algae and diatom primary production, and these stressors could bioaccumulate in fish and invertebrates.

The water quality changes of ASR recovered water were summarized in **Table 5.5.** An increase in arsenic, molybdenum, and gross alpha concentrations was observed in the recovered water. Iron, manganese, mercury, and methylmercury concentrations were lower in the recovered water as compared to recharge water.

Acute toxicity tests using *S. capricornutum* showed no effect on algal growth when exposed to recovered water. Bioaccumulation of arsenic, nickel and molybdenum was observed during Cycle 1. Arsenic, mercury and molybdenum were also bioaccumulated during Cycle 2 when the organisms were exposed to the recovered water mixing zone; methylmercury was not bioaccumulated.

3. Acute or chronic effects are observed on representative aquatic vertebrate and invertebrate species at various life stages.

Table 5.17 summarizes the acute and chronic data developed using over 80 toxicity studies over the 4 cycles at KRASR. Exposures to up to 100 percent recovered water resulted in no effects to:

- *S. capricornutum* growth (7 tests);
- *C. dubia* acute (17 out of 18 tests);
- *D. magna* chronic test;
- Bannerfin shiner acute (18 tests);
- Fathead minnow chronic (16 tests); and
- FETAX Frog (6 tests).

The *C. dubia* chronic test did show a response to recovered water during all cycles, near the end of the cycle (6 out of 17 tests showed a reduction in reproduction). For five out of the six effect observations, a dilution of the recovered water to 50 percent showed no further effects on reproduction. The one chronic test with a reproduction inhibition down to 7.2 percent recovered water also showed acute toxicity to this species; 1 out of 17 tests showed this effect.

The cause for this effect on reproduction is not known with certainty. Toxicity identification evaluation (TIE) studies were not conducted at KRASR because of the intermittent nature of the observed reproduction inhibition effect. A review of water quality concentrations that coincided with the observed reproduction inhibition points to elevated sulfide and hardness concentrations as potential causes of this effect, but the toxicity mode of action is not known. Based on the large volume of environmental toxicity data collected, minimal acute effects are anticipated from ASR implementation in south Florida. Minimal to moderate chronic effects may be observed during the mid- to late recovery cycles in the immediate vicinity of the ASR discharges. These data show that a 50 percent dilution of ASR recovered water is expected to result in minimal effects.

The potential for chronic toxicity is governed partly by the amount of base flow in the receiving water body that is available for dilution. Based on the hydrologic modeling analysis in Section 5.1 (**Figure 5.6**), it was anticipated that ASR facilities will recover and discharge water primarily during droughts, and that the severity of the drought will drive the volume of the discharge. In the period of record (1965-2005) there were some single years where ASR was predicted to discharge (e.g., 1965, 1967, 1993, and 2004), but there were some consecutive years where ASR was predicted to discharge a much higher overall volume (e.g., 1971-77, 1981-82, 1988-90, and 2000-01).

It is these latter scenarios where the greatest cumulative potential for effect of ASR discharges on the receiving stream biota is expected. **Tables 5.2, 5.3, and 5.4** characterize frequency, duration, and timing of ASR recovery and discharge. These frequencies have implications for both the magnitude of possible effects on the biota, and the recovery time (if an ecological impact is indicated) between recharge or recovery events. Across all alternatives, ASR recharges between 22 and 29 percent of the time, but recovers less than 15 percent of the time for all alternatives except ALT4S-11 which recovers 27 percent of the time due to lower number of wells (**Table 5.2**). From the data in **Table 5.3**, there were 26 to 33 recharge events lasting at least 30 days, with the average recharge event lasting approximately 3.5 to 4.5 months. The maximum duration recharge event for each alternative lasted at least 11 consecutive months. The number of "down-time" events was similar (33 to 36 events greater than 30 days), with an average down time of about 12 months. **Table 5.4** characterizes recovery/discharge events. There were 11 to 20 recovery events lasting at least 30 days, with the average recovery event lasting approximately 4 to 6.3 months. The maximum duration recovery events ranged from 14 (ALT2) to 20 (ALT4S-11) consecutive months. The average "down-time" ranged from 19 (ALT2) to 27 (ALT4) consecutive months. The minimum down time was 2 months, the maximums ranged from 80 to 122 months.

The average daily flow through the S-65E structure from January through April for all years in the POR was about 3,000 ac-ft/day (1,510 cfs). In May and June, the average daily S-65E flow was 1,800 ac-ft/day (908 cfs). However, during years when ASR alternatives were predicted to discharge, the average monthly flow at S-65E drops to less than 100 ac-ft/day for ALT4 and ALT4-S11 (50 cfs; during

January) and less than 500 ac-ft/day for these alternatives in the February through June period (**Figure 5.8**).

During both these times, the maximum possible ASR discharge for ALT2 (75 wells in the Kissimmee) was 1,150 ac-ft/day (580 cfs), resulting in a 1:11.6 cfs (Jan) or 1:2.3 cfs (Feb-Jun) S-65E to ASR discharge dilution ratio. However, ASR well discharges were variable in the simulation. For example, during the simulated 1981 drought in January, ASR wells discharged for only 16 of the total 31 days, but in the simulated 1982 drought, the ASR wells flowed for all 31 days in January. Therefore, the ASR discharge (at 1:11.6 ratio) overwhelmed river flows for approximately half of January 1981, but for all of January 1982. However, for the other 39 "Januaries" in the simulation, there was no ASR discharge, hence no effect. For the other alternatives, and using the following volumes: 460 ac-ft/day (ALT3, 232 cfs), 220 ac-ft/day (ALT4, 111 cfs), and 60 ac-ft/day (ALT4S-11, 30 cfs), the January dilution rates were 1:2.3 (ALT3), 1:1.1 (ALT4), and 3.3:1 (ALT4S-11). ALT4S-11 (15 wells) had a January dilution rate very close to that permitted by the FDEP for the one KRASR well (30 cfs at S-65E to one 5 mgd [7.74 cfs] well) of 3.9:1. It was anticipated that this dilution rate would not be problematic for fish or other aquatic life since it was established to prevent chronic effects.

For the March and April time frame (when S-65E flows were approximately 400 ac-ft/day), the S-65-E: ASR dilution rates were 1:2.9 (ALT2), 1:1.1 (ALT3), 1.8:1 (ALT4), and 6.7:1 (ALT4S-11). For the remainder of the dry season months (February, May, June, November, and December), the dilution rates would not be as potentially bad ecologically as in January but worse than those for March and April. Clearly, from these data and previously, ALT2 has the greatest chance of causing measurable effects in the Kissimmee River during droughts or periods of low flow at S-65E simply based on the lower dilution ratios? This analysis also indicates that dilution rates are ecologically favorable (low effects) for most of the dry season for ALT4S-11.

5.3.3.2.2 Mercury Precursor and Methylation Effects

4. ASR related changes in sulfate load delivered to Lake Okeechobee and the Greater Everglades does not result in increased methylation and potential bioaccumulation of mercury by fish and wildlife.

Lake Okeechobee

LOEM Simulation results indicate that mean Lake sulfate concentrations will increase from the long-term background of 30 mg/L to 50 mg/L, 34 mg/L, and 31 mg/L, for scenarios ALT2C, ALT2V, and ALT4V, respectively. Based on the ALT4V results, no change in the long-term average sulfate concentration would be expected from ALT4-S11 given its reduced recovered water volume discharged to the Lake. The additional sulfate loading for any of these alternatives is expected to have minimal impacts on MeHg production in Lake Okeechobee if the relationship between sulfate and MeHg is similar to that observed in the WCAs and ENP. While no detailed studies of Hg methylation in Lake Okeechobee have been conducted, Hg levels in the muscle of gar and other top predator fish collected from Lake Okeechobee are similar to, or lower than, those generally reported from other areas of the United States. Thus, although the levels of Hg in fish from the Everglades to the south of Lake Okeechobee are sufficiently high to result in human fish consumption advisories, there are no similar advisories for Lake Okeechobee. The reasons for this are not presently known, but there are several likely explanations. First, while there are some areas of mud and peat bottom sediments, most of the lake bottom consists primarily of rubble and sand with relatively low organic carbon content. This type of sediment is not generally associated with sulfate reduction and MeHg formation. Second, observed sulfate levels of ~30 mg/L in the lake place its condition in the zone of methylation inhibition. Third, several lines of evidence suggest that microbial sulfate reduction is not prevalent in Lake Okeechobee. Sulfur models for Lake Okeechobee indicate that it is more of a reservoir of sulfate within the ecosystem, and there is no source of sulfate and minimal retention of sulfur within the Lake (James and McCormick, 2012). The lack of sulfur retention further suggests that limited sedimentary sulfate reduction is occurring within the Lake. Thus, Lake Okeechobee receives sulfate inflow from rivers to the north, back pumping from the EAA, and small amounts from rainfall, some evapo-concentration of sulfate occurs due to the large surface area of the lake, and the sulfate passes through on its way to the EPA. Fourth, Lake Okeechobee does not commonly stratify with regard to oxygen, which is a condition frequently observed in lakes with elevated MeHg (Rask et al., 2010). Last, eutrophic lakes like Lake Okeechobee generally exhibit low MeHg levels, likely due to bio-dilution effects (Chen and Folt, 2006). Overall, there appears to be a low risk that any of the ASR alternatives would adversely impact mercury methylation dynamics within most of the Lake; however, there is a moderate level of uncertainty surrounding this risk characterization result since the Lake is very large and there may be locations within the Lake that favor mercury methylation which might be exposed to ASR flows.

Greater Everglades

Proportionately, the potential increase in sulfate load from ASR operations to the Greater Everglades is less than that predicted for Lake Okeechobee because the Lake provides only 1/3rd of the sulfate load to the Greater Everglades with the balance of the sulfate load coming from agricultural operations in the Everglades Agricultural Area and from atmospheric deposition. The impact of ASR related sulfate discharges into the Greater Everglades is primarily expected to be a change in the locations where water column sulfate is within the “goldilocks” concentration range that optimizes mercury methylation chemistry.

On behalf of the study team, the University of Florida and USGS undertook a study of the potential effects of ASR related sulfate on the Greater Everglades (Fitz, 2013, Orem et al., 2014). These efforts concluded that although ASR sulfate loading is not predicted to be a dominant source of sulfate to the EPA overall and does not appear to significantly alter the total area of the EPA impacted, it may have ecosystem effects locally. For example, localized ASR sulfate loading near discharge points during certain time periods could produce critical tipping points with regard to stimulation/inhibition of MeHg production (Orem et al., 2011). The ELM-Sulfate model shows that ASR water entering the EPA does increase overall sulfate loading, but only during certain time periods and primarily in areas directly adjacent to STA or canal discharge. When normalized to the baseline sulfate scenario, the impacts of ASR sulfate are minimal. This is primarily due to the dominance of EAA discharge with regard to sulfate loading to the ecosystem, and to dilution effects on the ASR discharge to the extensive EPA marshes. ALT2C was determined to have the biggest impact on sulfate loading to the EPA. Evaluation of long-term averages and short term "ASR stress periods" indicate that although sulfate loading from ALT2C was small compared to other sources, this scenario should be considered with caution, regarding the potential to increase sulfate concentrations within important localized regions of the marshes of WCA 3A. Western WCA (L28 discharge), northeastern WCA 3A (STA 3/4 discharge), and northwestern WCA 3A, which were most impacted by ASR sulfate loading in the ELM-Sulfate model output. ALT2C, however, is not necessarily the most realistic ASR scenario, and the assumptions used to derive ALT2C sulfate boundary conditions were very conservative (possibly higher than would occur under real world conditions). The more realistic ASR alternatives (ALT2V, ALT4V), which include varying sulfate concentrations, exhibited some increases in sulfate loading relative to the baseline, but these were very limited in magnitude and extent.

Overall, the areas of changed MeHg risk attributable to the ASR operations are predicted to be minimal, and are located near major canal water release points in western WCA3, north-central WCA2, and northern Shark River Slough. Because the relationship between sulfate and MeHg production is nonlinear and hump shaped, the model generally predicts both regions of net increases and net decreases in MeHg risk in near proximity to each other. That is not to say, however, that sulfate releases from ASR or other canal water sources are not important, because in the absence of sustained sulfate loading to this ecosystem, MeHg levels in the EPA would be substantially reduced - once internal recycling of sediment sulfate pools subsided. Given the ELM-Sulfate modeling output, the risk of ASR sulfate related methylation effects is characterized as moderate for ALT2 and ALT3 while the risk for ALT4 and ALT4-S11 are characterized as low due to the reduced ASR flows for these alternatives.

5.3.3.2.3 First Flush Effects

5. If the dissolved solids concentrations in recovered water exceed mineral solubility, spontaneous calcium carbonate and gypsum precipitation due to supersaturation may occur as the recovered water is discharged into the receiving water. Could this affect light penetration and the character and rate of sedimentation in the downstream environment?

ASR facilities may recover a “first flush” of particulates during the initiation phase of recovery. If this was discharged to a surface water body, interstitial substrate spaces with benthic aquatic invertebrates or fish larvae/eggs could be covered. However, the KRASR and HASR facilities have the capacity to collect and sequester the first flush from the aquifer that may have a high solids load. This first flush water cannot be discharged into a surface water body until the turbidity meets surface water quality standards. Based on the assumption that future ASR facilities would have similar capacity, the likelihood of sedimentation on aquatic life appears to be low.

5.3.3.2.4 Effects from Alkalinity Changes

6. What are the potential effects of alkalinity changes in the receiving water?

Sampling of surface water conducted at the KRASR facility indicated mean total alkalinity of 48 mg/l (min = 28 mg/l, max = 370 mg/l, median = 37.5 mg/l, N = 58). Mean hardness was 82 mg/l (min = 51 mg/l, max = 170 mg/l, median = 65 mg/l, N= 12). Sampling of the five UFA wells around the KRASR facility indicated mean alkalinity ranging from 77 to 98 mg/l (N=16), and mean hardness of 237 mg/l (N=3). Assuming that the KRASR well data is indicative of the worse case recovered water quality in terms of alkalinity and hardness, ASR discharges in the Kissimmee basin would have about 1.5 times the alkalinity and about 3 times the amount of hardness of ambient water in the Kissimmee River. For perspective, hard-water ecosystems (i.e., limestone spring streams) in Florida generally have even higher alkalinities levels (than the Upper FAS), ranging from 93 to 160 mg/l (mean = 124 mg/l, median = 126 mg/l, N = 99; raw data from Ponce DeLeon and Wekiwa Springs, 2002-2013). Hardness levels in the springs were roughly similar or slightly lower than the Upper FAS at KRASR and ranged from 57 to 283 mg/l (mean = 165 mg/l, median = 160 mg/l, N = 180). Using the 1981-1982 drought as a worse case example, if ALT2 were implemented (and assuming long-term mean alkalinity of 98 mg/l in the ASR discharge), monthly mean alkalinity in the Kissimmee River would increase from 48 mg/l (ambient) to 72 mg/l. The resulting mean Kissimmee River and Lake Okeechobee alkalinity levels with ASR in place would be approximately 60-75 percent of that in Florida spring streams. The potential for adverse effects from increased alkalinity or hardness on fish or other aquatic biota is low. Beneficial effects are possible. It is possible that some minor increases in primary productivity could result in the near-field if the alkalinity increases can be achieved and sustained; however, since ASR will only discharge periodically, it is unclear if this effect would be measurable over the long term. ALT3, ALT4, and ALT4-S11 each discharge less water, therefore, the increases in mean alkalinity in the river and lake would not be as great under those scenarios. However, even greater changes to alkalinity (than ALT2) could be achieved in reality with the occurrence of longer or more severe droughts or if recovered water from APPZ wells is discharged.

ASR related changes to alkalinity in the Greater Everglades is expected to fall within the range of existing alkalinity concentrations measured at the outfall of STA3/4 which discharges into WCA-3A. As with the upstream systems, the potential for adverse effects in the Greater Everglades from increased alkalinity or hardness on fish and other biota is low.

5.3.3.2.5 Dissolved Gas Effects

What are the potential effects of changes in dissolved gases in the receiving waters?

The effects of dissolved gases (other than oxygen) potentially in the ASR discharge on the fishery were assessed. ASR recovered water has a similar concentration of dissolved carbon dioxide as Kissimmee River water, but higher concentrations of dissolved hydrogen sulfide and un-ionized ammonia. Dissolved sulfide species (solute and gas) are higher in recovered water due to sulfate-reducing reactions in the aquifer. At a pH range of 7 to 8, most of the total dissolved sulfide occurs as the bisulfide ion (0.20 to 0.67 mg/L concentration range). Dissolved sulfide gas (H_2Sg); (more toxic than ionized sulfide) concentrations are about an order of magnitude lower (0.01 to 0.15 mg/L). No dissolved sulfide measurements were available for the Kissimmee River; however, sulfide species are unstable in the presence of dissolved oxygen so sulfide most likely is not detectable in surface water.

The nationally recommended water quality criteria compiled by the EPA recommends a chronic hydrogen sulfide concentration of 2 µg/L for the protection of aquatic life (USEPA, 1986). Concentrations of hydrogen sulfide in the ASR discharge were consistently an order of magnitude (occasionally two) higher than the recommended criterion. The nationally recommended criterion may not be specific to Florida aquatic species and is provided to serve as a guide to States when adopting water quality standards. Currently, the State of Florida does not have surface water quality criteria for hydrogen sulfide. While it is likely that hydrogen sulfide will be oxidized in the presence of dissolved oxygen, the area immediately surrounding the point of discharge may not be suitable for aquatic organisms. In addition, during periods when dissolved oxygen concentration is low in the river, hydrogen sulfide may not be oxidized as quickly. This risk could be minimized by redesigning the cascade aerator for not only dissolved oxygen addition, but also hydrogen sulfide removal prior to discharge into a surface water body. Ionized dissolved sulfide can only be removed chemically or electrolytically but because it is less toxic, the risk of adverse effects is low.

Ammonia and ammonium concentrations increase during storage in the UFA, so recovered water concentrations are higher than those of Kissimmee River surface water. Two ammonia species occur in recovered water: ionized ammonium (NH_4+) and un-ionized ammonia (NH_3). Ammonia toxicity to freshwater fish is based on un-ionized ammonia concentration (as mediated by temperature and pH), and the surface water quality criterion for this species is 0.02 mg/L for both Class I and Class III Florida surface waters. Most of the ammonia nitrogen in recovered water occurs as ionized ammonium (0.15 to 0.42 mg/L). Un-ionized ammonia concentrations are about an order of magnitude lower (0.002 to 0.016 mg/L). Although un-ionized ammonia concentrations are higher in recovered water, concentrations do not exceed the surface water quality criterion of 0.02 mg/L; therefore, the likelihood of adverse effects is low for the Kissimmee River and very low for Lake Okeechobee and the Greater Everglades due to dilution.

5.3.3.2.6 Effect on Lake Okeechobee Phosphorus

8. Lake Okeechobee Basin ASR will reduce phosphorus concentrations and load.

Recovered ASR water at the KRASR facility showed a marked reduction in total phosphorus concentrations when compared to the concentration in the recharge water. Table 5.13 shows that Lake Okeechobee ASR could reduce total phosphorus loads to the lake by 19 to 32 metric tons/yr depending upon the ASR implementation scenario. This amounts to about 6 to 10 percent of the load reduction required to meet the Lake Okeechobee TMDL target for total phosphorus. The LOEM modeling showed that the reduction in total phosphorus load attributed to ASR would not result in a decrease in lake water column phosphorus concentration.

5.3.3.3 Effects on Periphyton Communities

9. Surface water quality changes from recovered water do not have a measurable negative effect on local periphyton communities.

No significant patterns were found that would indicate that the KRASR discharge of recovered water affected the periphyton communities in the Kissimmee River. Regional implementation of ASR in the Kissimmee Basin could potentially have some adverse impact on periphyton attached to aquatic emergent vegetation in the vicinity of ASR discharge outfalls with flows greater than 5 MGD. The most likely effect on periphyton is likely to be associated with the lower concentration of phosphorus in the recovered water. Alternatives ALT2, ALT3, and ALT4 would have the greatest potential to alter periphyton in the Kissimmee River since these alternatives have the largest number of wells planned for this basin. ALT4-S11 would result in the least impact to periphyton since it has the equivalent of only four wells discharging recovered water into the river. Since ASR implementation within the Lake Okeechobee basin is not expected to alter Lake phosphorus concentrations, minimal impact to periphyton in the Lake or downstream in the Greater Everglades would be expected from regional ASR implementation in the Lake Okeechobee Basin.

5.3.3.4 Effects on Submerged Aquatic Vegetation

10. Do recovered water discharges affect SAV?

Lake Okeechobee

The effect of recovered water on SAV in the Kissimmee River was considered to be minimal given the limited coverage of SAV in this water body. **Figure 5.28** shows the LOEM predicted impact of ALT2 hydrology on Lake Okeechobee SAV coverage and biomass for the simulated period of 1999 to 2009. During this period, the lake experienced a significant drought in 2001. Following the drought, the SAV in the lake expanded to more than 50,000 acres which is greatest amount of SAV coverage ever measured. As a result of the 2004 and 2005 hurricanes, the SAV acreage crashed as a result of excessive turbidity which limited light transmittance which is important to SAV. . The lake elevation graph at the top of **Figure 5.28** is in meters. The 2.5 meter elevation is equivalent to a lake stage of 17.2 ft NGVD and the 0.5 meter elevation is equivalent to a lake stage of 10.6 ft NGVD. In mid-2001, the ALT2 hydrology increases the lake elevation by approximately 0.5 meters. This resulted in a predicted increase in SAV acreage of approximately 10,000 acres during a 90-120 day period. Similarly, in 2007 and 2008, the increased lake stage due to ALT2 ASR resulted in two instances where SAV acreage was increased by approximately 10,000 acres. Though ALT2 hydrology appears to increase SAV acreage, SAV biomass does not appear to be substantially impacted by this hydrologic scenario.

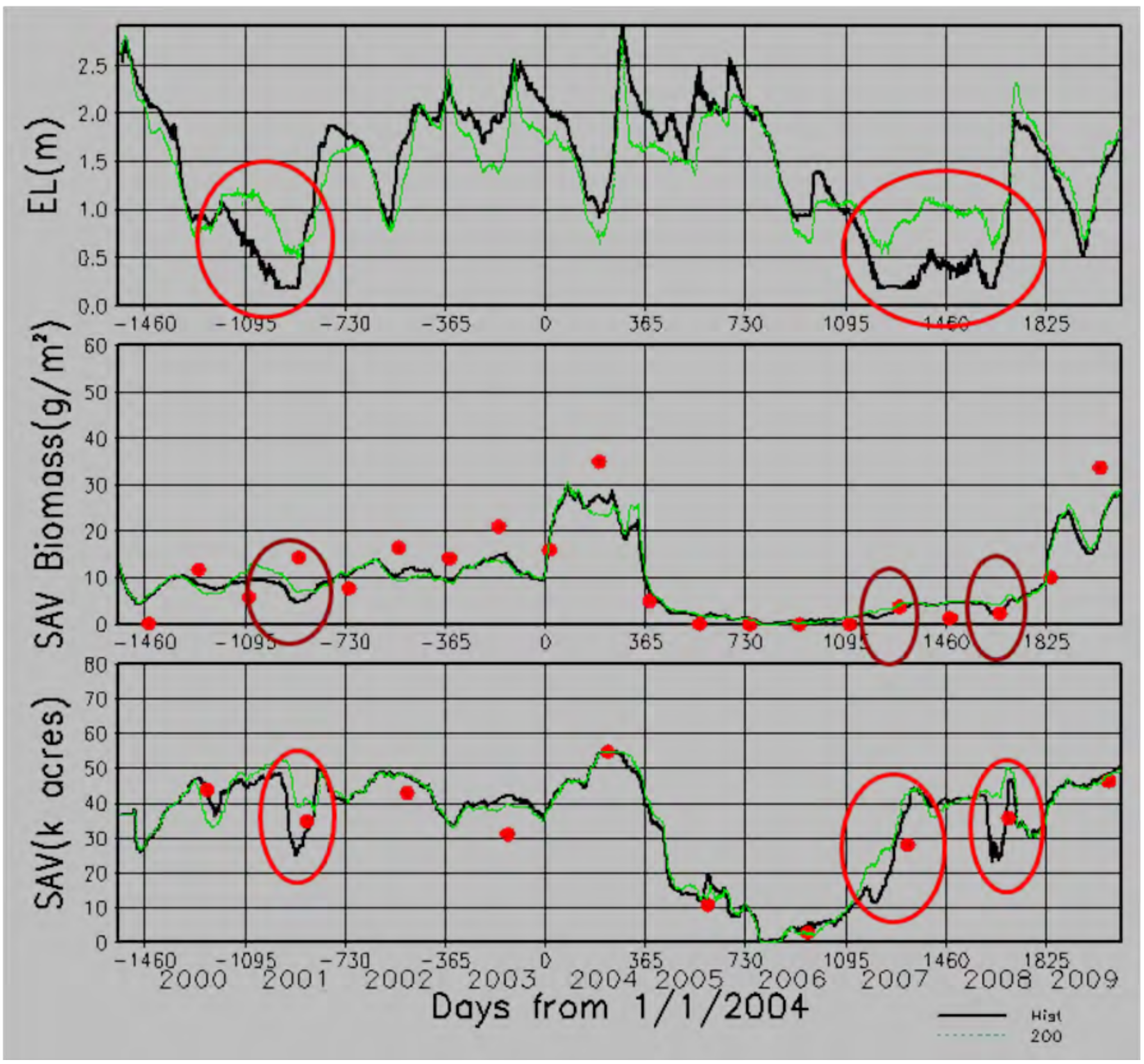


Figure 5.28 SAV Predictions for ALT2V Scenario. (Red dots represent field data.)

Figure 5.29 shows the impact of the ALT4C on SAV biomass and acreage. ALT4 hydrology increases lake stages during 2001 and 2007 by approximately 0.25

meters which is half the increase predicted for ALT2. The LOEM model predicts greater SAV acreage and biomass during 2001 and 2007 for ALT4V relative to the baseline prediction than that predicted for ALT2V. One possible explanation for this is that depth conditions and timing are more favorable for SAV under ALT4 during the 2001 and 2007 critical periods than that for ALT2.

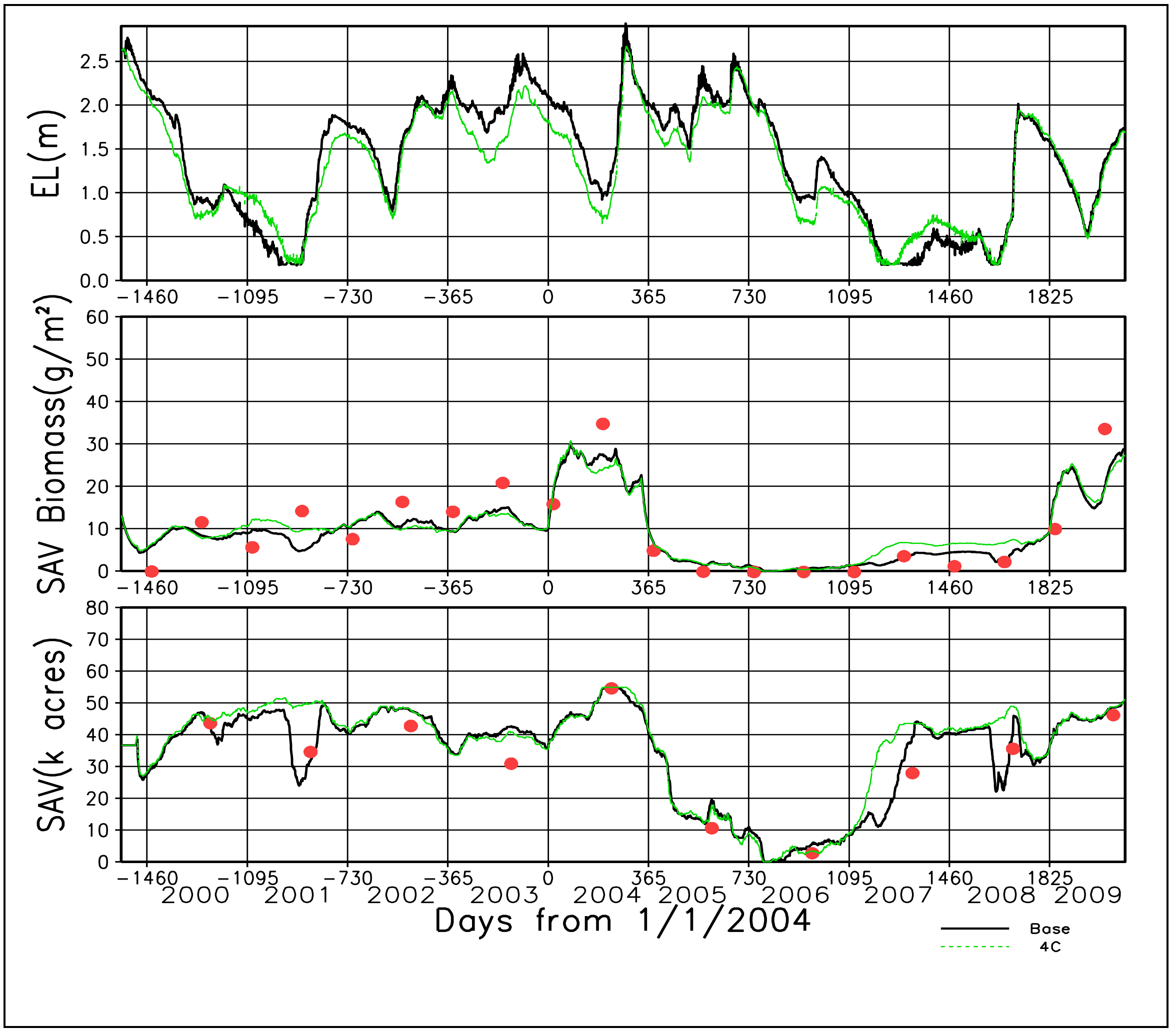


Figure 5.29. SAV Predictions for ALT4V Scenario.

As discussed earlier, the LOEM model was not used to simulate ALT4-S11 conditions since the LOEM modeling work was completed before this alternative was conceived. Rough projections of impacts to SAV caused by the implementation of ALT4-S11 can be made using SAV output from the ALT4 LOEM model run as a guide and the projected changes in minimum lake stage conditions from the LOOPS simulation output.

The maximum ASR related increase in lake stage from ASR is 0.6 ft for ALT4 and 0.1 ft for ALT4-S11. In comparison to the no ASR alternative, the lowest lake stage over the 41 year simulation period increases by 0.3 ft with ALT4 and decreases by 0.1 ft with ALT4-S11. With limited ASR recovery flows, ALT4-S11 performs worse under dry conditions relative to ALT4 and the no ASR alternatives and it is likely that SAV conditions in the lake would either see no improvement with this alternative or a decrease in SAV coverage and biomass. Poor low-lake stage performance for ALT4-S11 is a result of pumping large volumes of Lake water into the APPZ and BZ storage zones and never recovering this water. For instance, in ALT4S-11 the total volume of stored ASR water over the 1965-2005 period is 10 million ac-ft while the predicted recovered volume is less than 900,000 ac-ft. ALT4 has the same recharge volume but its recovery volume of the same period is approximately twice that of ALT4-S11 at 1.75 million ac-ft. Color and turbidity changes to Lake Okeechobee and the Greater Everglades from ASR discharges are considered to be low given the dilution and mixing of recovered ASR water with Lake water so no change to SAV from these water quality effects are anticipated.

Kissimmee River

The effects of ASR related changes to water color and turbidity on SAV communities in the Kissimmee were assessed. Specific survey results for SAV in the river in Pools D or E are not available; however, as part of the restoration project in Pools A and C, the SFWMD (2005) noted that the channelization of the river has eliminated much of the shallow water habitat capable of supporting SAV. Most recent surveys indicated primarily emergent or floating and mat-forming plant species (e.g., smartweed, pennywort, water lettuce, maidencane, water hyacinth, etc). *Ceratophyllum demersum* (hornwort or coontail) was the only SAV species that has been reported (Tetra Tech 2007), but the location was not noted. The exotic SAV *Hydrilla verticellata* should also be present in the river. Background color in the Kissimmee River is naturally high from tannins, and particulates from the floodplain. The water has little mineral sediment and few suspended clay particles under normal flow conditions; however, it can become very turbid under storm-flow conditions. When ASR discharges, the early-recovered water tends to maintain some of its high color, but gradually becomes clearer as more water is recovered. It is possible that the recovery of very clear water would support SAV growth in the future (where it exists already), by increasing light transmittance. However, this change would likely be short-lived as most discharge periods last for only a few months and are followed by long periods with no ASR discharge. In those simulated years (e.g., 1981-82, 2000-01) where ASR discharged for 16 contiguous months, there is a greater likelihood that SAV growth may be stimulated by ASR (especially considering a concurrent increase in alkalinity), but continued maintenance of the higher SAV biomass in the river once the ASR discharge is shut off would probably not occur as light transmittance would drop. The likelihood of adverse effects from changes in color or turbidity was characterized as low for the Kissimmee River. Any temporary increase in SAV could be a temporary benefit to aquatic invertebrates or fish species that inhabit the SAV in the Kissimmee.

5.3.3.5 Effect of ASR on Benthic Macroinvertebrates

11. Benthic macroinvertebrates will be affected by ASR discharges.

The poor habitat and resulting low benthic diversity and abundance would make it difficult to measure any future minor or moderate effects from ASR discharges on the benthic community. While the likelihood of ASR discharges negatively affecting the benthic community was characterized as low (based primarily on water quality data), the likelihood of not detecting a future ASR impact due to the poor condition of the benthic community, was characterized as moderate.

On January 25 and 26, 2012, the Corps sampled the intake stream for invertebrates and larval fish. Large amounts (no counts were made) of invertebrates were collected, including zooplankton, Chironomidae (midge larvae), *Chaoborus* sp. (glassworm or phantom midge larvae), and amphipods (probably *Hyalella* sp.). From this limited sampling event, it does seem likely that ASR could reduce the numbers of these types of small invertebrates in the river in direct proportion to the number of days of operation and the number of intake locations per alternative. Therefore, the likelihood of any invertebrate entrainment was characterized as high. The volume of recharge per event for ALT3 was about half of the other alternatives (i.e., half the total number of wells); however, the number of ASR recharge events was similar and predicted to occur between 22 percent (ALT4S-11) and 29 percent (ALT3 and ALT4) of the POR. Considering this pumping frequency with these species' short life spans, high reproductive rates, and likely ubiquitous distribution in the remainder of the watershed, the likelihood of this loss being measurable at a local ecosystem scale (i.e., Pool E) is probably moderate for ALT2, and low for ALT3, ALT4 and ALT4S-11. Measurements of invertebrate densities along the river shoreline along with additional quantitative invertebrate sampling of the ASR intake would reduce this uncertainty and validate this effects evaluation.

Within Lake Okeechobee, the effect of ASR on benthic macroinvertebrates is expected to be low in most areas of the Lake. In the southwestern littoral zone, the effect of ASR discharges on benthic macroinvertebrates could be moderate in vegetated shallow areas receiving a high proportion of minimally diluted ASR discharge. This would be avoided by ensuring that ASR discharges are not located directly upstream or adjacent to the southwest littoral zone of the Lake. For the Greater Everglades, the effect of ASR on benthic macroinvertebrates would be minimal due to upstream dilution of ASR flows.

5.3.3.6 Manatees

12. Manatees will not be negatively affected by the thermal profile at the point of ASR discharge or at the local level.

Manatees have been observed in the lower Kissimmee River. Most recently, three different manatees were observed during 2012 (one each on April 24, May 24, and July 9) near the S-65E and S-84 structures. On July 17, 2012, four manatees observed near the S-84. Two days later, one manatee was observed downstream of the S-65D and another was seen near the mouth of the Kissimmee River. It is not clear if these individuals were the same as those observed two days prior or different individuals. Regardless, there were at least seven different manatees that were observed in the Kissimmee River in 2012 downstream of S-65E.

In previous years (1980, 2003, 2009, 2010 and 2011) there were at least six additional manatee sightings reported to the FWC in Lake Okeechobee within 3 miles of the mouth of the Kissimmee River. These observations were reported from January to April, and November.

Manatees are present in Lake Okeechobee and the Kissimmee River primarily during warmer months of the year. They should migrate to coastal areas as water temperatures drop coincident with the onset of winter. Waters colder than 20 °C increase the manatees' susceptibility to cold-stress and cold-induced mortality. Because of this temperature restriction, manatees seek out warm water refugia to help reduce energetic maintenance costs.

The temperature of the KRASR discharge was consistently at or above 25°C (25.2 to 27.5 °C). Based on the ambient temperature data in Figure SS1, manatees are expected to leave the Kissimmee River in November-December as the water temperature approaches 20°C, and would not return until February or March. However, data exists for at least two manatee observations in January and February near the KRASR system. It is not clear at this time if manatees can find thermal refugia in the river or Lake Okeechobee during the winter, primarily because the river and lake are not part of the systematic winter survey area.

For potential risk to manatees from cold-shock, ASR would need to discharge in November and December but then stop before the end of February when ambient surface water temperatures are generally rise above 20°C. In the simulated hydrology from LOOPS, there were no occurrences where discharges were shut off during the January to April period for any of the alternatives. In cases where ASR was discharging in December or November, it continued through until after April when ambient temperatures would be warm enough to preclude thermal shock. Therefore, the risk of manatee mortality from thermal stress from ASR (any alternative) is minimal. If future ASR systems plan to discharge water warmer than 20°C into areas inhabited by manatees when the surrounding water is less than 20 °C, it should be coordinated with the FWC, USFWS, and NOAA prior to the start of the recovery phase (due to species protection under the Marine Mammal Protection Act).

5.3.3.7 Effects on Kissimmee Fishery

Larval and Egg Entrainment Effects

13. The entrainment of fish larvae/eggs or invertebrates by the ASR intakes does not have an effect on the Kissimmee fisheries.

The pumping of surface water during recharge represents a potential threat to fish and other aquatic resources through entrainment and impingement at the intake structure. Entrainment occurs when an organism is drawn into a water intake and cannot escape. Impingement occurs when an entrapped organism is held in contact with the intake screen and is unable to free itself. The severity of the impact on the fisheries resource and habitat depends on the abundance, distribution, size, swimming ability, and behavior of the organisms in the vicinity of the intake, as well as water velocity, flow and depth, intake design, screen mesh size, installation and construction procedures, and other physical factors (Canadian Department of Fisheries and Oceans, 1995). Based on limited sampling at KRASR (six composite samples were collected on January 25 and 26, 2012), fish larvae can be entrained through the intake structure. The KRASR intake was designed to limit impingement and entrainment by installation of a wedge wire screen with a pore size of 1 mm and an anticipated intake velocity at the screen face of 0.25 ft/sec. Similar intake screens would be installed on all future ASR intake structures.

Any fish species that spawns when ASR is recharging will likely have larvae at risk of entrainment. The larval and post-larval stages of black crappie are especially at risk because after the channelization of the Kissimmee River, Pool E became a favorite spawning location for this species. The typical spawning period for black crappies at this location is protracted, from January to May. Adults prefer to nest in colonies in shallow water near aquatic vegetation. A few days after hatching, post-larvae disperse from the nest area and eventually move to deeper water near the middle of the channel. Fry move vertically throughout the water column primarily to forage on zooplankton and secondarily to avoid predation. They follow the currents downstream into Lake Okeechobee. Their spawning requirements increase the likelihood that in the lower Kissimmee River, nest sites will be near both intakes and discharges (assuming that these structures will also be near or on the stream bank). The larval and post-larval stages are poor swimmers and would probably be unable to escape intake velocities (0.25 ft/sec) once drawn into the ASR intake flow-field. This is important to note not only for those fish hatching or near the shoreline, but also for those that may be drifting down from upstream spawning locations (including open-water spawners like threadfin or gizzard shad). However, larvae would need to be very close to the intake screen (within a few meters) to be at risk.

To assess this effect, the frequency of ASR recharge was evaluated (**Figure 5.5**) during the crappie spawning season (January through May). The 40-year LOOPS simulation predicted 16 times when ASR pumps could entrain crappie larvae for at least a portion of the spawning season (39 percent of the years in the POR). The FWC collected the greatest number of larval fish (all species) in Pools A and C during April to mid-May (1997-98). The number of larval fish that could be affected by ASR recharge events is difficult to quantify because there was no larval fish sampling in Pool E. However, the expectation is that the larval crappie densities in Pool E would be at least as abundant as those for Pools C and D. It is also expected that fish larvae naturally have a high mortality rate. The assumption is that ASR recharge operations could add to that mortality rate (but only for those years in which ASR operates). The effect of crappie larval entrainment in the Kissimmee Basin is characterized as high for ALT2 and ALT3 based primarily on the 2012 sampling data. This effect is lowest in the Kissimmee Basin for ALT4 and ALT4-S11 (characterized as moderate) which have approximately 20 to 50 percent of the wells in the Kissimmee as ALT2 and ALT3 respectively. Overall, for all Lake Okeechobee ASR installations, the risk of black crappie larval entrainment would be lowest for ALT3 since this alternative has half the number of wells than any other ASR alternative considered.

Assuming that many other species will spawn during the same period as black crappie, they could experience similar effects. For those species that spawn in the summer (shiners) or fall (some *Lepomis* sp.) the predicted effect is similar (15 and 16 events, respectively). The reason for this is that in years when ASR recharge starts in the spring, it generally continues through the fall. Conversely, catfish larvae are less likely to be affected by entrainment because they receive more parental protection after hatching and are more sedentary at this early life stage than other Kissimmee River fish species. The potential effect of entrainment on catfish is low.

14. The temperature and dissolved oxygen of recovered water discharge does not negatively affect fisheries at the point of discharge or in the local ecosystem.

Dissolved Oxygen Effects

The effects of ASR discharge temperature and dissolved oxygen changes in the receiving stream could affect the fisheries. Water temperature in the Kissimmee River varies with air temperature and may range from a minimum of 13 ^{o}C (55.4 ^{o}F) during January and February to a maximum of 30.5 ^{o}C (86.9 ^{o}F) during July to September (**Figure 5.30**). According to SFWMD (2005), channelization of the river has resulted in chronic low dissolved oxygen conditions and concentrations vary from zero to 4 mg/l for much of the year, but may range as high as 9 mg/l (in February, when water temperatures are low). However, after restoration, the SFWMD expects dissolved oxygen concentrations will increase from <1–2 mg/l to 3–6 mg/l during the wet season and from 2–4 mg/l to 5–7 mg/l during the dry season. The dissolved oxygen levels reported in SFWMD (2005) for Pools A and C are slightly lower than the more recent sampling in Pool E that was conducted for the KRASR facility. That sampling indicated higher monthly average dissolved oxygen concentrations in the river (always above 2 mg/l) (**Figure 5.31**); however, in 12 out of the 14 years (2000-2013), the annual minimum dissolved oxygen reading was less than 2.0 mg/l at the S-65 E.

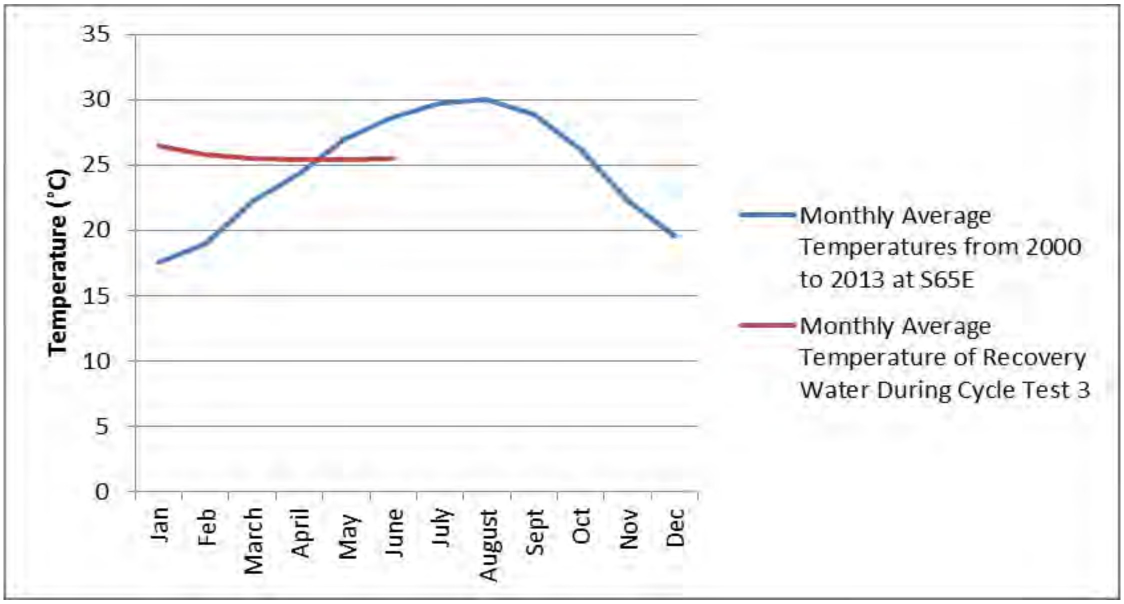


Figure 5.30. Average monthly water temperature at the S-65E structure (2000 to 2013; collected biweekly), and of recovered water during Cycle test 3 (2011)

The water temperature of the KRASR discharge is a relatively constant 25 ^{o}C (From weekly temperatures recorded during Cycle Test 3 discharge from January to June 2011) and the dissolved oxygen concentration ranged from 7.0 to 7.8 mg/l (increased by a cascade aerator prior to discharge) (**Figure 5.31**). From a fisheries perspective, the addition of oxygenated water would be a benefit during warmer months when ambient Kissimmee River dissolved oxygen may be less than 4 mg/l; however, if the ASR is shut down, then those refugia would disappear and fish kills may result. (Note: FDEPs new minimum dissolved oxygen standard for the Kissimmee River is temperature dependent and is 38 percent of saturation – ranges from 2.9 to 4.5 mg/l [62-302.533 of the Florida Administrative Code]).

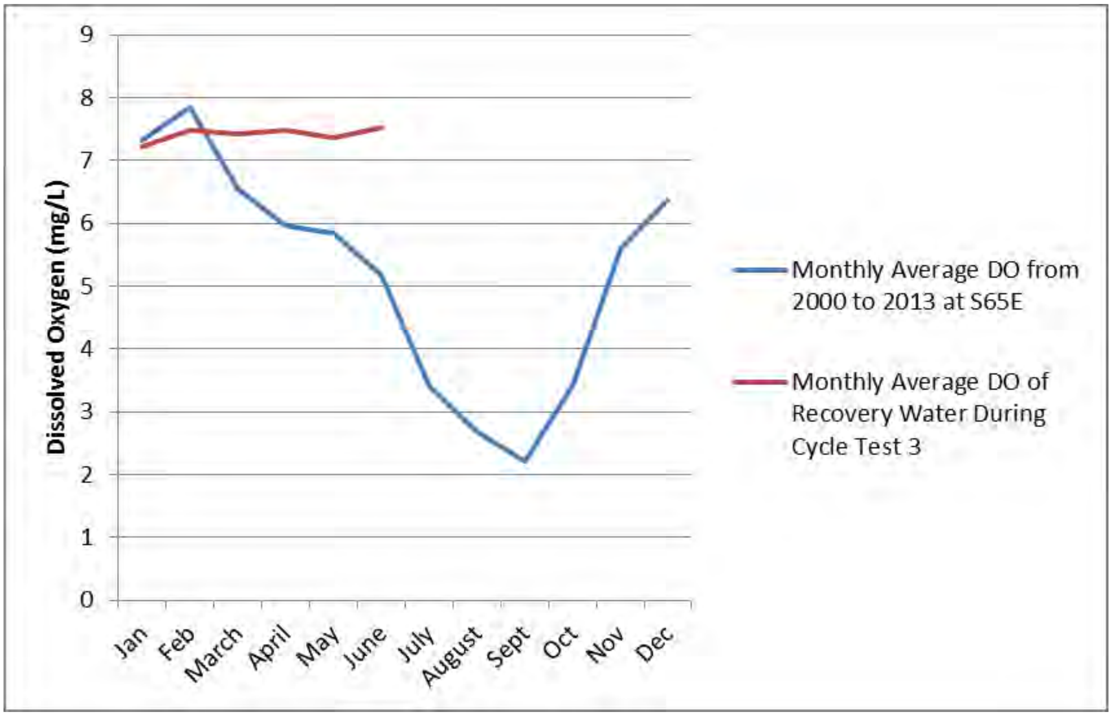


Figure 5.31. Monthly average dissolved oxygen concentrations at S-65E (2000 to 2013) and the KRASR discharge (January - June 2011)

Based on the LOOPS simulated 40 year hydrograph shown in **Figure 5.4**, ASR simulated discharges coincident with anticipated low ambient dissolved oxygen periods (July to October) occurred 13 times in the POR. The worst of these occurred during two simulated drought-event discharges from December 1980 to April 1982 and May 2000 to September 2001. The durations of the 1981-82 discharges were slightly different for each alternative (e.g., ALT3 started 4 months after the other alternatives; ALT4 ended about 3 months prior to the others); however, all alternatives discharged for at least 11 months from March 1, 1981 to February 1, 1982. For the 2000-01 drought (encompassed 17 months), the durations of discharges for all alternatives were very similar (only ALT2 was 30 days less). During discharge, the dissolved oxygen in the plumes could be above 7 mg/l for many consecutive months (i.e., at least 11 or 16 months, depending on the drought year) – certainly long enough for the fishery to respond and congregate in and around the plumes. Of course, the plume size is different for each well cluster site and each alternative based on discharge volume. The model simulation indicated that discharge would have been shut off after the first drought in early April 1982 when ambient dissolved oxygen in the river should have been around 6 mg/l. This drop from about 7.5 to 6 mg/l should not pose a hypoxia problem for resident fishes. For the second drought, the ASR discharge would have been shut off in mid-September 2001 when the river's dissolved oxygen (monthly average) would have been around 2.5 mg/l (although daily levels could have been lower). Despite the new FDEP standard (at this temperature, approximately 3 mg/l), it is likely that the drop in dissolved oxygen from about 7.0 to 2.5 mg/l within 12 hours or less would cause stress to aquatic life in the river and probably a hypoxia-related Fishkill (especially for more sensitive species). Occurrences for this scenario (where discharge began sometime between December to April, but then ended in August or September) for the entire POR ranged from six times for ALT2, four times for ALT3, three times for ALT4, to two times for ALT4S-11.

The extent of this fish kill would depend on the size of the plumes, the numbers and species of fish in the plumes, and existence of other adequate-oxygen refugia (possibly Lake Okeechobee) and whether ASR operations could be modified to taper discharges and allow fish to gradually adjust to lower DO concentrations.

Local gamefish (e.g., bass, crappie, and other sunfish) and forage fish (minnows and shad) prefer higher dissolved oxygen concentrations, and therefore, would be most at risk to dissolved oxygen drops. Conversely, some native fish species such as gar and bowfin are more tolerant of low dissolved oxygen concentrations and therefore, may not be as affected by large dissolved oxygen drops. It is also possible that any fish kill will not be immediate. Chronic stress from abruptly low dissolved oxygen may cause death only after days of exposure through metabolic depression (in part, associated with potentially warmer river water temperatures).

Due to the highest discharge volumes, ALT2 had a high risk of causing a fish kill due to dissolved oxygen drops. ALT3 had a moderate risk, and ALT4 and ALT4S-11 have a low risk. This risk occurred in less than 15 percent of the years in the simulation. This risk may be reduced by operational changes that gradually decrease ASR discharge flow rather than an abrupt stoppage, thereby allowing aquatic species to acclimate to ambient conditions.

Temperature Effects

Fish, particularly during spawning, are susceptible to thermal changes that can occur during recovery operations. Fish spawning in the Kissimmee River occurs during most months of the year so it is likely that ASR discharges would be co-incident with spawning. Depending upon the size and number of thermal discharge plumes, a significant fraction of the fish in the lower Kissimmee and other basins with ASR discharge may be exposed.

It is difficult to know how many fish could be in the ASR discharge plumes, however, The FWC data collected in 2004-2006 (**Section 3, Appendix B**) can be used to estimate the number of fish that may be within discharge plumes. Because the FWC sampling was based on 15-minute intervals (nine total per season) instead of a standard length of river, there is some uncertainty when converting these data to density. Using the average number of fish collected over all nine seasonal transects (448 fish; range = 250 to 692 fish), and assuming this abundance throughout the 3,600 to 5,400 ft sample area, a density range of 0.12 to 0.08 fish per foot of stream bank would be predicted based upon the reported sampling transect length. Assuming that Kissimmee River ASR installations are placed in Pool D and Pool E (**Figure 5.32**), the number of fish per stream bank in Pool E ranges from 6,600 to 9,700 fish. If the density were the same on both stream banks, this total would double. This probably represents only a minimum density of fish in Pools D and E because not all fish were collected during sampling along the stream bank (especially small fish) and only the stream bank was sampled (not the channel). To calculate the minimum number of fish potentially affected within any given ASR plume this stretch of the river, multiply the length of the plume by 0.08 to 0.12 fish per foot. Assuming that plumes were no larger than 800 meters (2,600 ft), per DEP regulations there would be a minimum of approximately of 210 to 320 fish in that plume (assuming it covered only one stream bank). The number of fish potentially affected by each alternative can be estimated under the assumption that each 5 well cluster would generate an 800 meter plume. For ALT2 which would have as many as 15 clusters in the Kissimmee, the discharge would affect up to 4,500 fish which is approximately all of the fish located along the stream bank at any one time in Poole D and Pool E. For ALT3 which would have as many as 7 clusters in the lower Kissimmee, the discharge would affect up to 2,000 fish which is between 1/2 and1/3rd of the fish in Pool E. ALT4 with 3 clusters below S-65E would affect up to 1,000 fish which is 1/4th to 1/6th of the instantaneous fish population. ALT4-S11 with 3 clusters but reduced discharge rate would affect approximately 250 fish which is between 1/16th and 1/25th of the instantaneous fish population in Pool E. Based on these estimates for fish potentially affected by ASR recovery events, ALT2 appears to present a high risk of causing adverse effects to the lower Kissimmee River fish population resulting from ASR discharge events. ALT3 and ALT4 might result in moderate effects to the lower Kissimmee River fish population resulting from ASR recovery events. ALT4-S11 appears to result in low to minimal effects to lower Kissimmee River fish populations resulting from ASR discharge events. Note that anglers may be attracted to any gamefish concentration in the plumes and that may result in increased harvest rates thereby affecting that portion of the fishery; however, the data to address this potential effect (fishing effort and harvest rates) are not available.

The effect of ASR discharge plumes on other Lake Okeechobee tributary fisheries would be similar depending upon the number of ASR wells and discharge locations planned for those locations as well as the availability of surface water for dilution.

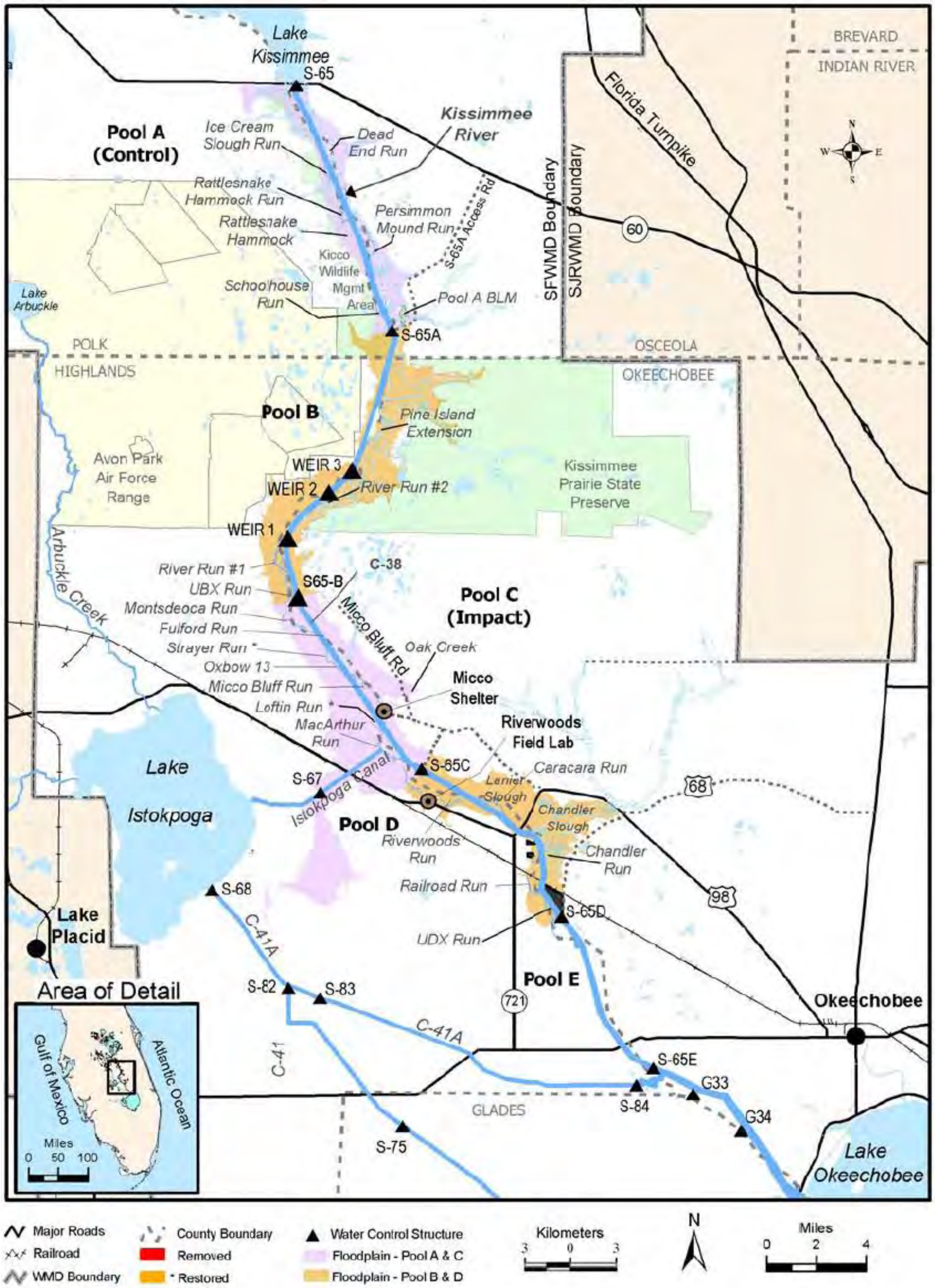


Figure 5.32 -- Map of the Kissimmee River from Lake Kissimmee to Lake Okeechobee (from SFWMD 2005)

5.3.3.8 Effect of ASR on Lake Okeechobee Fishery

15. What are the effects of ASR on Lake Okeechobee Fishery?

The diversity of fish in Lake Okeechobee is similar to that of the Kissimmee River (**Table 5.25**) and the C-44 Canal at Port Mayaca (**Table 5.26**). Relative abundance typically favors those freshwater species that prefer lacustrine habitats (e.g., largemouth bass, sunfish, shad, catfish, shiners, etc.). As discussed in Section 5.1 (LOEM), water quality in Lake Okeechobee was predicted to be minimally affected by ASR due to the dilution by lake water, wind, and circulation patterns. For example, using the location L001 (the middle of the northern end of the lake at the same latitude where Kissimmee River flows enter the lake), the LOEM predicted no changes in lake concentrations for nitrogen, phosphorus, water temperature, or dissolved oxygen from any ASR alternative. LOEM results did indicate a slight beneficial reduction in TSS from ASR.

However, sulfate and chloride concentrations appear increase with ASR, especially for alternatives that have the most wells discharging to the lake. For ALT2, the maximum sulfate and chloride concentrations doubled to 110 mg/L and nearly 200 mg/l, respectively. Maximum sulfate and chloride concentrations for ALT4increased slightly to approximately 62 mg/L and 120 mg/L. These increases (all alternatives) are well within the published tolerances of both the fishery and benthic invertebrate population within Lake Okeechobee. All concentrations returned to near baseline conditions for all alternatives shortly after ASR discharges cease. Therefore, the likelihood of ASR-influenced water quality changes (mercury methylation in the Lake is addressed in Hypothesis #8 above) adversely affecting aquatic life in Lake Okeechobee was characterized as low.

For water quality changes to be a concern within the lake, ASR facilities would need to discharge directly to the lake's littoral zone (which is extensive on the western side). The littoral zone is shallower, and therefore, does not mix as quickly as the near-shore or pelagic zones. It is also where the more valuable and diverse eco-receptors (birds, fish, invertebrates, and plants) occur. However, at this time, all ASR discharges to Lake Okeechobee are expected to enter canals, streams, or other water bodies, and as such would receive some dilution, prior to entering the Lake.

Section 5.1 discusses the beneficial effects of ASR discharge flows on Lake Okeechobee stage and SAV. While the tools are not available to extrapolate fishery benefits from improved SAV conditions, it is expected that increases in SAV acreage would benefit most if not all Lake biota.

5.3.3.9 Effect of Recovered Water on Other Potential ASR Sites in Lake Okeechobee Basin

16. What are the effects of recovered water on other potential Lake Okeechobee Basin ASR sites?

Based on the information describing each alternative in Section 5.1 (e.g., **Table 5.1**, **Figure 4.4**), there are nine other potential sites for which ASR could be implemented within the Lake Okeechobee Basin. These include Lake Okeechobee Reservoir (as yet not planned), Port Mayaca, C-40, C-41, Taylor Creek, L-63N Canal, Nubbin Slough, Lakeside Ranch Stormwater Treatment Area (STA), and two sites around Nicodemus Slough. The utilization and exact locations of ASR intakes and discharges at each site are only approximate. Assumptions were made regarding the source waters available for recharge and discharge locations. Each of these sites has different ecological conditions than the Kissimmee River and therefore, the risks to fisheries at those sites may also be different. There are also three potential locations in the Caloosahatchee River, but these were not part of the modeling exercise.

Lake Okeechobee Reservoir

The Lake Okeechobee Reservoir is conceptually positioned to occupy approximately 2,500 acres between the Kissimmee River and the C-40 Canal, and between the L-59 Canal and State Road 78. This reservoir would serve to augment water storage north of Lake Okeechobee and as such would support 25 ASR wells under ALT2, 20 wells under ALT3, and 15 wells under ALT4 and ALT4S-11. The fishery for this potential reservoir could be similar to that found in Lake Okeechobee or the Kissimmee River, but only if it does not dry out. Shallow reservoirs or STAs in Florida may dry out completely on a near annual basis, and therefore, the fishery is limited to species that can easily and quickly colonize ephemeral habitats (e.g., killifish, mosquitofish and some sunfish species). At this time, the source water for this feature is not clear. Therefore, it is difficult to characterize some of the ecological risks, but at a minimum, they should not be higher than those for the Kissimmee River site.

Port Mayaca

Port Mayaca is along the C-44 Canal approximately a mile downstream of Lake Okeechobee's S-308 structure. When water elevations in Lake Okeechobee are lower than 14.5 feet, and water in the C-44 Canal is higher, water will back-flow into the lake if the S-308 is open. If ASR discharges primarily when there is a water need, then the expectation is that S-308 would be open so that ASR discharges would flow into the lake. Port Mayaca was intended to be a pilot ASR site with a cluster of three ASR wells; however, it was never constructed. Water quality, benthic invertebrate, and fishery data were collected in 2004-2006. Water quality was similar to Lake Okeechobee water quality, when the S-308 structure was open. During the remainder of the year, water may become stagnant and dissolved oxygen levels may be low if the water is warm. From a benthic invertebrate perspective, it is similar to other regional canals in that it exhibits a pollution-tolerant assemblage more suited to low-velocity waters with muddy substrates.

The fishery community in the C-44 at Port Mayaca was sampled as part of the ASR baseline ecological monitoring done by the FWC in 2004-2006. This fishery was surprisingly diverse with 26 species including 5 exotic fish species and 6 species that are typically estuarine (needlefish, bigmouth sleeper, common snook, swordspine snook, striped mullet, and tarpon) (See **Section 3, Appendix B** for compiled results). Largemouth bass were less abundant than at Kissimmee, but adult black crappies were more abundant at Port Mayaca in fall 2004 and winter 2005 than at any time in the Kissimmee River samples. Total numbers of fish collected at Port Mayaca was less than at Kissimmee (with the exception of the fall 2004 sample). Total biomass was similar to or less at Port Mayaca with the exception of the summer 2004 sample where 16 snook comprised 30 percent of the total weight. Adult white catfish were abundant at Port Mayaca (similar to Kissimmee) in summer 2005 and spring 2006. The quality of the freshwater fishery at Port Mayaca may not be as abundant as or as diverse as at Kissimmee, but it is a significant resource that should not be ignored moving forward with ASR implementation. There are no larval fish data for C-44, but based on the numbers of adult black crappie and white catfish sampled, it is expected that those species spawn there.

Plume size should be developed based on channel morphology and the timing and volumes of discharges from Lake Okeechobee that would dilute ASR discharges at Port Mayaca. Note the simulation predicted that within each alternative, the ASR turns on and off at the same time across all locations. The discharge durations (and volumes) are different only between alternatives. ALT2 has 20 ASR wells at Port Mayaca. Their maximum discharge would be 9,205 ac-ft/month (154 cfs). Under ALT3 (10 wells), this volume would be half. ALT4 and ALT4S-11 both have 18 wells; however, ALT4-S11 has no recovery

Assuming a 70-meter wide channel at Port Mayaca (i.e., about half the width of Kissimmee), and only 20 wells (as opposed to 75 wells under ALT2 in Kissimmee), it seems that dilution of the discharge would be greater and that overall plume size may be smaller at Port Mayaca. The S-308 discharge (from Lake Okeechobee into C-44) from January 1 to June 1, 1981 averaged 222 cfs (max = 580 cfs, min = -106 cfs). For 80 percent of this time interval, the S-308 discharge was equal to or greater than the maximum ASR discharge (at least a 1:1 dilution rate). The negative and low flows (<20 cfs) at S-308 actually started at the end of December 1980 and continued for about 6 weeks. During this time, the water in the C-44 at Port Mayaca would be close to 100 percent ASR water; however, ALT2 was only discharging for 16 of those 41 days (39 percent of the time). ALT3 was not discharging, and ALT4 was discharging for 21 days (50 percent of the time). The duration of the 1981 event, which was more intense in the Kissimmee, does not seem to be as intense in Port Mayaca primarily due to higher dilution rates. A similar simulated event happened again in 2000 (May-July and Sept-Oct) where negative flows into Lake Okeechobee from the C-44 indicated that ASR would make up a large portion of that flow. However, once these plumes entered Lake Okeechobee, they would be greatly diluted by Lake water; therefore, any effects would be localized from the ASR outfall to the S-308 (~6,000 feet maximum). Effects to the fishery at Port Mayaca were either similar to those at Kissimmee or slightly lower due to fewer wells for ALT2, ATL3, and ALT4S-11. The likelihood of fish kill due to dissolved oxygen drops resulting in population-level effects for cold-water spawners was characterized as low, primarily due to a lack of spawning data at Port Mayaca. The actual effect may be greater; therefore, the uncertainty was characterized as higher than at Kissimmee.

Manatees have access to the C-44 Canal from both Lake Okeechobee and the Saint Lucie Estuary. There are few manatee observations from the C-44 near Port Mayaca (2005, mid 1990's). The systematic winter flights do cover the C-44 canal, but stop at the S-308 structure; however, manatees should not be in this area of the C-44 because water temperatures at this time are below 20 ^{o}C. Manatees may be there spring, summer, and fall and may be attracted to ASR plumes for thermal refugia. However, for the same reasons that the Kissimmee River site did not pose a threat to manatees, the Port Mayaca ASR would not be problematic. If additional discharge scenarios show that warm water could be discharged during November and December and shut off prior to March or April of the following year, then an effect would be anticipated.

C-40 and C-41 Canals

The C-40 and C-41 Canals (also known as the Indian Prairie Canal and Harney Pond Canal, respectively) flow into Lake Okeechobee on its western side. Water quality, benthic invertebrate, or fishery data for these canals is not available, but the expectation is they would exhibit generally poor ecological communities that are tolerant of low flows, low dissolved oxygen, and muddy substrates. Both canals receive surface flows from Lake Istokpoga and local runoff from surround agricultural lands.

Specific locations for ASR installation along these two canals are not available, but they should be closer to Lake Okeechobee to maximize the amount of surface water available for recharge. The C-40 is 100 ft wide at the Herbert Hoover Dike and C-41 is 160 ft wide. Under ALT2, both canals would have 10. Under ALT3, this number would be half, and for ALT4 and ALT4S-11 there would only be two wells in the Upper Floridan at C-40 (none at C-41). As with the Port Mayaca site, it seems likely that during droughts ASR could comprised a large percentage of flow in these canals (except for

ALT 4 and ALT4S-11). However, the aquatic resources of these canals is expected to be limited (therefore, lower ecological risk than at Port Mayaca or Kissimmee) and ASR flows would be greatly diluted after entering Lake Okeechobee. The collection of more complete biological and hydrological data for these two canals would be needed to confirm these predicted effects.

Taylor Creek

Taylor Creek used to flow directly into the north end of Lake Okeechobee. It is now partly diverted to the L-63 Canal and surface flows enter the lake from the northeast side. A 190-acre STA was built along the east side of Taylor Creek north of the City of Okeechobee and there are plans to build another water storage feature (2,000 to 3,000 acres) on the west side of the creek. It is not clear how ASR would operate at this facility – if it would pull water directly from the stream channel, the STA, or some future storage feature. However, the aquatic resources in Taylor Creek are limited due channelization and hydrologic extremes (flood in summer to sometimes dry in spring at the STA). Effects to the aquatic ecology of Taylor Creek (from 30 wells under ALT2, 15 under ALT3, or zero under ALT4 and ALT4S-11) are similar to those at C-40 (mostly characterized as low), with the exception of the risk of fish kill from loss of dissolved oxygen refugia (characterized as moderate). These conclusions should be re-evaluated before implementation of ASR at this site because it is not known how the aquatic resources of the STA, new storage feature, or stream may improve (due to restoration) in the future.

L-63N Canal

The L-63N Canal intercepts Taylor Creek flows and sends them around to the northeast side of Lake Okeechobee, but some flow may continue down to Lakeside Ranch STA and eventually to the C-44 Canal at Port Mayaca. There was one ASR well drilled near the SR 710 bridge by the SFWMD in 1989 but it was taken out of service for poor performance after some short-duration testing. Subsequent investigations of this well for ASR use occurred in 2008 and 2009. The L-63N Canal is of sufficient size (50 meters wide) to have an exotic and native fishery; however, specific data are not available. If implemented at this location, water would be pulled directly from the canal for recharge, and then discharged directly back to the canal, but would need to flow 7,400 meters before entering Lake Okeechobee. Ecological effects from ASR at this site would be similar to those for Taylor Creek or Nubbin Slough.

Nubbin Slough

Nubbin Slough is a small, flashy channelized stream that flows into Lake Okeechobee on the northeast side. It is similar in aquatic resources as Taylor Creek, but has a smaller drainage basin. There is a 900-acre STA to the east of the channel along SR 710, but it is not yet operational. ASR would most likely operate to keep the STA hydrated assuming it could recharge sufficient water quantities during the wet season. As with the Lake Okeechobee Reservoir, the fishery in the STA would be dictated, and probably limited by, the hydrology. Within the Nubbin Slough channel proper, the effect to aquatic life from ALT2 and ALT3 would be similar to that for Taylor Creek and L-63. There are no ASR wells planned for ALT4 or ALT4S-11 in Nubbin Slough.

Lakeside Ranch STA

Lakeside Ranch STA is approximately 1,000 acres and was operational in 2013. There is a contiguous ~1,000-acre STA component yet to be constructed. The STA pulls water from the L-63N Canal, treats it, and discharges to Lake Okeechobee. Again, ASR would likely operate to keep the STA hydrated. ALT 2 has 20 wells, ALT 3 has 10 wells, and ALT4 has 4 wells in the UFA at Lakeside Ranch. ALT4S-11 has 4 recharge wells, but no recovery. The aquatic ecological effect should be similar to that at the Taylor Creek, Nubbin Slough, and North of Lake Okeechobee ASR sites.

Nicodemus Slough

Nicodemus Slough is listed as a component of the C-41 ASR feature in **Table 5.4**. However, it is not hydraulically connected to the C-41. It is a small stream that flows into the western side of Lake Okeechobee south of Fisheating Creek. Its drainage basin is about 15,000 acres and is mostly a mix of pasture with herbaceous and forested wetlands. In 2013, a project was permitted to store water over much of the basin in order to reestablish a more natural sheet flow of water across the site, thereby enhancing and restoring wetlands. During high water events, surface water would be pumped from Lake Okeechobee to the western end of the Nicodemus project site. The sheet flow by gravity will allow water to stage behind a series of three low-head berms to allow for the natural treatment processes. If needed, water can also be discharged back to Lake Okeechobee and other regional wetlands through a series of existing canals. The project has the potential to store 30,300 ac-ft of water from Lake Okeechobee. ASR may operate in conjunction with this project for restoration and may pull recharge water from the LD-3 (north side), or L-306 (south side) Canals. Since both these canals are directly connected to Lake Okeechobee, the ecological communities in these canals likely mirror those in the lake. Therefore, the potential effect from entrainment and impingement at this site could be higher than at other canal locations (upstream from Lake Okeechobee). Impingement and entrainment effects could be similar to those at the Kissimmee River site (if water is pulled from Lake Okeechobee). If ASR discharges occur to the upstream end of Nicodemus Slough, then potential negative effects to aquatic biota would likely be ameliorated by the time the discharge reached Lake Okeechobee. Potential effects should be re-evaluated, including for the slough itself, as both ASR and Nicodemus Slough restoration plans are formalized or implemented, respectively.

6.0 RISK CHARACTERIZATION

Risk Characterization is the final phase of the ERA and it summarizes the predicted adverse ecological effects of regional ASR implementation as related to the assessment endpoints selected (**Figure 5.2**). In this section we have summarized the relationships between the stressors, effects, and ecological entities (receptors, ecosystems) in order to reach conclusions regarding the occurrence of exposure and the adversity of predicted effects. This information is presented by region, and as applicable by scenario.

Model simulation outputs for the Lake Okeechobee Basin were the basis for estimating the exposures to the near-field, mid-field, far-field, and far-far field receiving water bodies for the ASR scenarios evaluated in this ERA. For clarity, the CERP ASR implementation scenarios are summarized below (Section 4.4.7.1):

- **Alternative 1:** No ASR
- **Alternative 2:** 200 wells (matches D13R)
- **Alternative 3:** 100 wells (1/2 of D13R)
- **Alternative 4:** 200 wells (48 FAS, 32 APPZ and 120 BZ wells)
- **Alternative 4-S11:** 200 wells (48 FAS, 32 APPZ and 120 BZ wells, and reduced recovery)

A map of the well locations is shown in **Figure 5.12** and the geographical distribution of the wells is described in **Tables 4.5, 4.6, and 4.7**.

6.1 Risk and Benefits of ASR Recovered Water Discharges on Receiving Water Quality

The effect of ASR recovered water discharges on receiving water quality was evaluated using the water quality and toxicity data collected at the KRASR and HASR facilities. The initial water quality risks considered in this ERA included the possibility of non-compliance with surface water quality standards as well as significant changes to surface water concentrations of arsenic, gross-alpha (radium), sulfate, and total phosphorus. Changes in water clarity, water hardness and the potential of acutely or chronically toxic discharges were also evaluated.

6.1.1 Near-Field Water Quality Risks (Single ASR discharge)

The near-field receiving water body is defined as the waters within the probable mixing zone of a single ASR well discharge. The following discussion is based on data primarily from the KRASR. The maximum horizontal dimension of the mixing zone for wells on the Kissimmee River was determined to be 30 to 50 meters based upon plume modeling, temperature, and specific conductivity field data collected during ASR discharge. Sites with more than one ASR well would have larger mixing zones, though the maximum mixing zone dimension allowable by the State of Florida law is 800 meters. The risk profile for the near-field receiving water body is considered to be the same for all of the ASR implementation alternatives, though the maximum dimensions of the mixing zones for these alternatives are different.

Water quality and toxicity data collected at KRASR and HASR sites indicate that arsenic, gross-alpha, and chronic toxicity are the most likely water quality effects that could be observed within the recovered water discharge mixing zone (Section 4, Appendix A).

Arsenic. At the KASR site, measured arsenic concentrations exceeded the Class I and Class III water quality standards of 10 and 50 ppb during the initial discharges from Cycles 1 and 2. Arsenic measured in the recovered water from Cycles 3 and 4 showed much reduced arsenic concentrations that were at or below the Class I standard of 10 ppb. These arsenic water quality exceedances did not pose an acute risk to the near field aquatic species. No acute toxicity was observed for the recovered water during Cycles 1 and 2, and this observation was based on 19 acute toxicity tests that included survival as an endpoint. The species tested included sensitive green algae, waterfleas (*Ceriodaphnia* and *Daphnia*), early life stages of two fish species (*Pimephales* and *Cyprinella*), and frog embryos.

Bioconcentration tests during these two cycles showed that the arsenic being discharged was bioavailable and it accumulated in the tissues of the freshwater mussels exposed in the laboratory (Cycle 1, 100 percent recovered water) and in cages in front of the discharge (Cycle 2). The mussels collected from the Kissimmee River during Cycle 4 at KRASR seem to indicate an increase in arsenic is possible, though not enough samples were collected to statistically verify this observation. The laboratory tests showed that when the recovered water was diluted to 50 percent, arsenic bioconcentration did not occur.

The current theory for ASR systems utilizing moderately treated surface water is that arsenic is released by pyrite oxidation during recharge and is sequestered during storage and recovery by co-precipitation with iron sulfide. Testing evidence from the HASR and KRASR sites indicates that arsenic concentrations decrease for successive recharge/recovery cycles (Mirecki, 2012). Multi-year water quality datasets at other ASR facilities in Florida show continued declining arsenic in recovered water for successive ASR cycles (CH2MHill, 2007). Based on the arsenic data from KRASR and HASR, and evidence at other ASR facilities in Florida, there is a **moderate** risk that arsenic in recovered water will exceed state water quality standards during the initial recovery events, but after three to four cycle events, there appears to be **low** risk that recovered water arsenic concentrations for CERP ASR facilities would exceed state surface WQ standards.

The levels of arsenic discharged present a **minimal** risk of acute toxicity to aquatic species in the near-field receiving waters; but the initial cycles do present a **moderate** risk for arsenic bioaccumulation in biota in the near-field due initial higher concentrations. During cycle 1 it was shown that a 50 percent dilution of the recovered water was sufficient to preclude statistically significant arsenic bioconcentration from the recovered water. If as expected, subsequent cycles at future ASR installations show low arsenic concentrations, then the risk to the aquatic environment will be **low**.

<u>Gross-alpha</u>. Gross-alpha measurements at KRASR showed an exceedance of the Class III standard of 15 picocuries/L with a single measurement of 18 picocuries/L (Cycle 3 at KRASR), though the average concentration was below 7 picocuries/L. Since no other exceedance of the gross alpha standard was observed at KRASR or

HASR, the risk of exceeding the surface water standard for this parameter in the near-field is considered to be **moderate**. Bioconcentration studies using mussels were conducted during cycles 1 and 2, and they did not show any bioconcentration of radium gross-alpha in the mussel tissues. The risk of radium bioconcentrating from ASR recovered water discharges in aquatic biota is considered **minimal**.

Sulfate. For the Kissimmee River, the risk that elevated sulfate loading originating from the ASRs will increase in the near-field zone is **high** for all of the alternatives. It is plausible that the increased concentration of sulfate in the near-field zone during ASR recovery events could alter the dynamics of mercury methylation and potentially bioaccumulation. Given the complexity of the mercury cycle in the environment, it is difficult to conclude with any certainty the risk that additional sulfate could present on mercury methylation and subsequent bioaccumulation of mercury by aquatic biota in the near-field zone. However, for near-field discharges into the Lower Kissimmee River, the risk that ASR sulfate would adversely impact mercury methylation dynamics is estimated to be low given the physical and chemical similarities of this water body with Lake Okeechobee which was determined to present a **low** risk.

Phosphorus. The risk that relatively low concentrations of phosphorus in recovered ASR water would have a beneficial or detrimental impact on water quality or ecology in the near-field zone is **minimal** given the intermittent (less than 1/3rd of the time) and relatively short-term nature of ASR discharge events.

Water Hardness. The water hardness in the Kissimmee River averages around 60 mg/L as $CaCO_3$. The hardness in the KRASR recovered water averaged around 200 mg/L. Within the near-field zone, the ASR discharges will increase hardness significantly. Toxicity studies were conducted with two species of waterfleas, *C. dubia* and *D. magna*. *D. magna* is tolerant of hard waters, and *C. dubia* is less tolerant. The chronic test with *D. magna* showed no acute or chronic effect of recovered waters up to full strength recovered water. Seventeen out of 18 acute tests with *C. dubia* showed no effect up to full strength recovered water. The only test showing an effect was at 83.9

percent recovered water. Based on these data, there is a **low** risk of acute toxic effects on aquatic biota due to increased water hardness in canals such as the Kissimmee River.

Periphyton exposures conducted during cycles 1 and 2 in the vicinity of the discharge did not show statistically significant differences in community composition as compared to exposures outside the mixing zone. Periphyton communities are good indicators of water quality changes. Based on the exposures conducted, water hardness increases in the near field show a **low** risk to sensitive communities in the mixing zones. Water hardness is also expected to dilute in the receiving waters beyond the mixing zone, therefore the long-term risks of recovered water with higher hardness discharged into canals are expected to be **low**.

<u>Water Quality Chronic Effects.</u> As stated in Section 5.3.1.1, there appears to be a change in recovered water quality that occurs late in the cycles that results in a minor, but statistically significant, reduction in reproduction of *C. dubia*. This is a very sensitive test species and fecundity is also a sensitive endpoint. The tests that showed an effect on reproduction at full strength recovered water, also showed that a dilution less than or equal to 50 percent recovered water did not elicit this effect on reproduction. The only exception was the May 2011 test (during cycle 3), that showed an IC_{25} of 7.2 percent recovered water; meaning that reproduction was inhibited by 25 percent at 7.2 percent recovered water. The same set of May samples showed the only acute effect observed on *C. dubia*. Subsequent samples taken in June 2011did not replicate this chronic effect.

Six out of 16 tests showed a reduction in reproduction of *C. dubia* during the later periods of cycling, therefore this observation is credible. The source of the chronic toxicity is not known with certainty; it is possible that it could be related to elevated sulfide concentrations that occur during the later portion of a recovery event. Five out of the 6 tests showed that this effect on reproduction was no longer observed at 50 percent dilution. The risk of chronic toxicity in the receiving water is expected to be **moderate,** of short duration and localized to the vicinity of the discharge.

Color and Turbidity. Recovered ASR water has lower color and turbidity levels than the receiving waters and that quality may be beneficial to aquatic flora and fauna by improving light transmittance and water clarity. For the near-field zones modeled in the Kissimmee River, the potential for **improved water clarity is assumed to be high** but only for the duration of ASR discharges.

Table 6.1 summarizes the risks and benefits to the near-field environment from discharges from single ASRs.

Table 6.1 Risks and benefits to the near-field water quality from recovered water discharges from single ASRs

Risks to Near-field Water Quality (Mixing Zone – Single ASR Discharge)		
Consequence	**ALT2, ALT3, ALT4, ALT4-S11**	**Uncertainty**
Risk of Violating Class I Water Quality Standard for arsenic	Moderate to low	Moderate
Risk of acute toxicity – Arsenic Risk of bioconcentration – Arsenic	Minimal Moderate	Low Low
Risk of Violating Class I/III Water Quality Standards for gross alpha	Moderate	Low
Risk of bioconcentration – Gross-alpha	Minimal	moderate
Risk of Violating other Class I/III Water Quality Standards	Low	Low
Risk of beneficial or detrimental impact to surface water quality due to reduced phosphorus concentrations	Low	Low
Risk of ASR sulfate loads and concentrations adversely impacting mercury methylation / bioaccumulation	Low	Low
Risk of Acute Toxicity	Minimal	Low
Risk of Chronic Toxicity	Moderate	Low
Benefit to Near field Water Quality		
Water Clarity	High	Low

6.1.2 Mid-Field Water Quality Effects (Multiple ASRs in the Lower Kissimmee River)

The mid-field receiving water body is defined in this ERA as the waters immediately downstream of the ASR discharge mixing zone. The primary mid-field receiving water body evaluated in this ERA was the Kissimmee River, though the water quality risks presented here are generally applicable to other receiving water bodies immediately downstream of an ASR discharge site mixing zone. This discussion includes all the multiple ASR scenarios modeled. The mid-field risks are summarized in **Table 6.2**.

Water Quality Parameters. For the mid-field zone, the risk of violating water quality standards for arsenic, gross-alpha, and other Class I/III parameters was considered to be higher for the alternatives with greater recovered flow (ALT2 and ALT3) for the Kissimmee River since the mixing zones for these alternatives may include a significant portion of the total volume and area of the lower Kissimmee River Basin during low flow periods at the S-65E structure. With multiple ASR discharges in close proximity, the recovered water will not dilute as quickly as in the single ASR evaluation; however, after several cycles, the concentration of arsenic in the recovered water would decrease and this risk would be low.

Acute and Chronic Toxicity. The risk of observing acute toxicity in the receiving water mid-field is characterized as **minimal**, since this risk was minimal at the point of discharge. The risk of observing chronic toxicity in the mid-field is considered **moderate to low** since at times the complete receiving water canal may be comprised primarily by ASR recovered waters under some of the scenarios evaluated.

Sulfate. The risk in the Kissimmee River that elevated sulfate loading originating from the ASRs will increase in the mid-field zone is **high** for those alternatives such as ALT2 and ALT3 that discharge large quantities of ASR flow into the Kissimmee River. It is plausible for ALT2 and ALT3 that the increased concentration of sulfate in the mid-field zone during ASR recovery events could alter the dynamics of mercury methylation in the river. The risk is low for ALT4 and ALT4S-11, due to lower recovery volumes.

Given the complexity of the mercury cycle in the environment, it is difficult to conclude with any certainty the risk that additional sulfate could present on mercury methylation and subsequent bioaccumulation of mercury by aquatic biota in the mid-field zone.

Given that Pool E shares many of the same physical and chemical attributes of Lake Okeechobee, the impact of ASR related sulfate on mercury methylation in this portion of the lower Kissimmee River would likely be similar to that predicted for Lake Okeechobee. For Lake Okeechobee ASR sulfate is not expected to impact mercury methylation dynamics.

Water Hardness. Based on recovered water having about three times the concentration of hardness (200 mg/L) as the receiving water (60 mg/L), the risk of increased hardness in the mid-field is estimated to be **high** for ALT2 and ALT3, **moderate** for ALT4, and **low** for ALT4-S11 based on the relative volume of recovered ASR water for each of these alternatives. All water quality impacts in the mid-field zone associated with ASR are coincident with recovery events and are unlikely to persist after recovery ceases. Discharges of greater concentrations of hardness from deeper ASR wells completed in the APPZ is likely to be limited by the need to cease ASR recovery once on-site continuous measurement of specific conductivity exceeds 1,275 uS/cm.

Color and Turbidity. For the mid-field zones in the Kissimmee River, the potential for improved water clarity is assumed to be **high** for ALT2 and **moderate** for ALT3. Increased water clarity carries with it the risk of triggering cyanobacterial blooms; particularly under the nutrient enriched conditions of the receiving waters and especially if the zone of clarity extends beyond the edge of the near shore zone that is typically colonized by SAV. ALT4 and ALT4-S11 are not likely to show improved water clarity (over the background receiving waters) because of significantly less ASR recovered flows in these scenarios.

Table 6.2 Risks and benefits to the mid-field water quality from recovered water discharges from multiple ASRs in the Lower Kissimmee River

Risk to Mid-Field Water Quality (Multiple ASRs in the Lower Kissimmee River)					
Consequence	**ALT2**	**ALT3**	**ALT4**	**ALT4S-11**	**Uncertainty**
Risk of Violating Class I Water Quality Standard for arsenic	Moderate	Moderate	Low	Low	Low
Risk of Violating Class I/III Water Quality Standards for gross alpha	Moderate	Moderate	Low	Low	Low
Risk of Violating other Class I/III Water Quality Standards	Moderate	Moderate	Low	Low	Low
Risk that Sulfate load and concentration adversely impact mercury methylation	High	High	Low	Low	Moderate
Risk of ecologically significant increased hardness load	High	Moderate	Low	Low	Low
Risk of Acute Toxicity	Minimal	Minimal	Minimal	Minimal	Low
Risk of Chronic Toxicity	Moderate	Moderate	Low	Low	Low
Benefit to Mid-field Water Quality					
Potential for Increased Water Clarity (reduced color and turbidity)	High	Moderate	Low	Low	Low

6.1.3 Far-Field Water Quality Effects (Lake Okeechobee)

The far-field receiving water body is defined in this ERA as the waters immediately downstream of the mid-field receiving water body. The transition between the mid-field and far-field water bodies is located where additional mixing and dilution occurs as a result of other water flows or available storage. The only far-field receiving water body evaluated in this ERA is Lake Okeechobee. The most important predicted water quality changes for Lake Okeechobee were:

- The potential for reduced total phosphorus loading;
- The potential for improved water clarity;
- The discharge of ASR-related sulfate; and
- Ecologically-significant increase in Lake water hardness.

Table 6.3 summarizes the risks and benefits to Lake Okeechobee water quality from ASR recovered water discharges.

Total Phosphorus. A mass balance assessment and the results from the LOEM model were evaluated to assess these potential water quality changes. The storage and discharge of ASR flows within the Lake Okeechobee basin will reduce total phosphorus loading to the Lake by an average of 30 mTons/yr for ALT2, ALT4, and ALT4-S11. ALT3 would provide a reduction of an average of 19 mTons/yr of total phosphorus. The reduction in lake phosphorus load due to ASR operations is an important **benefit** of CERP ASR in this basin given it represents 7 to 10 percent of the current annual Lake phosphorus load and as such, assists potential attainment of the annual TMDL load for the Lake of 130 mTons/yr.

Color and Turbidity. Discharge of ASR recovered water into Lake Okeechobee has a **low** probability of significantly improving water clarity regardless of ASR alternative due to mixing with a much larger volume of Lake water and because turbidity caused by wind and wave tends to control water clarity within the Lake.

Sulfate. Simulation results indicate that mean Lake sulfate concentrations will increase from the long-term background of 30 mg/L to 50 mg/L, 34 mg/L, and 31 mg/L, for scenarios ALT2C, ALT2V, and ALT4V, respectively. Based on the ALT4V results which show minimal changes, no change in the long-term average sulfate concentration would be expected from ALT4-S11 given its reduced recovered water volume discharged to the Lake. The additional sulfate loading for any of these alternatives is expected to have **minimal** impacts on MeHg production in Lake Okeechobee if the relationship between sulfate and MeHg is similar to that observed in the WCAs and ENP. Factors that reduce the risk of increasing methylation in the lake include: non-organic lake sediments, elevated sulfate concentrations above methylation inhibition concentrations, minimal evidence of microbial sulfate reduction, and absence of thermal stratification in the lake.

Water Hardness. Lake Okeechobee water hardness would be impacted by several of the ASR implementation alternatives. Lake hardness is normally in the 110 to 140 mg/L as $CaCO_3$ range with a standard deviation of 25 mg/L. Using the simplified mass balance approach, the extended ASR recovery event in 1982, would increase hardness load by 70 percent for ALT2, 35 percent for ALT3 and ALT4, and 15 percent for ALT4-S11. If the increase in load is conservatively equated as an equivalent increase in concentration, ALT2 would result in a maximum hardness concentration of more than 200 mg/L as $CaCO_3$ while ALT3/ALT4 would result in a maximum concentration around 160 mg/L as $CaCO_3$. Based on the LOEM simulation results for chloride and sulfate, it is likely that increased lake hardness associated with ASR would be temporary and hardness concentrations would revert to baseline conditions within 6 to 12 months of the end of a recovery event. With reduced ASR discharges, the risk of adverse ecological impacts from ALT4-S11 related hardness is considered to be low though there is a moderate level of uncertainty with this estimate.

Table 6.3 Risks and benefits to the far-field water quality from recovered water discharges into Lake Okeechobee

Risk to Far-Field Water Quality (Lake Okeechobee)					
Consequence	**ALT2**	**ALT3**	**ALT4**	**ALT4S-11**	**Uncertainty**
Risk of increasing Lake Sulfate Concentrations	High	Moderate	Low	Minimal	Moderate
Risk that increased Lake sulfate concentrations result in increased mercury methylation	Low	Low	Low	Lowest	Moderate
Risk of ecologically significant increased hardness load	High	Moderate	Moderate	Low	Moderate
Benefits to Far-Field Water Quality (Lake Okeechobee)					
Potential for Decreased Total Phosphorus Loading	Moderate	Low	Moderate	Moderate	Moderate
Potential for Increased Water Clarity (reduced color and turbidity)	Low	Low	Low	Minimal	Low

6.1.4 Far Far-Field Water Quality Effects (Greater Everglades)

The far far-field receiving water body is defined in this ERA as the waters immediately downstream of the Lake Okeechobee. The transition between the far-field and far far-field water bodies is located where additional mixing and dilution occurs as a result of other water flows or available storage. The only far far-field receiving water body evaluated in this ERA is the Greater Everglades.

The most important risks to water quality for the Greater Everglades are the increase in sulfate load attributed to ASR discharges and the risk of significant increases in water hardness.

Sulfate. Proportionately, the potential increase in sulfate load from ASR operations to the Greater Everglades is less than that predicted for Lake Okeechobee because the Lake provides only 1/3rd of the sulfate load to the Greater Everglades with the balance of the sulfate load coming from agricultural operations in the Everglades Agricultural Area and from atmospheric deposition. The impact of ASR related sulfate discharges into the Greater Everglades is primarily expected to be a change in the locations where water column sulfate is within the "goldilocks" concentration range that optimizes mercury methylation chemistry.

On behalf of the study team, the University of Florida and USGS undertook a study of the potential effects of ASR related sulfate on the Greater Everglades (Fitz, 2013, Orem et al., 2014). These efforts concluded that although ASR sulfate loading is not predicted to be a dominant source of sulfate to the EPA overall and does not appear to significantly alter the total area of the EPA impacted, it may have ecosystem effects locally. For example, localized ASR sulfate loading near discharge points during certain time periods could produce critical tipping points with regard to stimulation/inhibition of MeHg production (Orem et al., 2011). The ELM-Sulfate model shows that ASR water entering the EPA does increase overall sulfate loading, but only during certain time periods and primarily in areas directly adjacent to STA or canal discharge. When normalized to the baseline sulfate scenario, the impacts of ASR sulfate are minimal. This is primarily due to the dominance of EAA discharge with regard to sulfate loading to the ecosystem, and to dilution effects on the ASR discharge to the extensive EPA marshes. ALT2C was determined to have the biggest impact on sulfate loading to the EPA. Evaluation of long-term averages and short term "ASR stress periods" indicate that although sulfate loading from ALT2C was small compared to other sources, this scenario should be considered with caution, regarding the potential to increase sulfate concentrations within important localized regions of the marshes of WCA 3A. Western WCA (L28 discharge), northeastern WCA 3A (STA 3/4 discharge), and northwestern WCA 3A, which were most impacted by ASR sulfate loading in the ELM-Sulfate model output. ALT2C, however, is not necessarily the most realistic ASR scenario, and the assumptions used to derive ALT2C sulfate boundary conditions were very conservative (possibly higher than would occur under real world conditions). The more realistic ASR alternatives (ALT2V, ALT4V), which include varying sulfate concentrations, exhibited some increases in sulfate loading relative to the baseline, but these were very limited in magnitude and extent.

Overall, the areas of changed MeHg risk attributable to the ASR operations are predicted to be minimal, and are located near major canal water release points in western WCA3, north-central WCA2, and northern Shark River Slough. Because the relationship between sulfate and MeHg production is nonlinear and hump shaped, the model generally predicts both regions of net increases and net decreases in MeHg risk in near proximity to each other. That is not to say, however, that sulfate releases from ASR or other canal water sources are not important, because in the absence of sustained sulfate loading to this ecosystem, MeHg levels in the EPA would be substantially reduced - once internal recycling of sediment sulfate pools subsided. Given the ELM-Sulfate modeling output, the risk of ASR sulfate related methylation effects is characterized as moderate for ALT2 and ALT3 while the risk for ALT4 and ALT4-S11 are characterized as low due to the reduced ASR flows for these alternatives.

Water Hardness. Given that the Greater Everglades was historically a soft water system, the discharge of hard water into this region could result in risk to aquatic plant communities. Loxahatchee National Wildlife Refuge (WCA-1) is considered to be a soft water system so intermittent discharges of ASR related hardness would present a moderate risk to aquatic plant communities particularly for ALT2 and ALT3. Interior portions of WCA-2, WCA-3, and ENP are still considered to be soft water systems during average hydrologic conditions though during droughts the surface water tends to become more mineralized. Current discharges of hard water from the EAA likely affects the aquatic plants in these areas particularly near canals. ASR related hardness would result in additional affects; however, given the intermittent nature of the ASR flows and the fact that hardness concentrations would remain within the present range of EAA hardness concentrations measured at the inflow to STA3/4 (360 mg/L ± 70 mg/L), the increase in risk is estimated to be low particularly for ALT4 and ALT4-S11.

Table 6.4 Risks and benefits to the far far-field water quality from recovered water discharges on the Greater Everglades

Risk to Far-Far Field Water Quality (Greater Everglades)					
Consequence	**ALT2**	**ALT3**	**ALT4**	**ALT4S-11**	**Uncertainty**
Risk that Sulfate load and concentration increase	Moderate	Moderate	Low	Minimal	Moderate
Risk of Increased Mercury Methylation	Low	Low	Low	Minimal	Moderate
Risk of ecologically significant increased hardness load	Moderate	Moderate	Low	Low	Moderate

6.2 Risks and Benefits of ASR Recovered Water Discharges to Aquatic Species and Communities

6.2.1 Algal Communities and Submerged Aquatic Vegetation in Lake Okeechobee

In-situ periphytometers were used at KRASR to measure the effects of recovered water on periphyton communities. Because there was only limited data available, among site comparisons could not be made for each operating phase, but when the data were pooled, there were no statistically significant separation (differences) in the community structure (as abundances) among the three types of sites (upstream, ASR and downstream). While the periphyton may not reflect what would occur in the phytoplankton community, if the ASR recovery water may have had an influence over the periphyton taxonomic community composition, it should have been evident in the community composition relative to that at the Upstream and Downstream sites. While the data were not robust enough to make among sites comparisons for each period, there was no indication at any of the grouped sites over both recovery periods compared to the baseline data that a shift to toxin-producing cyanobacteria-dominated phytoplankton communities might occur due to ASR well water releases, at least as evidenced in the periphyton data. Given the low nutrient concentrations in the ASR well water, the risk of a shift to cyanobacteria-dominated phytoplankton communities is low. In the near shore region of the Lake Okeechobee, both the phytoplankton and periphyton communities have been dominated by diatom taxa since fall 2003 (phytoplankton) and summer 2002 (periphyton), so at least some overlap in community structure between the phytoplankton and periphyton communities has been documented, at least through fall 2012.

The LOEM model was used to predict the potential for changes to Lake Okeechobee SAV biomass and coverage which are shown in Table 6.5. These LOEM predictions are largely based upon ASR related changes to lake stage conditions. While ASR discharges might increase water column transmissivity, this typically translates into increased photosynthesis and does not necessarily translate into more SAV. Increased cyanobacterial blooms, or an expansion of emergent aquatic vegetation are also likely outcomes depending on the precursor community, duration of clear conditions, nutrient levels, etc.

Table 6.5. Effect of ASR implementation on algal communities and submerged aquatic vegetation in Lake Okeechobee

Effect on Algal Communities and SAV in Lake Okeechobee					
Effect	**ALT2**	**ALT3**	**ALT4**	**ALT4S-11**	**Uncertainty**
Shift in Algal Communities	Low	Low	Low	Minimal	High
Increase in SAV Biomass	Low	Not Simulated	Low	Minimal	Moderate
Increase in SAV Coverage	Moderate	Not Simulated	Moderate	Low	Moderate

6.2.2 Kissimmee River and Lake Okeechobee

Table 6.6 summarizes the potential risks and benefits to aquatic biota from ASR implementation in the Lake Okeechobee Basin. This information is presented by assessment endpoint and attributes; the detailed basis for this table was presented in Section 5.3.

Table 6.6. Potential risks and benefits to aquatic biota from ASR implementation in the Lake Okeechobee Basin

Kissimmee River and Lake Okeechobee						
Consequence/Benefit	**ALT2**	**ALT3**	**ALT4**	**ALT4S-11**	**Uncertainty**	**Actions to be considered in order to reduce risks to receptors**
Risk of fishery being affected by inadequate aeration of ASR discharge	Minimal	Minimal	Minimal	Minimal	Low	
Risk of fishery being affected by inadequate de-gassing (H_2S, NH_3) of ASR discharge	Low	Low	Low	Low	Low	Design Cascade aerators to degas sulfide as well as re-oxygenate recovery flows
Risk of chronic or acute toxicity to fishery or aquatic life from ASR discharges (except for mercury)	Low	Low	Low	Low	Low	
Risk of ASR discharge plume size covering entire river width during low river flows (30 cfs)	High	High	High	Low	Moderate	Use Better plume measurements over varying conditions and modeling of longer-term discharge events prior to siting new ASR facilities
Risk of ASR discharge plume length exceeding 800 meters during low river flows (30 cfs)	High	High	Moderate	Low	Moderate	Use real time plume data to moderate discharge flows when approaching 800 meter limit.
Risk of sub-lethal adverse effects from increased alkalinity and hardness	Low	Low	Low	Low	Low	
Risk of effects from increased alkalinity and hardness	Moderate	Moderate	Low	Low	Low	
Risk of any fish kill from loss of dissolved oxygen refugia (gamefish, minnows)	High	Moderate	Low	Low	Low	Could use operations control to reduce abrupt termination of

						recovery flow.
Risk of any fish kill from loss of dissolved oxygen refugia (bowfin, gar)	Low	Low	Low	Low	Moderate	Could use operations control to reduce abrupt termination of recovery flow.
Risk (>15% of years) with a predicted fish kill from loss of dissolved oxygen refugia (gamefish, minnows)	Low	Low	Low	Low	Moderate	
Risk to fishery via water temperature modifying timing of fish spawning at least once (cold water spawners)*	High	Moderate	Low	Low	Moderate	
Risk to fishery via water temperature modifying timing of fish spawning (moderate temperature water spawners)**	Low	Low	Low	Low	Moderate	
Risk to fishery via water temperature modifying timing of fish spawning (warm water spawners)***	Low	Low	Low	Low	Low	
Risk that temperature modification of spawning will have measurable effects (cold water spawners)*	Moderate	Moderate	Low	Low	Moderate	
Risk that temperature modification of spawning will have measurable effects (brook silverside or other annual species)	Moderate	Moderate	Low	Low	Moderate	Determine the rate of migration of silversides into the river
Risk of larval fish impingement or entrainment during ASR recharge (non-catfish species)	High	Moderate	High	High	Moderate	
Risk of larval fish impingement or entrainment during ASR recharge (catfish species)	Low	Low	Low	Low	Low	
Risk that larval fish impingement or entrainment will affect fishery (non-catfish species)	Moderate	Moderate	Moderate	Moderate	High	Further refine design of intakes and operation schedules to minimize I&E impacts during recharge
Risk of adverse effects to	Low	Low	Low	Low	Low	

fish or aquatic life from sedimentation from ASR discharges						
Risk of adverse effects to fish or aquatic life from color or turbidity from ASR discharges	Low	Low	Low	Low	Low	
Risk of adverse effects from ASR discharges on manatees from loss of temperature refugia	Minimal	Minimal	Minimal	Minimal	Low	Could use operations control to reduce abrupt termination of recovery flow.
Risk of adverse effects from ASR discharges on benthic invertebrates	Low	Low	Low	Low	Low	
Risk of not detecting future ASR effects due to poor benthic community	Moderate	Moderate	Moderate	Moderate	Low	
Risk of invertebrate impingement or entrainment during ASR recharge	High	High	High	High	Low	
Risk of invertebrate impingement or entrainment resulting in measurable biological effect	Moderate	Low	Moderate	Moderate	High	
Risk of adverse effects of ASR discharges on Lake Okeechobee Fishery and invertebrate community	Low	Low	Low	Low	Moderate	
* Species includes black crappie, redear sunfish, redfin and chain pickerels, brook silverside, and pirate perch ** Species includes redbreast sunfish, threadfin and gizzard shads, swamp darter, pygmy sunfishes, and chain pickerel *** Species includes bluegills, bluespotted sunfish, catfish (all 5 species), killifish, and taillight and golden shiners						

7.0 CONCLUSIONS

This ERA was undertaken to answer as definitively as possible the original preliminary hypothesis as stated in the ASRRS PMP:

> "If water quality characteristics of the recovered water affect surface water quality at the Pilot ASR projects, in the near field environment, and the Everglades, there is a potential for various effects on flora and fauna in these receiving waters."

The study team has identified these risks and proposed several methods to reduce the risks. Readers of this document should keep in mind that ASR operations will be intermittent, therefore, potential for adverse effects and associated risk to the environmental is reduced. These risks can be reduced through additional investigation and incremental implementation of ASR technology.

Numerous lines of evidence were used to develop the risk descriptions presented in Section 6.0. These lines of evidence included field data, laboratory studies, field observational studies, and surface water models for CERP ASRs. The quality of the recovered water data, environmental toxicological studies, and field data were very adequate for this risk assessment since it was developed from two CERP ASRs and included a large number of measurements and studies. As stated previously, this ERA includes the largest environmental toxicological database ever generated for ASRs (more than 80 separate studies over two full cycles at KRASR). The exposure and fate models used were complex and site-specific for the Lake Okeechobee Basin. The biological life history information used was based on recent data collected in the aquatic environments being assessed. The methylmercury assessment model was based on the most recent geochemical and modeling information available. Sufficient information was developed and was available to address the risk assessment questions developed as part of Problem Formulation. The field tests and ecotoxicological studies were designed specifically to address the questions posed by this ERA. Toxicity tests and bioconcentration studies were replicated several times over the cycling periods of the ASRs, allowing for the evaluation of natural variability and water quality changes over the multiple cycles at the ASRs. Sufficient data were developed to support robust stressor-effect relationships. The lines of evidence developed related directly to the risk hypotheses being addressed and established clear cause and effect relationships. In Section 5 the data and model outputs generated were examined and evaluated independently and regionally in order to describe the potential effect and subsequent risk. In the case of potential for bioaccumulation of metals, the data generated in the mobile laboratory was supported by the field-generated data. The model outputs were used to evaluate ASR related changes in the concentrations of ecologically significant water quality constituents such as phosphorus, chloride, sulfate, and hardness in Lake Okeechobee and the Greater Everglades. This base of knowledge helped reduce the uncertainties associated with this ERA.

The following discussion presents the conclusions by assessment endpoint.

7.1 Similar or Improved Water Quality

As summarized in Table 6.1, the risks for impacts to water quality in the near-field (single ASR discharge) are moderate to low, and the benefits in the Kissimmee River from improved water clarity vary depending upon the I ASR implementation scenario. The risks are similar for the mid-field evaluations, except for increased sulfate load and water hardness which are estimated to be from high to low, based on the ASR implementation scenario. ALT2 presenting the highest risk for increased sulfate and water hardness due to the large number of ASR wells; followed by ALT3 with half the number of ASRs. The risk to Lake Okeechobee water quality was high for ALT2 for sulfate load and water hardness, and moderate for ALT3. For Lake Okeechobee, the benefit of decreased total phosphorus load was moderate to low, and the increased water clarity was low to minimal. The risk to the Greater Everglades of sulfate load and its impact on mercury methylation was moderate to minimal. The risk of increased water hardness to the Greater Everglades was considered low.

7.2 Survival of Fish, Aquatic Invertebrates, and Manatees

Based on the aquatic toxicological data developed for this ERA, the risk to the survival of fish and invertebrates from water quality changes is low under all scenarios.

The risk to manatees from temperature effects was considered minimal.

7.3 Reproducing Populations (Fecundity) of Native Fish

The effects evaluated were loss of dissolved oxygen refugia, water temperature changes, and impingement or entrainment of fish larvae by the ASR intakes. The risk of ASR negatively affecting the reproduction or survival of native fish in the lower Kissimmee River was characterized as moderate to low for most ASR implementation scenarios. In other surface water bodies potentially directly receiving ASR discharges (e.g., C-44, Taylor Creek, C-40, and C-41), these risks were comparatively lower primarily due to less sensitive (i.e., lower abundance and diversity) fish communities in those water bodies. For alternatives with more wells or more pumps (ALT2 and ALT3, generally), the risk of adverse effects was higher. ALT4 and ALT4S-11 generally posed lower risks regardless of water body due the lower number of wells. The risk of any larval fish impingement or entrainment was high to moderate for all alternatives; however, the risk that this loss would be detectable in the fish population was less.

Dissolved oxygen – The ERA considered the risk of fish kills from the loss of ASR created DO refugia during summer months for different fish species. This evaluation considered the availability of temporarily high DO areas in the receiving water caused by the discharge of aerated recovered water, followed by periods of no recovered water discharge. Gamefish and minnows were identified as being at moderate to low risk based on the number of wells in each alternative (more wells equates to higher risk).

Temperature – The ERA evaluated the risk to fisheries from temperature plumes in the vicinity of the ASRs. The risk of modifying the timing of fish spawning was considered from moderate (ALT2) to low (ALT4) for cold water spawners in the Lower Kissimmee River, Nubbin Slough, and C-44 at Port Mayaca. The risk that these temperature modifications of spawning could result in measurable effects was considered moderate (ALT2 and ALT3) and low (ALT4 and ALT4S-11) for cold water spawners and brook silversides (or other annual species). In other water bodies, the risk was lower. Moderate temperature and warm water spawners were considered to have a low risk from temperature changes in the receiving water at all ASR discharge locations.

Impingement and Entrainment -- The ASR water intakes present a high risk of any impingement or entrainment for fish and invertebrates under most scenarios evaluated. The only exception were catfish because based on their reproductive strategy (hiding in submerged objects), their young are less vulnerable. The risk that this entrainment potential will result in a measureable effect on native fisheries and invertebrates was characterized as moderate (lower Kissimmee River and C-44 at Port Mayaca) to low (other water bodies. Due to limited larval fish sampling, this risk characterization has a high level of uncertainty.

7.4 Diversity and Abundance of SAV, Periphyton, and Algal Species

The potential risk of ASR recovered waters on the diversity and abundance of periphyton and algal species is considered low though the uncertainty is considered to be high given the limited available data at KRASR for periphyton and absence of phytoplankton data. A low to minimal benefit as an increase in SAV biomass was predicted, and a moderate to low potential increase in SAV coverage was also anticipated.

7.5 Protection from Methylmercury Accumulation in Wildlife and Humans

The effect of ASR related sulfate loads on mercury methylation in the Kissimmee River and Lake Okeechobee are characterized as minimal. Within the Greater Everglades, the areas of changed MeHg risk attributable to the ASR related sulfate are predicted to be minimal particularly with the ALT4 and ALT4-S11 alternatives, and are located near major canal water release points in western WCA3, north-central WCA2, and northern Shark River Slough. Because the relationship between sulfate and MeHg production is nonlinear and hump shaped, the ELM-Sulfate model prediction generally shows both regions of net increases and net decreases in MeHg risk in near proximity to each other. Given the complexity of mercury methylation in the environment, the uncertainty with these risk characterizations is considered to be moderate.

7.6 Uncertainty

There is always uncertainty associated with risk assessment predictions, depending on the quality, quantity and variability associated with available information. When information is uncertain, it is standard practice in a risk assessment to make assumptions that are biased towards safety. The uncertainties inherent in modelling exposures are compensated for by the use of conservative input parameters. Collectively, these conservative assumptions weigh heavily towards risk estimates that over-estimate the true risk. Thus, there is usually a high degree of confidence that risks have not been underestimated.

Biological uncertainty was recognized in this ecological risk assessment for fish and other aquatic life. Lack of data resulted in greater uncertainty with respect to effects on invertebrates and larval fish from entrainment (e.g., no larval fish data were available for Pool E of the Kissimmee River and only six separate intake samples were collected at KRASR of entrained larval fish and other aquatic organisms). The lack of data for spawning fish in the C-44 Canal at Port Mayaca also resulted in greater uncertainty about how ASR technology might affect fish reproduction in those ecosystems. The positive aspect about all these uncertainties is that they can be reduced by collecting more data.

Biological uncertainty was also concluded simply due to natural variation within and among species. For example, the constant temperature of the ASR discharge may differentially affect cool-water and warm-water fish species because they have different preferred spawning temperatures (as reported in the literature). For species that prefer to spawn at 25-27 ^{o}C, the uncertainty is low that ASR discharge would limit spawning based solely on temperature. However, for species that have a wider range of preferred temperatures where the top of that range is 25-27 ^{o}C, the uncertainty of effect is greater (i.e., some individuals within a species may prefer the cooler end of the temperature range). Seasonal differences in ambient water temperature affect the size and persistence of thermal discharge plumes. Unlike a discharge plume for alkalinity where discharge concentration and in-stream concentration are relatively constant, temperature in the river varies throughout the year. Therefore, plume size for water temperature will also vary, depending on differences of discharge water, ambient water, and air temperatures.

Additional sources of uncertainty for this ERA include:

1. Extrapolation of data from a one or two pilot ASR wells. (Future ASR wells are expected to have somewhat different recovered water quality);
2. Differing operating schemes than predicted by the models;
3. Partial understanding of the factors that influence mercury methylation and potential for bioaccumulation;
4. Location of assumed ASR facilities and assumed storage aquifer. A different implementation scheme with different wells locations, and aquifers would likely provide different risk profiles; and

Potential for under/over estimation of fishery impacts.

7.7 Future ASR Performance Assessment

Although this ERA did not identify substantial ecological effects from a water quality perspective, there is an acknowledgement that water quality conditions would need to be monitored under ASR implementation primarily to satisfy CERPRA, UIC, and NPDES permit requirements but also to reduce the uncertainties identified in this report. The required permits are very likely to require monitoring of potential heavy metal discharges, fish mercury tissue concentration, and toxicological effects. Additional field monitoring of the aquatic community may be warranted to address subtle effects not captured with water quality monitoring. One of the easiest, most accurate, and inexpensive methods for determining water quality effects on the environment is through sampling the benthic macroinvertebrate population. However, at potential ASR sites where the benthic community is impaired this methodology is not appropriate since it cannot be used to detect subtle changes that may be result from ASR discharges.

In areas where ASR is proposed that have significant fisheries or high quality aquatic habitat, additional monitoring such as fishery surveys, fish tissue mercury concentration, and stream condition index monitoring is recommended. This expected permit required monitoring and suggested supplemental monitoring should ensure that the uncertainty risks identified in this report are minimized.

7.8 CERP Performance Metric Assessment for ASR

This risk assessment and the Regional Hydrogeological Modeling Report (USACE, 2013) identified ALT4 (Scenario 9) and ALT4-S11 (Scenario 11) as the preferred ASR well placement and operations that best meet the hydrogeological and ecological constraints. These alternatives both include 200 ASR wells as envisioned by CERP; however, more than half of the wells are completed in the APPZ and BZ storage units of the Floridan Aquifer. As discussed elsewhere in this report, APPZ wells are assumed to have 30 percent recovery efficiency and BZ wells are assumed to have zero percent recovery. In comparison, UF aquifer wells are assumed to have a recovery efficiency of 70 percent. In ALT4 there are 48 UF wells, 32 APPZ wells and 120 BZ well. In recharge mode, these wells remove as much water from the surface system as envisioned by CERP. The long-term maximum recovery efficiency for ALT4 and ALT4-S11 is estimated to be 21 percent of the total volume of water pumped into the ASR wells. The remaining 79 percent of the injected water is assumed to be unrecoverable due to mixing with highly mineralized groundwater. To determine the effect of reduced CERP ASR recovery volumes, the Lake Okeechobee water supply and ecological performance metrics were assessed under the assumption of CERP ASR implementation and the 2008 LORS operating plan for the lake. The results are discussed below and the full assessment is included in **Appendix D**.

Based on the standard lake ecological and water supply metrics, the original plan for 200 ASR wells (ALT2) would provide improved lake performance both on the ecological side for discharges to the Caloosahatchee and St. Lucie Estuary as well as on the water supply side for reduced LOSA shortages. ALT3 with half of the originally envisioned 200 ASR wells within the Lake Okeechobee basin does not perform as well as ALT2 but it still appears to improve most ecological and water supply metrics when compared to the baseline condition of no CERP ASR (ALT1). ALT4 and ALT4-S11 generally provide worse ecological and water supply conditions for periods of limited water availability. For periods of ample water availability, ALT4 and ALT4-S11 generally perform better than the baseline or ALT2 and ALT3. Placement of ASR wells into the Boulder Zone in ALT4 and ALT4-S11 results in an overall lower water budget for the lake because water injected into the BZ wells is not recovered. ALT4-S11 further constrains the Lake water budget due to the reduced recovery rate for UF and APPZ wells. Downstream water users in the EAA and Lower East Coast Service Area would likely not readily accept ASR implementation that would increase the number and duration of water shortages such as presented by the ALT4 and ALT4-S11 ASR scenarios.

Assessment of CERP performance metrics for the Greater Everglades was not done for the ALT3, ALT4, and ALT4-S11 scenarios since these metrics are not available in the LOOPS model. Assessment of these metrics requires that the SFWMM or successor models be configured for these ASR implementation scenarios. In light of the reduced performance in the lake associated with the most feasible ASR alternatives (ALT4, ALT4-S11), it is apparent that the CERP plan should be revised to account for reduced ASR effectiveness

8.0 DISCUSSION

This ERA primarily investigated ecological and water quality impacts associated with CERP ASR in the Lake Okeechobee Basin. The risks posed by CERP ASR in the Caloosahatchee, C-51, North Palm Beach, and Site 1 basins were not explicitly addressed in this report; however, given the similarities between the Lake Okeechobee basin and these basins, the risks characterized here serve as reasonable estimates for these basins. This ERA and the Regional Hydrogeologic Modeling Report indicate that CERP ASR is not feasible at the scale contemplated at least for the Lake Okeechobee Basin. While the hydrogeologic modeling did show that CERP ASR recharge quantities can be achieved through the use of wells completed into lower Floridan Aquifer units (APPZ and BZ), the recovery volumes contemplated in CERP are not achievable within the hydrogeologic constraints imposed by the Martin and St. Lucie County groundwater protection rules that require the maintenance of artesian conditions in the Floridan Aquifer. Mitigation actions could be employed (see Table 6.6) that reduce the likelihood of large-scale ecological damage. In the case of entrainment and impingement, options such as timing of recharge events may reduce impacts to fisheries though the effectiveness and feasibility of this has yet to be determined. That said, the ALT4 and ALT4-S11 scenarios pose the least risk to fisheries in the Kissimmee and Lake Okeechobee as well as the least risk of increased methylation within the Greater Everglades and would likely be more acceptable to water managers and the public than the original CERP ASR configuration.

The cause of intermittent chronic toxicity measured at the KRASR facility was not determined in this ERA. Given the incidence of this chronic toxicity, the FDEP would likely require that any future CERP ASR facility be located where sufficient dilution water is available for a mixing zone. The dilution volume specified in the KRASR NPDES permit was 3.9 times the ASR discharge volume. Assuming that future CERP ASR facilities would need the same dilution volume, a five-well cluster ASR system would have to be located where a minimum of 150 cfs is continuously available during recovery events. The requirement for dilution water may be problematic since this flow quantity would have to be available during droughts and the dry season. It is likely that

Kissimmee River Basin and perhaps the C-43 and C-44 basins could support dilution flow requirements; however, several of the sub-basins around Lake Okeechobee such as Nubbin Slough, Taylor Creek, C-40, and C-41 may not be capable of supplying this water during the dry season or during droughts.

From the ecological and water quality perspective, water managers should continue to consider CERP ASR as a viable technology to achieve the ecological and water supply objectives of Everglades Restoration. Given that the findings of this ERA are presented with an acknowledgement of uncertainty in the risk characterizations, implementation of the CERP ASR should be incremental and geographically disperse until the uncertainties identified here are resolved.

The fact that the most hydrogeologically feasible alternative (ALT4-S11) is also the alternative that would result in the least toxicological and water quality harm is re-assuring. However, this alternative fails to improve water supply and lake ecosystem performance metrics due the greatly reduced volume of water recovered from ASR storage. The Corps and SFWMD should undertake a revision of the CERP plan to determine what changes are necessary to CERP in light of reduced ASR performance. Implementation of incremental CERP ASR facilities need not wait for this update.

9.0 RECOMMENDATIONS

This risk assessment identified the likely ecological and water quality risks associated with the installation of CERP ASR components primarily within the Lake Okeechobee Basin. Generally, for Lake Okeechobee and downstream basins, the findings of this study indicate that ecological and water quality risks will be low to minimal if ASR recovered water discharges are minimized through the completion into the APPZ and BZ units of the Floridan Aquifer of more than half of the 200 ASR wells contemplated by CERP. If ASR is implemented as part of CERP the following are recommended.

1. Implementation of cluster well ASR facilities at one or more locations within the Lake Okeechobee Basin. The maximum capacity of these facilities should be no greater than 25 MGD and the recommendations found in **Table 6.2** should be undertaken to mitigate risks. ASR sites located in the Kissimmee, C-40, and C-41 basins should be preferred given the favorable groundwater quality of the Upper Floridan Aquifer in these areas and the availability of dry season dilution flows likely required as an ASR facility NPDES permit condition.
2. An update to the CERP plan should be prepared using the ALT4 and ALT4-S11 well installation scenarios or other similar scenarios outlined in the Regional ASR Hydrogeologic Model report.

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