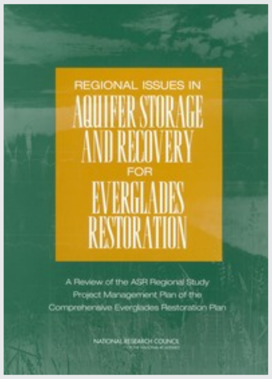

Regional Issues in Aquifer Storage and Recovery for Everglades Restoration: A Review of the ASR Regional Study Project Management Plan of the Comprehensive Everglades Restoration Plan (2002)

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CONTRIBUTORS

Committee on Restoration of the Greater Everglades Ecosystem, National Research Council

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REGIONAL ISSUES IN AQUIFER STORAGE AND RECOVERY FOR EVERGLADES RESTORATION

Committee on Restoration of the Greater Everglades Ecosystem

Water Science and Technology Board

Board on Environmental Studies and Toxicology

Division on Earth and Life Studies

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COMMITTEE ON RESTORATION OF THE GREATER EVERGLADES ECOSYSTEM (CROGEE)[1,2]

JEAN M. BAHR[3], *Chair*, University of Wisconsin, Madison
SCOTT W. NIXON, *Vice-Chair*, University of Rhode Island, Narragansett
JOHN S. ADAMS, University of Minnesota, Minneapolis
LINDA K. BLUM, University of Virginia, Charlottesville
PATRICK L. BREZONIK[3], University of Minnesota, St. Paul
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LARRY ROBINSON, Florida Agricultural and Mechanical University, Tallahassee
REBECCA R. SHARITZ[3], Savannah River Ecology Laboratory, Aiken, South Carolina, and University of Georgia, Athens
HENRY J. VAUX, JR., University of California Division of Agriculture and Natural Resources, Oakland
JOHN VECCHIOLI[3], U.S. Geological Survey (ret.), Odessa, Florida
JEFFREY R. WALTERS[3], Virginia Polytechnic Institute and State University, Blacksburg

Consultants to the Committee

THOMAS MORRIS[3], Las Vegas Valley Water District, Nevada
MARYLYNN V. YATES[3], University of California, Riverside
MICHAEL C. NEWMAN[3], Virginia Institute of Marine Science, Gloucester Point

NRC Staff

STEPHEN D. PARKER, Director, Water Science and Technology Board
DAVID J. POLICANSKY, Associate Director, Board on Environmental Studies and Toxicology
WILLIAM S. LOGAN[3], Senior Staff Officer, Water Science and Technology Board
PATRICIA JONES KERSHAW, Staff Associate, Water Science and Technology Board

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[1] The activities of the Committee on Restoration of the Greater Everglades Ecosystem (CROGEE) are overseen and supported by the NRC's Water Science and Technology Board (lead) and Board on Environmental Studies and Toxicology (see Appendix B).
[2] For a list of acronyms, see Appendix D.
[3] A subgroup consisting of CROGEE members Patrick Brezonik, Rebecca Sharitz, John Vecchioli, Jeffrey Walters, plus consultants Thomas Morris, Marylynn Yates, and Michael Newman, and CROGEE chair Jean Bahr, with support by NRC senior staff officer Will Logan, took the lead in drafting the report.

Preface

This report is a product of the Committee on Restoration of the Greater Everglades Ecosystem (CROGEE), which provides consensus advice to the South Florida Ecosystem Restoration Task Force ("Task Force"). The Task Force was established in 1993 and was codified in the 1996 Water Resources Development Act (WRDA); its responsibilities include the development of a comprehensive plan for restoring, preserving and protecting the south Florida ecosystem, and the coordination of related research. The CROGEE works under the auspices of the Water Science and Technology Board and the Board on Environmental Studies and Toxicology of the National Research Council (NRC).

The CROGEE's mandate includes providing the Task Force not only with scientific overview and technical assessment of the restoration activities and plans, but also to provide focused advice on technical topics of importance to the restoration efforts. The first of these items, approved by the Task Force in May 2000, was Aquifer Storage and Recovery. The workplan item noted that:

> Aquifer storage and recovery (ASR) is a key component of the Comprehensive [Everglades Restoration] Plan [CERP]. It is important that aspects of this technology, including water quality and its feasibility at the large scales being planned, be understood as soon as possible. Thus the CROGEE proposes that very high priority be given to the task of understanding and analyzing the ASR pilot projects and in addition, to incorporating the pilot test results into an ongoing assessment of regional impacts of the large scale ASR operations…Much of the value of adaptive management comes from designing pilot and other projects to maximize opportunities for learning. This is especially true for a large-scale project like ASR, where it is important to design (local) pilot projects that will allow inferences about injection, storage, and recovery aspects and impacts on water quality expected for the full project over the south Florida region."

On October 19, 2000, a workshop on the pilot projects and related plans for ASR in the Lake Okeechobee and Western Hillsboro areas was held by the CROGEE in Miami, Florida. The workshop was open to the public and was attended by about 60 people including personnel from the South Florida Water Management District (SFWMD) and U.S. Army Corps of Engineers (USACE), federal, state and local agencies, universities, consulting firms, and environmental organizations. There were 10 invited experts from government, academia and the private sector, and eight members of the CROGEE present. A report was subsequently published, titled 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 Areas (NRC, 2001).

Shortly before the workshop, CERP planners extracted much of the proposed work on regional analysis of the subsurface from the Lake Okeechobee and Western Hillsboro pilot projects and reorganized it into a proposed Aquifer Storage and Recovery Regional Study. The NRC (2001) report commended this proposal, and recommended various elements for such a study. Much of the proposed work on geochemistry, water quality, and ecotoxicology was also added to this study. A fourth draft of the project management plan for the ASR regional study (http://www.evergladesplan.org/pm/mgmtplns.shtml) was prepared by the USACE and the SFWMD in May 2002, and the Task Force requested that the CROGEE conduct a technical review of this document. Specifically, this review examines the adequacy of the proposed scientific methods to address key issues raised in the CROGEE February 2001 report and other issues previously raised by the ASR Issue Team of the South Florida Ecosystem Restoration Task Force Working Group in their 1999 report. Our conclusions and recommendations are based primarily on the collective experience and knowledge of the authors.

In addition to the CROGEE members who took the lead in drafting this report, I would also like to particularly thank three consultants to the committee, Tom Morris, Marylynn Yates, and Michael Newman, who graciously provided their time and expertise to this effort. We are also grateful for the assistance of Ronnie Best (U.S. Geological Survey), co-chair of the Science Coordination Team; Peter Ortner (National Oceanic and Atmospheric Administration), South Florida Ecosystem Restoration Working Group liaison to CROGEE; Terrence "Rock" Salt and Kevin Burger, Executive Director and Deputy Executive Director of the South Florida Ecosystem Restoration Task Force; and Glenn Landers (U.S. Army Corps of Engineers) and Peter Kwiatkowski (South Florida Water Management District), Project Managers for the Aquifer Storage and Recovery Regional Study.

This report has been reviewed in draft form by individuals chosen for their diverse perspectives and technical expertise, in accordance with procedures approved by the NRC's Report Review Committee. The purpose of this independent review is to provide candid and critical comments that will assist the institution in making its published report as sound as possible and to ensure that the report meets institutional standards for objectivity, evidence, and responsiveness to the study charge. The review comments and draft manuscript remain confidential to protect the integrity of the deliberative process.

We wish to thank the following individuals for their review of this report:

Charles Haas, Drexel University
Mark Sandheinrich, University of Wisconsin, LaCrosse
Zhuping Sheng, Texas Agricultural and Mechanical University, El Paso
Amelia Ward, University of Alabama
Carol Wicks, University of Missouri, Columbia

Although the reviewers listed above have provided many constructive comments and suggestions, they were not asked to endorse the conclusions or recommendations nor did they see the final draft of the report before its release. The review of this report was overseen by George Hornberger, University of Virginia. Appointed by the National Research Council, Dr. Hornberger was responsible for making certain that an independent examination of this report was carried out in accordance with institutional procedures and that all review comments were carefully considered. Responsibility for the final content of this report rests entirely with the authoring committee and the institution.

Jean M. Bahr, Chair
Committee on Restoration of the Greater Everglades Ecosystem

Contents

Executive Summary

The Comprehensive Everglades Restoration Plan (CERP) is a framework and guide to restore, protect, and preserve the water resources of central and southern Florida, including the Everglades. It covers an 18,000-square-mile area, includes more than 60 elements, and will take more than 30 years to implement. It is designed to capture, store and redistribute fresh water previously lost to tide and to regulate the quality, quantity, timing and distribution of water flows. The need for water storage for the CERP has led to the proposal to drill over 300 aquifer storage and recovery (ASR) wells in south Florida (Figure 1). ASR is "the storage of water in a suitable aquifer through a well during times when water is available, and recovery of the water from the same well during times when it is needed" (Pyne, 1995). The CERP would use porous and permeable units in the Upper Floridan aquifer (UFA) to store excess surface water and shallow groundwater at rates of up to 1.7 billion gallons per day (bgpd) (6.3 million m^3 per day) during wet periods for recovery during seasonal or longer-term dry periods.

ASR has advantages and disadvantages compared to surface storage. ASR systems generally require less land and may avoid water losses due to seepage and evapotranspiration. ASR wells can be located in areas of greatest need, thus reducing water distribution costs, and ASR permits recovery of large volumes of water during severe, multi-year droughts to augment deficient surface water supplies (USACE, 1999). Potential disadvantages of ASR wells include low recharge and recovery rates relative to surface storage, which limit capture rates of excess water, and losses due to mixing within brackish or saline aquifers (USACE, 1999). While slightly brackish water may be acceptable for drinking water, increases in salinity, and other water quality changes resulting from inputs of ASR water to surface ecosystems, may have unknown ecological effects. Operations and maintenance costs may also be higher for ASR, largely due to high energy requirements.

While ASR technology has been employed successfully in Florida since 1983, concerns have been expressed about the use of large-scale ASR in south Florida. Many of these concerns were outlined in a report prepared by the Aquifer Storage and Recovery Issue Team of the South Florida Ecosystem Restoration Working Group. These included suitability of proposed ASR source waters, paucity of regional hydrogeologic information, hydraulic fracturing of the aquifer, impacts on existing wells, water quality concerns, mercury bioaccumulation, and others. The Committee on Restoration of the Greater Everglades Ecosystem (CROGEE) held a workshop to examine two ASR pilot projects, and subsequently issued a report in 2001 that recommended additional research on regional science and water quality issues.

The ASR Regional Study, conceived just prior to the workshop, was designed to answer many of these questions concerning the feasibility of full-scale ASR implementation, reduce uncertainties related to full-scale CERP ASR implementation by conducting scientific studies based on existing and newly acquired data, develop a regional groundwater model of the Floridan Aquifer System (FAS), and identify an appropriate magnitude of ASR capacity with minimal impact to the environment and existing users of the FAS. A fourth draft of the Project Management Plan (PMP) for the study (http://www.evergladesplan.org/pm/mgmtplns.shtml) was prepared by the USACE and the SFWMD in May 2002, and the Task Force requested that the CROGEE conduct a technical review of this document. To accomplish this task, the CROGEE formed a working group, composed of existing members of the committee and supplemented with special consultants.

The PMP is organized primarily into a series of "technical tasks," each having a budget, a timetable, subtasks, and a list of assumptions. The Executive Summary and Table of Contents of the PMP are in Appendix A of this report. Most of this report focuses on Chapter 3 of the PMP, which outlines the technical tasks. There is also considerable discussion of Appendix L, which contains many of the details of Tasks 10 through 13 (water quality and ecological studies). Overall, this report evaluates the draft PMP with respect to the adequacy of the proposed scientific methods to address key issues raised in the 2001 NRC CROGEE report and other issues previously raised by the ASR Issue Team.

The Regional ASR PMP clearly responds to issues identified earlier by the South Florida Working Group ASR Issue Team and later by the CROGEE. The report recognizes the importance of acquiring information through the proposed Regional Study to resolve or better understand the issues that are involved with the consequences of implementation of ASR regionally in south Florida at the unprecedented scale of 1.7 billion gallons per day. The PMP goes a long way to providing the needed information. It is comprehensive, for the most part, and is integrated well with the pilot ASR studies. The authors of the document should be commended for the effort that went into producing the plan and for the comprehensiveness of the proposed study.

The most important overall improvement to the document would be a greater attention to the CERP principle that "each incremental step [be] viewed as an experiment accompanied by one or more hypotheses that predict how that step will improve the system" (USACE, 1999), a concept generally termed adaptive management. Some of the task descriptions suggest that the study will be conducted as a relatively routine engineering exercise rather than a comprehensive and integrated scientific study to "investigate regional technical and regulatory issues governing the feasibility of full-scale ASR implementation…and develop tools to assess the feasibility and increase the level of certainty of successful ASR implementation," which is the stated objective of the study. This structure is of some concern given that results of the regional study may show that ASR at the scale being proposed is not feasible due to hydrogeological, geochemical, ecological, or other reasons. In such cases, the proposed plans to (1) apply the model (or collect the sample), (2) collect the results, and (3) move on to the next task will not be appropriate. Additional advanced consideration is warranted concerning what to do if the results of some phase(s) indicate that ASR, as originally planned, will not work.

The regional modeling described in Task 9 may come closest to this ideal; in this task the plan specifically discusses multiple model runs for a range of alternatives (in terms of well locations and numbers). Likewise, the flow chart of Figure 3, which shows "adaptive feedback" loops between water quality, ecological, and toxicological investigations, is a useful tool that might be more broadly applied elsewhere in the report. The PMP acknowledges the need for some flexibility in modification of the plan if early results warrant changes, and this is commendable. However, the question remains whether the overall study plan will be sufficiently flexible to allow for evaluation of alternative plans/procedures if a particular aspect of the original plan is problematical. Articulation of specific hypotheses within the PMP is highly desirable, and this approach should be coupled with a plan that ensures evaluation of results in each step in a timely manner to assure flexibility and implementation of alternative procedures or approaches in place of those that are problematical or do not work.

A moderate number of the tasks in the PMP are not described in enough detail to allow for a substantive critique of methods at this stage. While this is understandable given the scope of the effort, these include such important topics as tracer tests, numerical modeling, interpretation of bioassay results, packer test intervals, and sampling frequency. These topics deserve additional attention in later drafts.

Ecological and water quality studies are described both in the descriptions of Tasks 10 through 13 and, somewhat independently, in Appendix L. Unfortunately, the task descriptions and the appendix are not well integrated, and sometimes appear contradictory. The writers of the PMP are urged to make these sections more consistent with each other.

In addition to these general recommendations on the overall structure and organization of the PMP, recommendations related to more specific tasks of the Regional Study are as follows:

- The proposed additional monitoring at the pilot sites is a good step, but probably still does not go far enough in terms of numbers of wells and well nests to characterize both hydraulic and biogeochemical processes. Vertical and horizontal heterogeneity of the aquifer system will make this a difficult task that will require extensive testing. Likewise, recharge of the ASR wells should continue, if at all possible, until some time after the injection water is detected at all of the monitor wells, to understand the physical and chemical behavior of the system as fully as possible.
- Likewise, improved understanding of potential geochemical reactions should be a priority at all pilot sites. This may require additional monitoring during cycle testing beyond that anticipated in the PMP. Given the heterogeneity of the FAS with respect to salinity and physical properties at existing ASR sites, there may be significant variability in these properties from site to site.
- Some of the funds necessary to expand such monitoring and sampling should come through de-emphasizing continuous coring. While coring can be useful, it is costly and may yield unreliable and non-representative data. Given these limitations, it might be prudent to reduce the coring program and use the savings to support installation of additional monitoring wells for field tests of hydraulic properties and for hydrogeochemical characterization.
- Column studies are proposed to assess interactions between microorganisms and the subsurface materials. Due to the presence of fractures and other features in the Florida Aquifer system, it will be difficult, if not impossible, to obtain representative, quantitative information on transport using column studies. Such results should be treated with caution.
- The proposed bioassays and mesocosm studies emphasize response of individual taxa rather than community- and ecosystem-level effects. However, these studies may reveal only sublethal effects (e.g., altered growth rates) of contaminants on the sampled organisms. Such results would be difficult to extend to impacts on the larger ecosystem (e.g., shifts in community composition or changes in frequencies of algal blooms), for which little monitoring is proposed. Thus, the ASR Regional Study's ecological monitoring and research components are poorly connected to the ecosystem- and community-level restoration objectives of CERP. This can be

remedied by adding monitoring and assessment of ecological indicators to the proposed bioassays of Task 13. In coordination with other CERP science initiatives such as RECOVER (REstoration COordination & VERification), an opportunity exists to develop indicators that can be employed in both system-wide monitoring and the ASR Regional Study.

- The extended bioassay testing and monitoring of biological impacts are expected to occur over six- to twelve-month cycles. This sampling period may need to be longer to allow assessment of potential long-term effects on community composition, especially given interannual variability in factors such as rainfall, temperature, extreme events, etc.
- Surface water quality modeling and ecosystem modeling tends to focus on Lake Okeechobee. However, it appears more likely that negative effects of ASR-recovered water could occur within the Everglades itself. This is where surface waters are low in nutrients and dissolved solids, and where input, either directly or via pathways that include Lake Okeechobee, of recovered ASR water with relatively high ionic strength would represent a major ecological change. More emphasis should be placed on modeling of these more sensitive ecosystems and identifying water quality changes that could cause irreversible shifts in community composition.

1

Introduction

This report reviews plans for a regional study related to a water storage and recovery component of the Comprehensive Everglades Restoration Plan (CERP). The CERP is a framework and guide to restore, protect, and preserve the water resources of central and southern Florida, including the Everglades. It covers an 18,000-square-mile area, includes more than 60 elements, and will take more than 30 years to implement. It is designed to capture, store and redistribute fresh water previously lost to tide and to regulate the quality, quantity, timing and distribution of water flows. Among its many features are removal of barriers to sheetflow, wastewater reuse, treatment wetlands, surface water storage reservoirs, and underground water storage (USACE, 1999).

OPTIONS FOR WATER STORAGE IN THE CERP

The need for water storage for the CERP has led to the proposal to drill over 300 aquifer storage and recovery (ASR) wells in South Florida (Figure 1). ASR is "the storage of water in a suitable aquifer through a well during times when water is available, and recovery of the water from the same well during times when it is needed" (Pyne, 1995). A conceptual diagram of an ASR well in south Florida is shown in Figure 2. The CERP would use porous and permeable units in the Upper Floridan aquifer (UFA) to store excess surface water and shallow groundwater at rates of up to 1.7 billion gallons per day (gpd) (6.3 million m3/day) during wet periods for recovery during seasonal or longer-term dry periods (USACE, 1999; SFWMD, 2000). Ambient groundwater in the UFA is brackish to saline. During the recharge phase of ASR system operation, ambient groundwater would be displaced by the injected fresh water such that a zone, or "bubble," of fresh water would be created and stored around each well. This bubble of fresh water could be drawn upon later by the same ASR wells during dry seasons or droughts. In practice, the bubble may be highly irregular, especially in karstic and fractured aquifers such as the UFA.

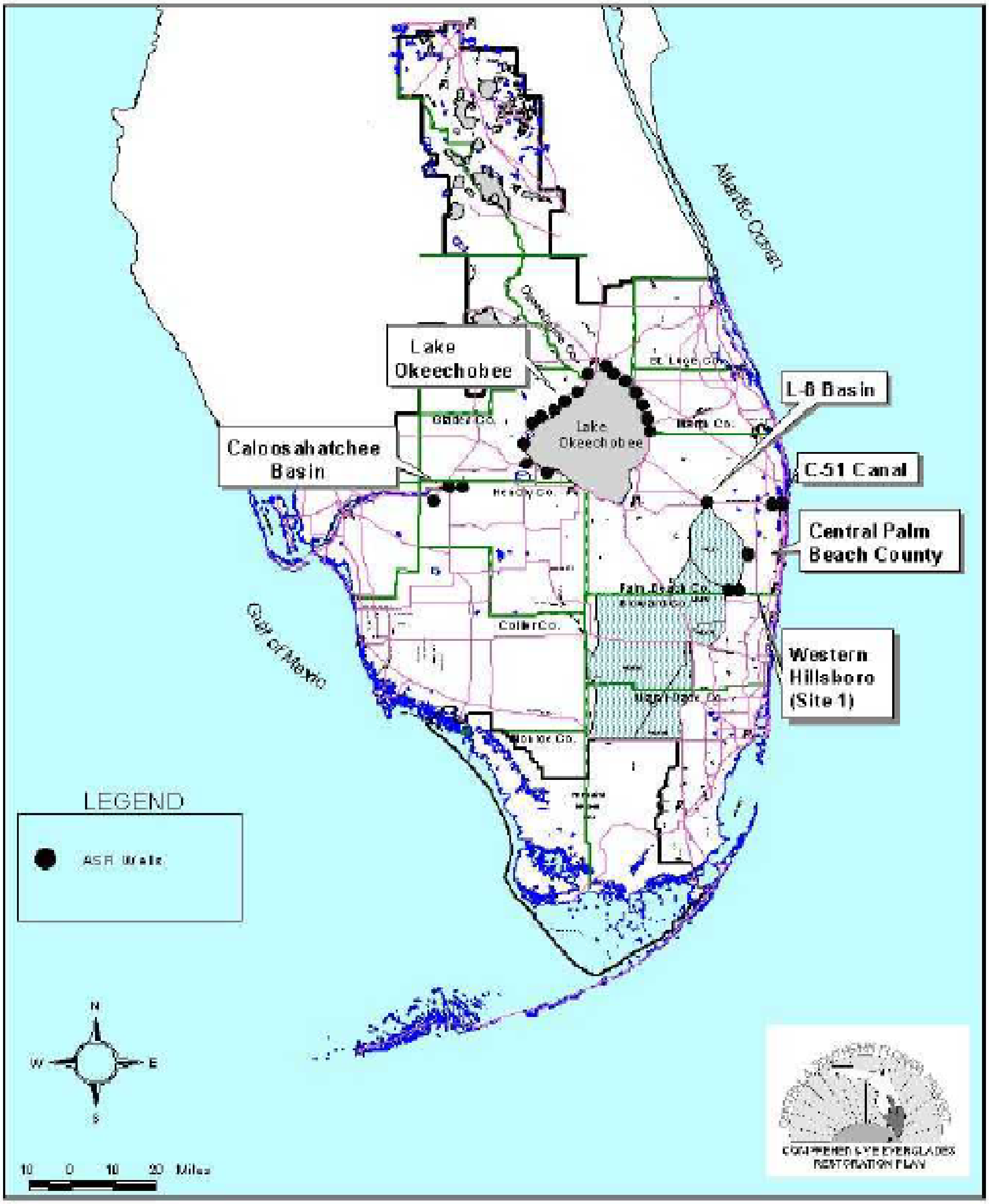

FIGURE 1 Proposed ASR systems in the Comprehensive Everglades Restoration Plan. SOURCE: CERP, 2002.

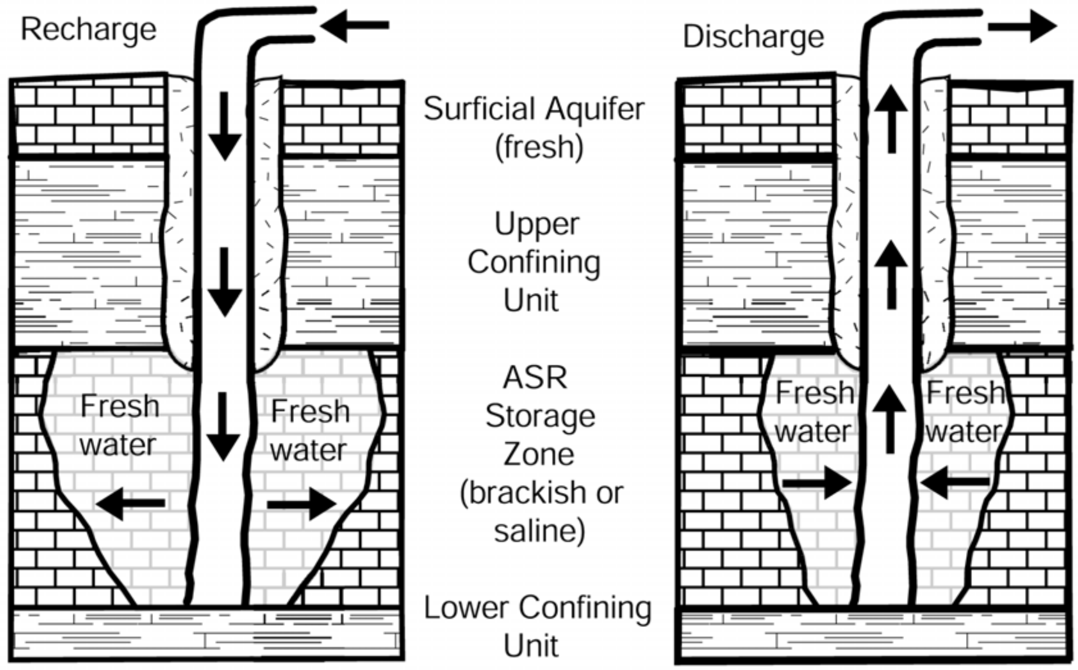

FIGURE 2. Schematic diagram of the recharge and recovery phases of ASR for a typical south Florida system. The relatively symmetric spread of fresh water away from the well shown assumes a fairly homogeneous, isotropic aquifer with negligible regional flow relative to the flow rates induced by pumping during recharge or recovery. The actual configuration of the storage bubble may be considerably more complex. SOURCE: NRC, 2001.

ASR has advantages and disadvantages compared to surface storage. ASR systems generally take up less land and may avoid water losses due to seepage and evapotranspiration (USACE, 1999). This is of particular importance in south Florida, where land acquisition costs are high and flat topography coupled with a shallow water table place constraints on surface reservoir construction. Additional advantages cited for this strategy are that ASR wells can be located in areas of greatest need, thus reducing water distribution costs, and that ASR permits recovery of large volumes of water during severe, multi-year droughts to augment deficient surface water supplies.

Potential disadvantages of ASR wells include low recharge and recovery rates relative to surface storage, which limit capture rates of excess water, and losses due to mixing within brackish or saline aquifers (USACE, 1999). While slightly brackish water may be acceptable for drinking water, increases in salinity, and other water quality changes resulting from inputs of ASR water to surface ecosystems, may have unknown ecological effects. Operations and maintenance costs may also be higher for ASR, largely due to high energy requirements. Because of the complementary strengths of ASR and surface storage, these two storage options may be used in tandem.

PREVIOUS RECOMMENDATIONS CONCERNING ASR

While ASR technology has been employed successfully in Florida since 1983 (Pyne, 1995), with individual well clusters having capacities up to about ten million gpd (38,000

m^3/day), concerns have been expressed about the use of large-scale ASR in south Florida. Many of these concerns were outlined in a report prepared by the Aquifer Storage and Recovery Issue Team of the South Florida Ecosystem Restoration Working Group (ASR Issue Team, 1999) and presented to the Working Group in January 1999. The concerns addressed by the Issue Team, some of which were also noted in U.S. General Accounting Office (2000), were summarized in the following seven questions:

- Are the proposed ASR source waters of suitable quality for recharge without extensive pretreatment?
- What regional hydrogeologic information on the UFA is needed but unavailable for regional assessment?
- Will the proposed ASR recharge volumes result in head increases sufficient to cause rock fracturing?

What will be the combined regional head increases from the regional scale ASR, and how will this affect individual ASR operation, change patterns of groundwater movement, and impact existing ASR wells, supply wells, or underground injection control (UIC) monitoring wells?

- What are the likely water quality changes to the injected water resulting from movement and storage in the aquifer, and will the quality of the recovered water pose environmental or health concerns?
- What, if any, is the potential impact of recovered water on mercury bioaccumulation in the surface environment?
- What are the relationships among ASR storage zone properties, recovery rates, and recharge volumes?

These reports were considered in the formulation of project management plans (PMPs) for CERP ASR pilot projects for the Lake Okeechobee, Western Hillsboro, and Caloosahatchee River regions (http://www.evergladesplan.org/pm/mgmtplns.shtml). The first two of these were evaluated by the CROGEE in a workshop in 2000. This resulted in a report (NRC, 2001) that recommended additional research on regional science and water quality issues. These included the following:

- Development of a preliminary list of data needs and compilation of available data for a regional assessment,
- Development of a regional-scale groundwater flow model in parallel with initial data compilation to identify data gaps,
- Drilling of exploratory wells in key areas, including core sampling, downhole geophysical logging, hydraulic testing and water quality sampling,
- Seismic reflection surveys, used in conjunction with results from exploratory wells, to constrain the three-dimensional geometry and continuity of hydrostratigraphic units,
- Use of the regional model in conjunction with other regional data sets to develop a multi-objective approach to ASR facility siting during final design of the regional ASR systems,
- Scientific studies, including laboratory and field bioassays and ecotoxicological studies, to help determine appropriate standards that consider not only the initial receptors of the recovered water, but also downstream receptors,
- Characterization of organic carbon of the source water and studies designed to anticipate the effects of this material on biogeochemical processes in the subsurface,

- Laboratory studies to evaluate dissolution kinetics and redox processes that could release major ions, heavy metals, arsenic, radionuclides, and other constituents from the aquifer matrix, and
- Studies designed to enhance understanding of mechanisms responsible for mixing of dilute recharge water with brackish to saline groundwater (NRC, 2001).

GOALS OF ASR REGIONAL STUDY

The ASR Regional Study was conceived just prior to the abovementioned CROGEE workshop, and was designed to answer many of these questions. Its authors, the members of a broad, interagency "project delivery team," stated that the study "will investigate regional technical and regulatory issues governing the feasibility of full-scale ASR implementation, as identified in the CERP, and develop tools to assess the feasibility and increase the level of certainty of successful ASR implementation" (CERP, 2002).

According to the Executive Summary of the PMP (included as part of Appendix A in this report) the primary goals of the ASR Regional Study are the following:

1. Address outstanding issues of a regional nature that cannot be adequately addressed by the authorized ASR Pilot Projects,
2. Reduce uncertainties related to full-scale CERP ASR implementation by conducting scientific studies based on existing and newly acquired data and evaluate potential effects on water levels and water quality within the aquifer systems, and on existing users, surface-water bodies, and the flora and fauna that inhabit them, and
3. Develop a regional groundwater model of the Floridan Aquifer System (FAS) and conduct predictive simulations to evaluate the technical feasibility of the proposed 333-well CERP ASR system, or if determined to be infeasible, identify an appropriate magnitude of ASR capacity with minimal impact to the environment and existing users of the FAS (CERP, 2002).

REPORT OBJECTIVE AND OVERVIEW

A fourth draft of the ASR Regional Study PMP was prepared by the USACE and the SFWMD in May 2002, and the Task Force requested that the CROGEE conduct a technical review of that document. The executive summary and table of contents for the PMP are shown in Appendix A. The entire PMP, including appendices, may be found online at http://www.evergladesplan.org/pm/mgmtplns.shtml. The PMP is organized primarily into a series of "technical tasks," each having a budget, a timetable, subtasks, and a list of assumptions. Most of this report focuses on Chapter 3 of the PMP, which outlines the technical tasks. There is also considerable discussion of Appendix L, which contains many of the details of Tasks 10 through 13 (water quality and ecological studies).

This review examines the adequacy of the proposed scientific methods to address key issues raised in the CROGEE February 2001 report and other issues previously raised by the ASR Issue Team of the South Florida Ecosystem Restoration Working Group. As with NRC (2001), the principle of adaptive management forms a backdrop to the report. That is, the plans are evaluated from the perspective of how they will contribute to process understanding that can improve design and implementation of restoration project components.

Following an overall assessment of the PMP, Chapter 2 of this report focuses on the "tasks" outlined in the "Project Scope" of the PMP, in the order in which they are introduced in that document. Chapter 3 addresses other technical issues that are not directly related to these tasks. Chapter 4 summarizes the conclusions and recommendations of this review.

2

Tasks

This chapter begins with an overall assessment of the report, followed by comments on specific aspects of the plan are intended to highlight positive aspects of the plan, to identify potential limitations, and to strengthen tasks that are still in preliminary stages of development. All appendices, page numbers and figures mentioned in this chapter, except where noted, refer to appendices, pages and figures in the PMP, not those of this report.

OVERALL ASSESSMENT

The Project Management Plan (PMP) is generally well conceived and well organized, and this is to be commended. The plan is broad and inclusive, and with minor adjustments will go a long way towards determining the feasibility of ASR as an important component of the CERP.

The most important overall improvement to the document would be a greater attention to the CERP principle that "each incremental step [be] viewed as an experiment accompanied by one or more hypotheses that predict how that step will improve the system" (USACE, 1999), a concept generally termed *adaptive management*. Some of the task descriptions suggest that the study will be conducted as a relatively routine engineering exercise rather than a comprehensive and integrated scientific study to "investigate regional technical and regulatory issues governing the feasibility of full-scale ASR implementation…and develop tools to assess the feasibility and increase the level of certainty of successful ASR implementation" (CERP, 2002). This structure is of some concern given that results of the regional study may show that ASR at the scale being proposed is not feasible due to hydrogeological, geochemical, ecological, or other reasons. In such cases, the proposed plans to (1) apply the model (or collect the sample), (2) collect the results, and (3) move on to the next task will not be appropriate. Additional advanced consideration is warranted concerning what to do if the results of some phase(s) indicate that ASR, as originally planned, will not work.

The regional modeling described in Task 9 may come closest to this ideal. In this task the plan specifically discusses multiple model runs for a range of alternatives (in terms of well locations and numbers). Likewise, the flow chart of Figure 3, which shows "adaptive feedback" loops between water quality, ecological, and toxicological investigations, is a useful tool that might be more broadly applied elsewhere in the report. The PMP acknowledges the need for some flexibility in modification of the plan if early results warrant changes, and this is commendable. However, the question remains whether the overall study plan will be sufficiently flexible to allow for evaluation of alternative plans/procedures if a particular aspect of the original plan is problematical. Articulation of specific hypotheses within the PMP is highly desirable, and this approach should be coupled with a plan that ensures evaluation of results in each step in a timely manner to assure flexibility and implementation of alternative procedures or approaches in place of those that are problematical or do not work.

TASK 1 – BUILD INVENTORY OF EXISTING DATA AND INFORMATION

According to the text and the project schedule summarized in Appendices C and D, this task is already underway. The general description of types of data that will be reviewed and compiled indicates that this should constitute a thorough and comprehensive review of existing information. In addition to examining basic data and reports available from federal, state and local agencies, the inventory should draw on relevant data and reports from the academic community and industry. (These data sources may already be included implicitly in the plan, but the text specifies only "agency" sources.)

TASK 2 – EVALUATION OF DRILLING AND GEOPHYSICAL METHODS

The project delivery team should be commended for including this task designed to allow the project to take advantage of new technologies. Based on experience of the Las Vegas Valley Water District (LVVWD) in drilling of ASR wells in karst limestone, dual-wall reverse rotary drilling may be a useful technique. This method provided good return of cuttings and detection of fractures by rig chatter, allowed for drill stem tests and permitted reaming to 12 inches for installation of multi-port or nested monitoring wells. Large diameter (18-inch) flooded reverse circulation produced the highest efficiency ASR wells at LVVWD because vacuum action at the drill bit minimized formation clogging and damage during the drilling process.

TASK 3 – DEFINE PRELIMINARY HYDROGEOLOGIC FRAMEWORK

This task is a logical first step for utilizing the information compiled in Task 1. Based on the project schedule summarized in Appendices C and D, this task will begin in January 2003, while some of the data compilation efforts of Task 1 are still in progress. This is a reasonable approach to the iterative process of conceptual modeling of the hydrogeologic framework.

As noted in the task description, the initial conceptual model of the hydrogeologic framework can be used in the development of the initial regional numerical model of flow. The project timetable indicates that numerical model development will begin in August 2003, shortly after the scheduled completion of this task in July 2003. It is not clear, however, that this initial conceptual model development will occur in time to aid in siting of pilot ASR wells (as suggested in the task description). According to the timetable listed in Appendix C, the design and permitting of pilot wells (presumably including siting) will be completed in July 2002 for the Lake Okeechobee ASR pilot project, in September 2002 for the Hillsboro pilot project, and in November 2002 for the Caloosahatchee pilot project. Furthermore, the May 2002 Progress

Report for the Lake Okeechobee ASR Pilot project[4] indicates that three exploratory wells for this project will be permitted, constructed and tested by March 2003.

Identification of data gaps in this task is essential to planning of the hydrogeologic field data collection (Task 6). The plan for Task 6 is to be formulated within a one-month period (mid-July to mid-August 2003) immediately following completion of Task 3. This sounds like an ambitious schedule, but it may be reasonable given that the same divisions of the SFWMD (Water Supply Planning and Development) and the USACE (Geotechnical Branch) are responsible for both Task 3 and Task 6.

TASK 4 – GEOCHEMISTRY

In general, the inclusion of the extensive geochemical and microbial tests and experiments, plus the associated water quality sampling programs for aquifer water and the rock matrix, is commendable and responsive to concerns raised in the review of the ASR pilot projects.

Subtask 4.1 – Data/Literature Review

This subtask is an important initial step. The Project Delivery Team has identified the relevant categories of source materials, including unpublished consultant reports.

Subtask 4.2 – Characterize Hydrogeochemical System

The overall description of this subtask states that it involves "compilation of existing groundwater quality data." However, the individual subtask descriptions indicate that this subtask will actually involve collection and analysis of water samples from existing and new wells, both before ASR operations and during pilot project cycle testing. A better definition of this task would be that it involves "characterizing the geochemistry of *ambient* (or *native*) groundwater in the FAS, prior to ASR testing, and of changes in groundwater geochemistry during ASR testing."

The list of analytes is generally comprehensive. Given the expense of strontium isotope analyses, it would be prudent to assess the variability of these in samples of "native water," aquifer solids, and potential source water prior to making a final decision on the use of these for cycle test estimates of carbonate dissolution during storage.

The analysis of native groundwater is intended to define both vertical and lateral variations in groundwater chemistry and to characterize "different flow zones within the FAS." Collection of samples during packer testing, as proposed, is an appropriate method for characterizing vertical variations in background water chemistry within a given well. If the sampled intervals correspond to discrete flow zones, this approach will partially address the latter objective. However, without additional information on how the 30 wells will be selected, it is not clear whether the planned sampling program will be sufficient to provide useful information on lateral variations, either as a function of regional trends or within specific flow zones. In

[4] See http://www.evergladesplan.org/pm/projects/project_docs/status/ proj_32_current.pdf

addition, the text does not specify whether all 30 of the wells used for background sampling will be subjected to packer tests. If sampling from discrete, packed-off intervals is planned only for the 14 new wells that will be installed as part of the Regional Study, the vertical variations in water chemistry over much of the area may remain poorly constrained. (Of the 14 new wells, a few will be sited to provide hydrogeologic data in areas where there are no existing wells, but most will be located near ASR pilot sites or in areas subjected to pumping stresses.)

Water quality sampling during cycle testing is planned at only three of the five pilot sites during the second, longer duration, round of cycle testing. If there is potential for significant differences in reactions among the sites, due to differences in the recharge water, the native groundwater chemistry, or the rock matrix mineralogy, it may be important to conduct detailed geochemical sampling at all sites during the second cycle of pilot tests. Given the heterogeneity of the FAS with respect to salinity and physical properties at existing ASR sites (Reese, 2002), such spatial variability is likely. Analysis of results from the first cycle test could be used to select an appropriate subset of geochemical parameters for monitoring during the second cycle test at each site.

The statement in this subtask that "[i]t is very important that detection at the monitor wells occur" is very appropriate. However, the continuation of the same sentence that "it is understood that this may not occur, given that the injection volume may be limited" does not follow logically. Detection of injected water is, indeed critical to understanding the physical and chemical behavior of the system. Numerous modeling studies in complex porous media have shown the importance of having data from the entire breakthrough curve of a solute (e.g., McKay et al., 1997; Stafford et al., 1998). Therefore, recharge of the ASR wells should continue, if at all possible, until some time after the injection water is detected at all of the monitor wells, to understand the physical and chemical behavior of the system as fully as possible.

Although there will be four new "multi-zone" wells installed near ASR pilot project wells to provide additional monitoring capabilities, the text and the sampling schedule listed in Appendix F Tab B assume detailed cycle test sampling of only two monitor wells that will be installed as part of the pilot projects. Descriptions of the pilot projects imply that all monitor wells will be sampled to some extent, and the multi-zone wells could provide particularly valuable data on the vertical variations in migration of the injected freshwater bubble. Thus, frequent sampling of these during cycle testing should be a high priority.

There appears to be some inconsistency between descriptions of cycle testing in Subtask 4.2 compared to that in the Functional Area Plans portion of the report (Section 7). On page 23, the text states that "[r]ecovery will continue until discharge water quality TDS (total dissolved solids) and chloride concentrations exceed regulatory thresholds." However, on pg. 91 the text notes "The recovery phase of each cycle will continue to a predetermined water quality level. At this time, the background total dissolved solids content of the canal/reservoir is the expected criterion." Given that the background chloride and total dissolved solids concentrations in the receiving surface water bodies may be well below the regulatory limits, there could be a significant difference in duration of the recovery cycle depending on which criterion is employed.

The background discussion of the summary report on groundwater quality during cycle tests suggests that samples collected during the storage phase of each ASR cycle "best represent geochemical equilibrium conditions between water and rock." The assumption of geochemical equilibrium may not be appropriate if dissolution-precipitation, sorption, or redox reactions are slow. For example, work of Back and Hanshaw (1970) and subsequent studies of the carbonate aquifers in Florida (e.g., Palciauskas and Domenico, 1976) have shown that groundwater at significant distances from recharge areas is not at equilibrium with respect to calcite, dolomite, and other aquifer minerals. The interpretation of results of the cycle tests is planned to consider a variety of processes including redox conditions and “microbial fractionation.” It is not clear from the description whether microbially mediated redox reactions, such as oxidation of dissolved organic carbon coupled to reduction of electron acceptors such as iron and manganese from the aquifer matrix, are among the reactions anticipated. If the source water for ASR injection contains higher concentrations of organic carbon than the native groundwater, these types of reactions should be anticipated.

For the purposes of cost estimation, the PMP assumes two ASR cycle tests, including a short duration test in which recharged water is stored for approximately one month, and a long duration test in which a significantly greater volume of recharged water will be stored for six months to one year. Given that neither of these time frames approaches the multiyear storage that may occur during full scale operation of the regional systems, extrapolation of geochemical results to expected water quality changes during full scale operation would require a good understanding of reaction rates. Will the tests also examine potential effects of seasonal variations in chemical and microbial characteristics of the ASR source water or of the surface water body that receives recovered water?

The purpose of Subtask 4.2 is to characterize the hydrogeochemical system. The Scope states that existing water quality data will be compiled, and samples of groundwater and surface water (Subtask 10.2) will be collected and analyzed. Detailed information is provided on the chemical analytes; however, only vague statements are made with respect to microbial analytes. Specifically, the document states (Subtask 4.2.3 Scope and Subtask 4.2.3.2 Scope) “Other primary and secondary drinking water analytes (…microbes) that are necessary for ASR Pilot Study regulatory criteria…will be analyzed and budgeted in the context of the ASR Pilot Studies.” Given the lack of information provided, it is difficult to evaluate these subtasks. Information on the specific microorganisms to be assayed, the numbers and frequency of samples to be collected, and the locations of those samples is necessary to properly evaluate these subtasks.

In subtask 4.2.3.1, it is not clear why one would look for disinfection byproducts (DBPs) in the native groundwater. While DBPs may be of concern in chlorinated injection waters (e.g., Thomas et al., 2000), it would seem that they would likely not be present in native groundwater.

Subtask 4.3 – Laboratory Geochemical Tests

The description of this task focuses on use of batch and column tests to estimate distribution coefficients (Kds). The use of a Kd to characterize interactions of solutes with the aquifer matrix is only strictly appropriate in the case where the reaction of interest is sorption that can be modeled with a linear, reversible isotherm and if the reaction is fast enough that equilibrium is reached during the experiment. This might include weakly sorbed organic species such as pesticides present at trace levels (Langmuir, 1997). It would not be the appropriate parameter with which to characterize effects of precipitation-dissolution reactions, non-linear or irreversible sorption, or even linear sorption if competing reactions such as complexation or interaction with natural organic matter affect the solute concentration. Most of the species recommended for analysis in Appendix F, Tab B would be involved in one or more of these kinds of reactions. The design of laboratory experiments should be based on specific hypotheses related to the chemical reactions of interest. Subsequent interpretation of results should be based on a more comprehensive set of likely reactions.

Subtask 4.4 – Geochemical Reaction Modeling

The usefulness of this modeling will be highly dependent on adequate identification of the reactions that affect groundwater chemistry under ambient conditions and during ASR operations. Limitations arising from inadequate characterization of native water chemistry in Subtask 4.2, including ambiguities that may result from water samples that represent a mixture from a zone with significant vertical variations in solute concentrations, and those arising from insufficient data on reaction rates and equilibria obtained from Subtask 4.3, could severely constrain this effort.

Subtask 4.5 – Investigations of Water-Rock Microbe Interactions

In Subtask 4.5, interactions between microorganisms and the subsurface materials will be investigated. The document states that field tracer tests will be performed, and then column studies may be initiated, pending the results of the literature review and tracer studies. The rationale behind conducting column studies *after* field tracer studies is not clearly articulated. Typically, column studies are conducted prior to field studies to aid in the design and conduct of the field studies.

Experience at the LVVWD indicates that growth of microbial mats ("floaters") within the stagnant water column of the ASR well during inactive periods of seven days or more can create clogging of the ASR well during the start-up of injection phases. The potential for this type of microbial activity on operations should be assessed. Operations plans may need to address prescribed purge cycles prior to injection to minimize clogging.

Subtask 4.5.1 – Assessing Microbe Transport Potential

Field tracer tests are proposed under this subtask but are not described in sufficient detail to allow for a detailed critique. The success of the tracer tests will likely depend on the adequacy of the monitoring well network to allow for detection of conservative tracers, microspheres (as proxies for microbes) and viruses without excessive dilution. Since this subtask does not describe installation of additional monitoring wells for the tracer tests, it appears that these tests will utilize the monitor wells to be installed under Subtask 6.2. Issues related to those monitor wells are included in the discussion of that subtask. The relationship between the tracer tests proposed for this subtask and those described in Subtask 6.5 is not clear. Ideally, the types of tests conducted under Subtask 6.5, which are intended to measure travel times of water within the aquifer and to yield information on morphology of the freshwater "bubble," should precede any tests designed to examine possible non-conservative transport of micro-organisms.

The project team has recognized the potential problems associated with obtaining the necessary permission to conduct the microsphere and bacteriophage studies. Have any alternative plans been developed to evaluate microbial transport if these two tracer tests cannot be performed? With respect to the microspheres, what size spheres will be used, and what method will be used to analyze the samples? Other investigators have found the sample processing and enumeration of microspheres to be a cumbersome, time-consuming process. How will adsorption of the microspheres to the subsurface materials be assessed? Consideration of the surface characteristics of the microspheres will also be important, as that will greatly influence the potential for adsorption and transport of the particles.

If permission to conduct the tracer studies is obtained, the project team should consider designing the experiments in such a way that information about vertical transport as well as horizontal transport can be obtained.

As a minor point, there appears to be an error in the reference to "microbe survival studies described in Subtask 4.6.3." The relevant subtask is 4.5.3.

Subtask 4.5.2 – Microbe Attachment Studies

In the Background section for this subtask, it is stated that microorganisms range in size from 1 nanometer (1×10^{-9} meters) for certain viruses to 10 nanometers for some protozoa. This is inaccurate; although viruses are extremely small, the lower size limit is generally considered to be approximately 18 nanometers in diameter. Of more concern is that statement about the size of parasites; the (oo)cysts of protozoan parasites, such as *Giardia* and *Cryptosporidium*, are much larger – 5000 nanometers or more in diameter.

In the Background comments for Subtask 4.5.2, it is stated that interactions between microorganisms and the solid surface will likely retard transport. It also should be noted that those interactions may prolong survival of some microorganisms, and may stimulate growth and development of microbial communities with different rates of metabolism and processes from those unattached in the water column.

In the Scope section, the statement is made that the tracer studies will provide qualitative estimates of bacterial transport at field scale. It is not clear whether the word "microbial" was intended in place of "bacterial." If so, the description of the tracer studies (Subtask 4.5.1) is not sufficiently explicit to enable one to conclude that bacterial transport can be estimated

Subtask 4.5.2 is to conduct column studies to assess interactions between microorganisms and the subsurface materials. Due to the nature of the subsurface in the FAS (i.e., the presence of fractures and other features that contribute to secondary porosity), it will be difficult, if not impossible, to obtain representative, quantitative information on transport using column studies. Even in the case of transport in zones where secondary porosity is not well developed, column studies involving vertical flow through cores are likely to be a poor simulation of flow conditions in the aquifer. This is because of the interlayering of high-permeability and low-permeability zones (Reese, 2002), which must result in significant horizontal-to-vertical anisotropy of the unit.

Another consideration when conducting column studies in an effort to mimic field-scale transport processes is the observation that many hydraulic properties (e.g., hydraulic conductivity and porosity) vary on a spatial scale much larger than can be observed in a column experiment. This makes the information obtained in a column study, especially when the column is much smaller than the field of interest, of limited value. Consideration should be given to redirecting the resources proposed for this phase of the project into a better characterization of the spatial variability of the critical hydraulic properties of the field site.

The document also states that the microorganisms to be used in the column studies will be determined through the literature review. As relatively few studies of microbial transport have been conducted in materials that resemble the FAS, reliance on the literature alone may not be sufficient to determine the most suitable microorganisms. The project team should consult with experts in the field to ensure that the microorganisms chosen are appropriate for this purpose.

Subtask 4.5.3 – Microbe Survival Studies

The down-hole diffusion chamber studies are a relatively novel and potentially effective method to assess rates of subsurface inactivation of microbes of interest. Four bacteria and one virus will be used in the study. As it is well documented that some parasitic protozoans are capable of surviving for extensive periods of time, why are they excluded from the survival studies? Given the presence of fractures in the FAS, these microorganisms might be transported.

Subtask 4.5.4 – Literature Review: Microbe-Induced Changes in Metal Mobility and Toxicity

The literature review conducted under Subtask 4.5.4 will serve as the basis for the experimental design in this task. However, from the description it is not clear how that review will form the basis for deciding which microorganisms will be used in the survival studies.

TASK 5 – PRESSURE INDUCED CHANGES

A potentially significant limitation of modeling efforts proposed for this task stems from the anticipated assumption that hydraulic and geotechnical properties of the limestone and Hawthorn Group deposits are homogeneous and isotropic. This is unlikely to be true at most scales (e.g., Yobbi, 2000). At the least, this assumption at the scale of the test should be supported by an analysis of available data from hydraulic and geotechnical tests on these units.

As noted in the previous CROGEE review of ASR pilot studies, these studies of pressure induced changes and fracture potential should be combined with results of the regional hydrogeologic models in order to assess the potential for fracturing during full-scale ASR operation. It appears from Appendix C Tab C that such an evaluation will be made; this should be made more explicit in the text.

In addition to an assessment of fracturing potential resulting from pressure buildup during injection, it will be important to assess both local and regional scale changes in flow patterns as a result of ASR operations. These effects can be examined through a combination of field testing and modeling that are incorporated in Tasks 6 and 9, but some relevant questions and informative observations based on the LVVWD experience are included within the critique of this task since it deals specifically with pressure induced changes. Although the LVVWD initially assumed that pressure changes would not be a significant factor, these have turned out to be major constraints on operations. (Here, as elsewhere in the report, the experience of the LVVWD is highlighted. Although there are major differences between the hydrogeologic conditions at the LVVWD and south Florida, the experience gained at LVVWD illustrates many practical issues that should be considered.)

- *Will the increased head in the FAS cause pressure-induced changes in the surrounding area and aquifers?* At the LVVWD, unanticipated increases in head of nearly 100 ft in the aquifer systems created a potential for loss of water to surface streams (or dry creek beds) and structural problems for building foundations. The locations of injection had to be modified during operations to manage these problems.
- *What are the general directions of head increases in the FAS resulting from large-scale injection?* The LVVWD found that the injection wellfield created a mound that functioned as a hydraulic "dam" in the groundwater system. Outflow on the downstream side of the dam remained similar to pre-injection rates, but natural recharge pooled upstream of the injection area creating a regional mound in the valley. Under these conditions, two sets of monitoring wells are needed: downgradient wells to detect and recover water quality samples and upgradient wells to monitor the pressure head changes. Again, the proposed monitoring for the pilot and regional studies is likely inadequate to assess these effects.
- *What down-gradient regional flow patterns will occur resulting from perturbed heads near the ASR wells?* The increased flow induced by injection can be accommodated by increased heads and hydraulic gradients or by increases in flow system permeability downgradient of the injection mound due to dissolution. Development of a new equilibrium gradient between the well field and regional discharge areas may occur quickly, take tens of years, or may not be possible at all due to poor conductivity in the fractured flow system. It is also important to recognize that migration of a pressure front may not correspond to migration rates of the injected water. In the LVVWD, the groundwater mound developed as a result of injection appears fairly stable at this time. However, the actual injection water may have moved much farther away as upgradient water appears to be present within the area of the hydraulic dam. This again suggests questions of how many monitor wells are needed to track the chemical and hydraulic properties.
- *What impact will pressure head changes have on the injection performance of the wellfield?* The experience at the LVVWD indicates that as pressure rises in the formation, the injection rate gradually declines by as much as 20-30 percent during an eight-month cycle of continuous recharge. While this was initially attributed to clogging by bacteria, air, and precipitants, further analysis revealed that this was the result of hydraulic interference (Morris, 2001; Morris and Quinn, 1999; Cole et al., 1995). Failure to recognize the mechanism responsible for decreased injection efficiency led to costly studies of biogeochemical processes and well rehabilitation efforts. The difficulty in identifying the hydraulic controls on injection rates was partly the result of the narrow cones of impression, with less than one foot of water level rise observed in a monitoring well within 150 ft of the injection well. This again points to the necessity of careful placement of monitoring wells to detect pressure head changes within the wellfield as well as at the wellhead. Given the uncertainty of the local and regional hydraulics, the pilot projects probably need at least one on-site monitor well within 100-500 feet. Recalling that directions of water movement may not coincide with observed directions of pressure head changes, an additional three to four monitor wells within 1,000-2,000 feet of the test well in all possible flow directions are recommended.
- *What effect will the resulting pressure head changes have on recovery equipment performance?* Although the introductory section for this task mentions potential limitations on pumping equipment as a result of pressure changes, this topic is not discussed in much detail in

the subtask descriptions. The LVVWD experienced nearly 100 feet of pressure head change at some wellheads, resulting in pumps operating far outside of optimal ranges based on their efficiency curves. This reduced the lifespan of some of the pumping systems by half. With the 100-foot head change (accumulated over 10-years), pump bowls of 67 recovery wells had to be restaged at least once, if not twice, to keep up with the changes. This resulted in a very large capital cost item that had not been foreseen in the early stages of the project. If pressure head shifts of 30 feet or more are anticipated, then an aggressive maintenance and pump repair program must be evaluated, cost accounted for, and implemented. Other users in the hydraulic zone of influence may experience the same difficulties and may require compensation for additional pump repair costs.

TASK 6 – HYDROGEOLOGIC FIELD DATA COLLECTION

Subtask 6.1 – Formulate Field Data Collection Plan

This subtask explicitly recognizes the potential need for revision of field plans in response to new knowledge acquired during earlier stages of the study, and thus is consistent with an adaptive management approach.

Subtask 6.2.1 - Test Well Pairs

Leakance of the Upper Floridan aquifer, or more selectively the target ASR zones, is an important hydraulic parameter for construction of the numerical models for simulating head changes and solute transport. The Project Delivery Team recognizes the lack of reliable leakance data and has proposed gathering such data through aquifer performance tests at several locations using pairs of wells, one that is a production well and one that is a monitoring well. Although the monitor well is described as a "tri-zone" well, the intervals to which this well will be open are not specified. If both the production well and the monitor well are open only to intervals within the ASR zone, then the leakance determined through the test analysis will be a lumped leakance representing flow out of the top and bottom of the ASR zone. An additional monitoring well open somewhere in the lower part of the Hawthorn Group is one way to evaluate the extent of upward leakage versus the downward leakage component. Application of the Neuman-Witherspoon method of analysis (1968, 1972) is applicable in this regard. Evaluation of the hydraulic connection between the FAS and the overlying aquifers could also be done with a monitoring well open to the Surficial Aquifer System (SAS). An alternative approach is given later in this subsection.

Coring, geophysical logging and packer tests on the first well of each pair should yield useful information on vertical variations in hydrogeologic properties. A coordinated program of water quality sampling while intervals are isolated for packer tests could contribute to activities of Subtask 4.2 on hydrochemical characterization.

The first well is to be completed as a "tri-zone" monitor well. It is not clear from the description how the three zones selected for monitoring will be chosen. Will these be three zones within the FAS or will they include one interval in the SAS, one in the intermediate confining units, and one in the FAS? What are the expected lengths of the open intervals in the monitor zones? If long open intervals are anticipated, how will complications arising from vertical gradients be resolved? How will these zones be isolated from each other for monitoring (packers, multilevel devices such as a Westbay Type sampler, other)? Will the proposed method of isolation allow for simultaneous and continuous monitoring of water level responses in all three zones, or only for monitoring of a single zone, followed by deflation of packers and re-setting them at a different position in the borehole?

The second borehole will be pumped for stress tests repeatedly during its construction; at times its depth extends to selected test intervals. It is not clear from the description whether the well will be cased (or packed off) above (a) the top of the FAS and or (b) the top of the selected test interval during these tests. The relationships between the proposed test intervals for the pumping well and the three zones of the monitoring well are not discussed. The usefulness of these tests to evaluate leakance will depend on appropriate selection of monitoring intervals and pumping zones.

One strategy for evaluating leakage between the FAS and the SAS, based on experience from the LVVWD, might be the following. First drill down to the Hawthorn and test the lower SAS. Then drill to the base of the Hawthorn, cement back 10 feet, and test the combined Hawthorn and SAS. Drill through the Upper Floridan aquifer (UFA), pack off at the 10-foot grout ring at the base of the Hawthorn, and test. Drill to the base of the confining unit between the upper and lower UFA, cement back 10 feet, pack at the Hawthorn, and test. Finally drill to the total depth of the lower UFA base, pack off at grout ring in the UFA confining unit, and test.

Subtask 6.2.2 - Pilot Site Monitor Wells

The new monitor wells proposed in this subtask are generally responsive to CROGEE recommendations that additional monitoring wells be installed that allow sampling of discrete intervals to assess the geometry of the freshwater "bubble" and the extent of mixing between injected and ambient pore water during storage. However, the text provides no information on how many discrete zones will be available for sampling in each of these wells, which makes it difficult to assess whether the proposed wells will be adequate. The description also does not include any information on how long the open intervals in these zones will be and how they will be isolated from each other. Different sets of zones might be optimal for different objectives such as characterizing vertical variations in native groundwater chemistry, identifying first arrival of injected water during tracer tests, or constraining the geometry of the freshwater "bubble."

Overall, as noted in preceding discussions under Task 5, a single monitoring well per site will make characterization very difficult. There is a potential that pressure head changes and fresh water plumes may not coincide, and may even migrate in different directions. When attempting to predict and explain pressure responses or water-quality changes, it should be kept in mind that the UFA is not homogeneous and isotropic because of fractures and solution conduits, especially at the local scale. It is strongly anisotropic in at least the vertical direction and in places also laterally. Without information on regional effects and the potential for the reversal of local flow directions, three to four monitoring wells within 1000-2000 feet of the pilot ASR wells would be advisable, with each of these being multi-port/nested piezometers that can be used to detect heads in discrete zones. Shortchanging monitoring during the initial phases of this multi-billion dollar project will result in many lost "golden opportunities of information" down the road during the operation phase.

Subtask 6.2.3 - Single Wells with Continuous Cores

The four wells proposed for this subtask should provide a very useful set of core samples for stratigraphic analysis, geotechnical testing, and rock geochemistry. The proposed geophysical logging and packer testing will provide valuable information on hydraulic properties and correlations with lithologic properties. In addition to standard geophysical logs, borehole flowmeter tests conducted in these wells under ambient and pumping conditions could also provide useful information on preferential flow zones. As in the case of the test well pairs, water quality sampling could be conducted in conjunction with packer testing to provide additional constraints on vertical variations in native groundwater chemistry. This information might also be useful in selecting open intervals for completion of the wells as monitoring points.

Despite the potential usefulness of this subtask, it should be recognized that continuous coring is costly and it may not yield useful data in some geologic settings. Scale-dependency of hydraulic conductivity, for example, in heterogeneous or anisotropic porous media, is well established (Schulze-Makuch et al., 1999). As a practical example, the LVVWD spent a fair amount of time and money in the beginning trying to retrieve good core to characterize the in-situ conditions. They experienced multiple failures trying to get representative cores from flow zones because the flow zones had fractures and enhanced permeability features, all easily destroyed by the mechanical coring process. In contrast, excellent core recovery came from the non-fractured, no-flow sections. Laboratory tests to determine hydraulic properties from disturbed sections would yield unreliable data. Such core could, however, be used for leaching experiments, but not for determination of hydraulic properties. Given these limitations, it might be prudent to reduce the coring program and use the savings to support installation of additional monitoring wells for field tests of hydraulic properties and for hydrogeochemical characterization.

Subtask 6.2.4 - In-fill Near Pumping Stresses

The two wells to be drilled under this subtask will be completed as "dual-zone" monitor wells. It would be useful to include information on how these zones will be selected. Are they intended to provide information on vertical variations in response to pumping within the FAS, between the FAS and the SAS, or between the FAS and some other hydrostratigraphic unit? As in the cases of other new wells, geophysical logging and packer testing will yield valuable information. Again, a water-sampling program that is coordinated with the packer testing could contribute to Subtask 4.2.

Subtask 6.3 - Seismic Reflection

The proposed use of seismic reflection surveys to provide information on regional stratigraphy and structure is responsive to recommendations from the previous CROGEE review of the ASR pilot studies. Filling data gaps in the area covered by Lake Okeechobee is a reasonable initial focus for new data collection activities.

In the subtask devoted to analysis of previous seismic survey data, the maximum coverage of existing seismic reflection lines to be reprocessed is limited to 10 miles. This seems inadequate for an aquifer system that covers such a large portion of the state of Florida. Perhaps the 10-mile length refers to an initial purchase and processing to assess the usefulness of this approach. If so, the PMP should clarify that success of this method would trigger purchase and reprocessing of additional seismic data sets.

Subtask 6.4 - Groundwater Monitoring

Water level records collected from the network of wells should provide very useful data for calibration of the regional flow model. The distribution of available monitoring wells and target areas for additional monitoring shown in Figure 2 of the PMP appear to provide reasonable areal coverage. Re-evaluation and refinement of the network at the end of the initial three years (as proposed in the PMP) should make use of sensitivity information obtained during initial phases of the regional model development.

No information is provided on the location of the 20 wells that will be used for the monthly water quality samples proposed for this subtask. Thus, it is not possible to assess the adequacy of the areal coverage that will be provided by these samples. Perhaps even more significant is the lack of information on elevations of open intervals in the wells and the potential for these to provide resolution of vertical variations in salinity that may be important to calibration of the density dependent flow model. Without information on the anticipated temporal variations in salinity at the sites selected for monitoring, it is not clear why a monthly sampling frequency was selected.

Subtask 6.5 - Tracer Tests

As noted in the discussion of Subtask 4.5, there is no information provided in the PMP on the relationship between these tracer tests and those proposed to evaluate microbial mobility and survival. As in the case of the tracer tests described under Subtask 4.5, there is no information provided on construction of monitoring wells for these tests. The success of the tests will be highly dependent on the availability of an adequate monitoring network. Design of an adequate monitoring network may require an iterative test program to identify potential preferential flow paths based on hydraulic and geochemical characterization. In particular, it should be kept in mind that the direction of fresh water plume migration may not correspond to directions of maximum changes in pressure head.

With an adequate monitoring network in place near a pilot ASR well, monitoring of conservative solutes that are present in or added to the injected water during ASR cycle tests could provide an additional set of tracer data.

Subtask 6.6 - Field Testing of Existing Wells

Geophysical logging and hydraulic testing of existing wells should provide useful information at a reasonable cost. Experience at the LVVWD suggests that the following log suites may be particularly useful:

- Geologic information: focused induction, 16-64 resistivity, natural gamma
- Water movement: temperature differential, fluid resistivity, spontaneous potential
- Porosity/Voids/Fractures: sonic, focused induction, 16-64 resistivity, caliper.

In addition to these suites of geophysical logs, borehole flowmeter logging should also be considered.

Subtask 6.7 - Tomography

Inclusion of seismic tomography in this study to help characterize the permeability and porosity variations in the aquifer around a pilot ASR well is particularly commendable. This technique, developed in the petroleum industry, may be the best approach to acquiring information needed to understand the movement of the injectant away from the ASR well and for developing a realistic local scale solute-transport numerical model for predictive purposes. It should be noted, however, that this method does not yield a direct measurement of permeability. Derivation of “permeability cross-sections” will, therefore, require demonstration of a strong correlation between seismic signatures and hydraulic properties measured with similar support scales.

Subtask 6.8 - Post-Cycle Test Logging

While this logging following cycle tests is a reasonable exercise, the short duration of the cycle tests may not be sufficient to induce readily measurable changes in permeability due to dissolution of the aquifer matrix. However, the LVVWD has experienced increased production over time in the nine wells situated in a “limestone like” fracture flow setting. During long-term operation, annual production and injection performance efficiency testing may be useful to identify wells that are candidates for repeated logging to interpret changes in hydraulic properties.

Perhaps the most useful method proposed in this subtask is the placement of a well-characterized sample of the FAS in the well during cycle tests, with re-characterization of the sample after completion of the cycle testing. In contrast, it may be impossible to infer changes in porosity resulting from cycle testing in new cores collected after the cycle tests since natural heterogeneity would preclude direct comparison to any cores collected prior to the tests.

TASK 7 - LABORATORY ANALYSES

Subtask 7.1 – Geotechnical Testing

Given that these tests are designed to evaluate effects of pressurization on the rock matrix, it would be useful to clarify which of the proposed geotechnical tests will be used to estimate pressures at which the rock will fracture.

Subtask 7.2 – Analysis of Core and Cuttings

In addition to the proposed core sample analysis of porosity and permeability, presumably using cylindrical "plugs," air permeameter measurements on split core could provide additional constraints on permeability of the carbonate in zones that have not be extensively altered by dissolution.

The proposed thin section work may be useful for the sequence stratigraphy analysis, but it may not provide useful data on porosity, since the porosity of primary interest is that caused by the megascopic fractures and solution conduits that will not be captured in the thin sections.

A minor point is that while the PMP title for this subtask specifies "*existing* core and cuttings," the more detailed subtasks also include analysis of *new* core.

Subtask 7.3 – Geochemical Analysis of Rock Matrix

A fairly comprehensive set of analyses is proposed in this subtask. While the total number of samples (280) is large, the limited number of samples from any one core (8) may constrain the potential to evaluate local-scale vertical heterogeneity. Samples from the cores will need to be selected carefully and with the objective of testing specific hypotheses related to sources and mobility of metals or other constituents of interest. An iterative approach should be considered in which a limited number of samples are selected for initial analyses and results of those analyses are used to inform the selection process for subsequent samples.

Subtask 7.4 – Fracture Trace/Lineament Analysis

Identification of major structural features by interpretation of remote sensing images should be useful to the development of the regional hydrogeologic model.

TASK 8 – FINALIZE CONCEPTUAL HYDROGEOLOGIC FRAMEWORK

The flexible approach outlined in the description of this task is appropriate given its dependence on results of the field and laboratory programs. This task will need to be closely coordinated and integrated with the following task on regional groundwater model development.

TASK 9 – REGIONAL GROUNDWATER MODELING

Construction of the regional numerical model should begin early in the time frame of the regional study, as soon as the preliminary hydrogeologic analysis is completed. Such a model could be useful in defining a framework for studying the system dynamics and in organizing field data even before calibration, prediction, and sensitivity analysis are performed (Anderson and Woessner, 1992). The PMP states that the task "Regional Model Development - Phase I" will begin in August 2003, directly following the task "Define Preliminary Hydrogeologic Framework." However, the text suggests that much of the initial work on the modeling will be directed towards choosing an appropriate code and developing algorithms to handle density dependent flow. Although the final model is intended to be capable of handling density-dependent flow, initial regional-scale modeling efforts employing available codes that do not have the capability to handle variable density problems may still be useful to guide the test-drilling program and associated data acquisition as well as the aquifer performance test program. This is especially true in areas with lower salinity, or where pumping-induced gradients are high. Modifications can be made to this model as the acquired data warrant in parallel with development of models with density dependent flow capabilities. Overall, the PMP outlines a reasonable strategy for developing, calibrating, testing and documenting a regional model as well as high-resolution inset models of selected areas. The Project Delivery Team recognizes the many technical challenges that will need to be addressed. It is not clear if the potential importance of horizontal anisotropy in hydraulic parameters will be evaluated, as in Yobbi (2000). Given the generic nature of the modeling task description provided in the PMP, a more substantive critique of the modeling methodology is not possible at this time. Comments relevant to the water level and water chemistry data that may provide constraints on these models are included in the discussion of Subtask 6.4. Calibration efforts should also make use of flux targets wherever possible to provide improved constraints on model parameters and boundary conditions. The Project Delivery Team should be commended for including peer review of the methodology and of the resulting model throughout the development process.

ECOLOGICAL AND WATER QUALITY STUDIES – APPENDIX L AND TASKS 10-13

Tasks 10 - 13 are, in general, not described in the Project Scope (section 3.0) in detail sufficient to evaluate the adequacy of the monitoring or experimental studies. Also, these task descriptions are not as fully developed as are those of Tasks 4, 6, 7 and 9, which also address field and laboratory studies and modeling efforts. Appendix L, Ecological and Water Quality Studies, provides far greater detail and clarifies many of the questions that are raised by the task descriptions. Overall, there appears to be a poor linkage between the task descriptions provided in the main body of the PMP and the descriptions of studies in Appendix L. The appendix provides much of the needed description of these tasks, but it is never cited in Section 3 of the PMP. Either information that is contained in Appendix L should be incorporated into the task descriptions, or there should be substantial citing of appropriate sections of the Appendix throughout. There also appear to be some inconsistencies between the task descriptions and the Appendix.

The comments on the following tasks are, in many cases, integrated with comments on related aspects of Appendix L. For this reason, they are not strictly organized according to the subtasks specified in Section 3 of the PMP.

TASK 10 – SURFACE WATER QUALITY DATA ANALYSIS

Components of this task are presented in a very general way, without detail about monitoring or experimental studies. One example of the lack of clarity here is the statement that "...interim environmental effects evaluation report will begin after 5 years of data collection." It is not clear what data are to be collected for five years, where the data will be collected, and for what specific purposes. Similarly, it is not clear what sort of environmental effects will be evaluated. Some aspects of these studies are described much more fully in Appendix L, and it would be useful to cite appropriate sections of Appendix L throughout the description of this task.

It is not clear why Tasks 10 and 11 are separated rather than combined into a single task. Task 10 focuses on surface water quality assessment, but it also has a subtask on environmental effects evaluation that includes development of a conceptual model of the major processes affecting contaminant fate, transport, and receptor exposure. These data and the model are to be used in designing the experimental studies that are discussed in Task 11, and Subtask 10.4 is repeatedly cited in Subtasks 11.3 and 11.4.

Subtask 10.1 - Establish Study Area, Source Basins, and Relevant Water Quality Criteria. Subtask 10.2 - Characterize Potential ASR Water Supplies.

These two subtasks will provide descriptive information on the potential sources and volumes of water potentially available for ASR. They are necessary prerequisites for planning regional implementation of ASR and, although few details regarding their scope are given, they appear to yield the required information.

Subtask 10.3 - Compile and Evaluate Existing Surface Water Quality Data

This compilation and review of existing data is an important task. The scope states that it will be done "to identify and flag non-compliance by location and parameter." It is not clear what criteria will be used to define non-compliance. Furthermore, Florida's existing Class III water quality criteria (for protection of fish and wildlife) may not be sufficient to ensure that use of ASR water does not have negative ecological impacts.

Subtask 10.4 – Environmental Effects Evaluation

This subtask focuses on exposure to contaminants and their toxicological properties and on whether full-scale ASR implementation will increase risks to humans and ecological resources. As recommended in the previous CROGEE review of ASR pilot studies, experimental studies are to be developed to assess ecotoxicological and environmental effects. The scope does not describe the nature of these experimental studies, and reference should be provided to the appropriate descriptions in Appendix L.

Subtask 10.5 – Surface Water Quality Data Validation

It would be useful if the term “data validation” were defined in the text.

Subtask 10.6 – Final Surface Water Quality Evaluation

The proposed trend analyses to determine potential long-term water quality problems are a critical part of the process. It is especially important that future water distribution patterns be considered, given the great diversity in chemical composition among surface waters within south Florida.

TASK 11 – WATER QUALITY MONITORING OF SOURCE AND RECEIVING WATERS

The monitoring and experimental studies described in this task are a critical part of the overall PMP. This includes not only monitoring of surface water for an array of parameters, but also chemical analysis of biological samples in the waters. The various subtasks are described in only very general terms, and it is not possible to evaluate the adequacy of the monitoring program or of the experimental tests. More complete descriptions are given in Appendix L. It would be appropriate to incorporate that information into the scopes of the subtasks in this section, or provide references to the more detailed descriptions in the appendix.

Subtask 11.2 – Early Source/Receiving Water Quality Monitoring

Five ASR Pilot intake/discharge locations are to be monitored, but there is no information about which sites will be monitored, or how they will be distributed geographically and in terms of their discharge waters. The scope indicates that a broad array of parameters will be measured, as well as chemical analysis of periphyton, macrophytes, sediment, fish and mollusks. No further information is provided about which water quality parameters or what biotic species will be included, frequency of sampling, and other aspects of the monitoring program. This information is not given until Appendix L.

TASK 12 – SURFACE WATER QUALITY MODELING

Subtask 12.1 – Lake Okeechobee Ecosystem Modeling

This task involves simulation modeling of dilution, dispersion and transport to interpret the bioassay results in the context of regional impacts to the lake ecosystem. This section refers to ecotoxicological bioassay tests, which presumably are those alluded to in Task 10, Subtask 10.4. There is not an adequate description of these tests, however, to allow evaluation of their suitability. Either further description, or reference to appropriate sections of Appendix L, should be provided here. It is also not clear how submerged aquatic vegetation (SAV) will be sampled and incorporated into the model.

Based on the information provided in the PMP, it is not clear why the Lake Okeechobee ecosystem modeling (Subtask 12.1, p. 59-60) will be done. The lake water has high dissolved solids and nutrient concentrations already (Steinman et al., 1999), and it is not likely that aquatic organisms in the lake (including fish and SAV) will be sensitive to major ion levels or nutrients in water recovered from ASR wells. It is possible, of course, that radionuclides or heavy metals leached from the aquifer could pose a problem for plants and animals in the lake, but that does not seem to be the focus of the modeling effort proposed in Subtask 12.1. It seems much more likely that negative effects of ASR-recovered water could occur within the Everglades itself, where surface waters are low in nutrients and dissolved solids, and where input, either directly or via pathways that include Lake Okeechobee, of recovered ASR water with relatively high ionic strength would represent a major ecological change. More emphasis should be placed on modeling of these more sensitive ecosystems and identifying water quality changes that could cause irreversible shifts in community composition.

Subtask 12.2 – Ecological Methylmercury Model (plus other studies related to mercury bioaccumulation)

This section responds in part to the ASR Issue Team's recommendations (1) to continue ongoing biogeochemical studies and modeling to simulate the effects of chloride and sulfate concentrations on methylmercury production and its bioaccumulation, and (2) to evaluate the effects of ASR on chloride and sulfate concentrations at the point of discharge into the Everglades. Accordingly, the research proposed in the PMP focuses primarily on biogeochemical processes and modeling.

As noted by the ASR Issue Team, mercury bioaccumulation potential is often correlated with chloride and sulfate concentrations of water bodies, and inversely correlated with pH (e.g., Jornberg et al., 1988; Grieb et al., 1990). In addition, mercury concentrations in tissues may also be inversely correlated with alkalinity, calcium, conductivity, and chlorophyll a concentrations (Lathrop et al., 1989), and selenium (Paulsson and Lundbergh, 1987; Nuutinen and Kukkonen, 1998). Total organic carbon in water may also be important, although its effects are still poorly understood (Jornberg et al., 1988; Mason, 2002). Planned mercury modeling or biomonitoring efforts may be enhanced by consideration of some of these species.

Biological and ecological factors also have a strong influence on mercury bioaccumulation. Changes in water flow or quality associated with ASR could influence biological processes, potentially shifting species abundances and thereby changing trophic dynamics. This may influence mercury concentrations in higher trophic level species such as alligators (Khan and Tansel, 2000). Such effects could be positive or negative. Studies assessing changes in trophic structure and biomagnification of mercury similar to those of Cabana and Rasmussen (1994) and Cabana et al. (1994) would generate essential data complementing those from biogeochemical studies already planned.

The concentration realized in an organism is also strongly influenced by its age and size (Bache et al., 1971; Olsson, 1976; Rincon et al., 1987). Thus, if hydraulic flow or water quality altered growth rates through changes in primary productivity or trophic structure, mercury concentrations in sports fish consumed by humans could change. Fish of a legal size would tend to be younger or older than legal sized fish present prior to the change in growth rates. This potential for human risk due to subsistence fishing in some Lake Okeechobee basin communities reinforces the recommendation that careful attention be given to ecological as well as biogeochemical factors. The proposed risk assessments to be conducted as part of the regional ASR study should examine the human health risks associated with enhanced exposure to mercury in fish and should pay special attention to risks in the most sensitive human populations. Statistical models of trophic structure (i.e., studies applying nitrogen, sulfur, and carbon isotopic ratios) should be developed to document any shift in potential for accumulating higher concentrations of mercury in key species.

Overall, the planned studies on mercury methylation and bioaccumulation are responsive to the Issue Team's (1999) call for further study of these issues. The proposed tasks could be better described and organized, however, to facilitate evaluation. Subtask 12.2 (p. 60) "Ecological Methylmercury Model" is brief and lacks details on what will be done. It refers forward to Subtask 13.5 for details, but the latter section deals primarily with fish/mollusk mesocosm tests designed to evaluate radionuclide bioaccumulation, not mercury. In turn, this section refers to Subtask 13.4 for a brief description of mercury methylation testing, which involves mesocosms to evaluate effects of recovered ASR water at five pilot wells on mercury methylation rates. More detailed descriptions of the mesocosm studies should be provided, especially with respect to how long the studies will be continued. Additional questions related to Subtask 13.4 stem from the statement that it will be done only if the interim environmental effects evaluation report (Subtask 10.4.2) indicates that enhanced mercury methylation is a significant risk of ASR implementation. Subtask 10.4.2, presumably part of Subtask 10.4, is not described explicitly in the plan. Neither Subtask 10.2 nor Subtask 10.4 is further subdivided, and neither mentions anything about mercury.

TASK 13 – ECOTOXICOLOGICAL AND ECOLOGICAL FIELD STUDIES

The studies described here are critical to assessing the effects of ASR discharge waters on the Everglades ecosystem. As is noted, recovered waters may be more or less toxic to native flora and fauna. The likelihood that changes in the biota will occur cannot be determined merely by conducting chemical analyses as part of the Pilot ASR or by short-term laboratory bioassays. In its previous review of the ASR pilot program, CROGEE recommended that ecotoxicological studies, including long-term bioassays be conducted at the field scale to evaluate the ecological impacts of water quality changes. The studies proposed here will be valuable in assessing these impacts but not adequate to fully determine their ecological extent. There is too little information provided in this section to judge the experiments, although more detailed descriptions are given in Appendix L. In addition, throughout this section the focus is on ecotoxicological screenings, which give an indication of individual organism/species response but not of potential shifts in community composition. Studies should consider effects on community composition, especially of the vulnerable and fragile periphyton and SAV communities of the oligotrophic southern areas of the Everglades.

Subtask 13.1 – Screening Bioassays

A general concern about the proposed bioassays relates to the analysis of ecological effects within the Everglades of recovered ASR water. Appendix L states that screening bioassays will be conducted with three standard laboratory test species and with two native organisms. Use of standard test species such as fathead minnow (*Pimephales promelas*), water flea (*Ceriodaphnia dubia*), and green algae (*Selenastrum capricornutum*) allows some comparison with other toxicity studies, but will not get at the concerns that ecologists have about negative impacts of ASR water on native biota. Native Everglades species should be used as indicator species in the screening bioassays. The native SAV bioassay should include an analysis of the periphyton component that is usually associated with it.

Such bioassays will provide useful results only in a gross screening sense and only if the results are "unfavorable." That is, if acute or chronic toxicity is found with these organisms, the investigators will have to conclude that the recovered water is toxic. However, if toxic effects are not found, the investigators will not be able to conclude that the recovered water is "safe" for organisms in the Everglades – or even in the other areas that will receive recovered ASR water. This is because a major concern about ASR is not that the water is toxic *per se*, although it may be, but that the water is unsuitable for plant species and possibly some animal species that are well adapted to the low-nutrient, low-alkalinity, soft water that presently characterizes the Everglades. Such organisms may not die in recovered ASR water, at least not within the relatively short duration (a few days for algae to four weeks for fish) of the proposed bioassays. However, because they are not adapted to these conditions, they likely will be replaced over time by plants and animals that prefer more alkaline, hard waters. The situation is analogous to the replacement of native emergent plant species in the conservation areas by cattails. The native plants do not die because of high nutrient levels; they simply are out-competed by the cattails when nutrient levels are elevated.

Subtask 13.2 – Extended Bioassay Testing

The stated purpose of this task is, very appropriately, to examine longer-term ecological effects of water recovered from ASR pilot facilities on native aquatic biota. Recovered water from the five ASR Pilot wells that has been subjected to different storage periods will be used in mesocosms containing the species of interest. Simple bioassays, as proposed in Subtask 13.1, are not adequate for this purpose. Subtask 13.2 makes a small step in the right direction in that it will "include species of aquatic biota typical of Lake Okeechobee (and the Everglades)...." It is not clear why "the Everglades" is included only in parentheses in both paragraphs of this section. Is this because inclusion of Everglades biota is not a firm decision? Exclusion of what is likely the most critical group would be unfortunate.

There is insufficient information about the experimental design, including what test species may be used, to evaluate the overall adequacy of the study. It might be inferred that the tests will be similar in scope and lack of complexity to those in Subtask 13.1; that is, they will not involve mesocosms of sufficient physical scale and biotic complexity to provide a real test of the sustainability of the biotic communities in the receiving waters if they are exposed to recovered ASR water for months or years.

The Project Scope Subtask 13.2 indicates that the mesocosm studies will examine effects on aquatic biota from three sites: Lake Okeechobee (and the Everglades), the Caloosahatchee River and Estuary, and the St. Lucie River and Estuary. Appendix L also describes extended bioassay testing, but the areas to be examined are not consistent with those in Subtask 13.2. Here, the areas listed are Lake Okeechobee, the Caloosahatchee River and Estuary, and the Everglades Protection Area. This would seem to be a more appropriate choice of sites, and certainly the tests should include the aquatic biota of the Greater Everglades. Not only should there be consistency regarding the selection of sites for the extended bioassay testing, but the PMP should also include a thorough rationale for the selection of these sites in relation to overall goals. In general, the emphasis in this section of Appendix L is generally on response of individual taxa rather than on community level effects. There should be more consideration of shifts in community composition as well.

The test organisms described in section 3.2.1.1 of Appendix L include algae, plants, invertebrates and fish, and thus are an expanded list beyond those used in the screening bioassays (3.1). This appears to be an appropriate choice of taxa for these studies. Changes in the taxonomic structure of the periphyton community should be a sensitive indicator of water quality. It should be mentioned in the task description of the Project Scope section that such assessments of community change will be used as indicators of effects on the ecosystem.

The experimental treatment section of Appendix L (3.2.1.2) describes important components of the ecological studies not mentioned in the Project Scope, such as evaluating the effects of duration of storage of ASR water, dilution with surface water upon recovery, and the seasonality of release. All these factors need to be incorporated into both ecotoxicological studies and experimental studies of community impacts.

Section 3.2.3 of Appendix L acknowledges the current uncertainty regarding the specific routing of ASR water to the Everglades marshes and points to the need for assessments of potential impacts to central and southern areas. This point is not made in the Project Scope, but it should be. These assays will examine scenarios that include direct discharge to the marsh, discharge to the canal network and then to the marsh, and discharge to the canal network, through the stormwater treatment area (STA), and then into the marsh. The assessment of potential impact should definitely be extended to all environments that may be affected by the discharges, and these studies should be considered a critical component of the overall assessment of the ecological effects of ASR. This section also states that a variety of response variables, including community characteristics, will be measured.

Subtask 13.3 – Monitoring of Localized Biological Impacts

This task calls for surveys of selected biota in areas of potential effect at four ASR Pilot facility discharge points. It is not clear why four sites were chosen, when other monitoring and testing are to be conducted at five sites, and again a rationale should be given for selection of these sites in relation to overall goals. It would seem appropriate to conduct extensive surveys of the biological communities at these sites, rather than of selected biota, in order to evaluate shifts in overall community composition. Perhaps such broad surveys are intended, but this cannot be determined from the description. One baseline survey at each site is likely to be insufficient to characterize the biotic community, and will not catch seasonal variability or that associated with rainfall or other hydrologic inputs; thus, this would appear to be a minimal baseline data set.

These surveys are expected to occur over a 24-month period, and to occur during six- to twelve-month recovery cycles and upon termination of a six- to twelve-month recovery cycle. It is not clear that this sampling period will allow assessment of potential long-term effects on community composition. Furthermore, the effects of discharged ASR water also may be greatly influenced by additional factors, such as rainfall and season of discharge, and such variability may not be measurable in these relatively short duration survey periods.

APPENDIX L, SECTION 3.2.3.1 – ECOLOGICAL INDICATORS

Ecotoxicological and ecological field studies (Task 13) are integrated with surface water quality monitoring (Tasks 10-12) to conduct a risk assessment (Appendix L, section 2.0) for several possible contaminants in water recovered from ASR wells. The likelihood of acute toxicological effects appears to be remote. It is more likely that the proposed bioassays and mesocosm studies would reveal smaller, sublethal effects, for example, altered growth rates of sampled organisms. In most cases, it will be very difficult to translate such sublethal effects into impacts on the ecosystem, which nonetheless may be significant (e.g., Atchison et al., 1996.) Thus the Regional Study, and especially its ecological monitoring and research components, are poorly connected to the ecosystem- and community-level restoration objectives of CERP. In contrast, it is better connected with at least some population-level objectives of CERP. For example, Subtask 12.2 provides for modeling of methylmercury production and bioaccumulation, the output of which will be used for a probabilistic ecological risk assessment model to calculate hazard coefficients for various fish-eating wildlife, especially wading birds such as the endangered wood stork. Both toxic effects of contaminants and more subtle impacts on the ecosystem (e.g., changes in frequencies of algal blooms) are envisioned (Appendix L, 1.0), but only monitoring of the former is proposed. We recommend the addition of monitoring and assessment of ecological indicators to Task 13. Overall, neither the Plan nor Appendix L provides sufficient detail regarding the approach to be taken to translate the bioassay, mesocosm, and bioassessment results into a quantitative assessment of the likelihood that ecological restoration goals will be attained at the regional scale under various scenarios of ASR distribution and operation.

The PMP does not provide sufficient information on the ecological risk assessments that are proposed to evaluate potential beneficial or adverse effects of full ASR implementation. In particular, the PMP needs to provide information on *assessment endpoints* – that is, specific attributes of the Greater Everglades ecosystem that are most highly valued and thus to be protected – and how these endpoints will be used to develop *measurement endpoints* for the bioassay and mesocosm studies. The PMP represents the very early stage of risk assessment (that is, early problem formulation), and thus it is not realistic to expect that details regarding the two kinds of endpoints will be highly developed. Nonetheless, it is important to identify the ecosystem attributes that are most highly valued and develop testable hypotheses regarding potential effects of ASR on these attributes (e.g., see Rapport and Whitford, 1999; and Rapport et al., 1985). There is no evidence in the draft PMP that the risk paradigm was used in developing the material in Tasks 10-13 and Appendix L.

Coordination with the RECOVER (REstoration COordination & VERification) program of the CERP, which is appropriate and well described (7.13), includes coordination with the system-wide monitoring plan (item 5). The lack of system-wide ecological indicators that can be used to measure progress toward restoration in the system-wide monitoring plan is a complicating factor. An opportunity thus exists to develop indicators that can be used in both system-wide monitoring and the Regional Study. Recent work on the development of bioindicators of ecosystem health for the Estuarine Environment Research Program funded by the EPA[5] may provide some useful direction. In addition to measures indicative of ecosystem function, measures of diversity and abundance of key organisms are needed. In many cases, the test organisms selected for contaminants studies also can serve as ecological indicators. The choices of organisms are well justified, and usually these same justifications are relevant to choices of ecological indicators.

An example may be illustrative. Periphyton is to be used as test organisms at Lake Okeechobee, and the PMP states that "changes in periphyton taxonomic structure and/or biomass can affect the animals at higher trophic levels" (Appendix L, 3.2.1.1). The sampling plan proposes to expose periphyton collected from the field to contaminants in the laboratory, but it will not be possible to determine from these tests how the periphyton community in the field would change in response to ASR discharges. Therefore, it would be important also to measure taxonomic structure (diversity) and biomass (abundance) of periphyton at the monitoring site where the organisms are collected.

Some of the acknowledged limitations of the Regional Study could be addressed by the addition of ecological indicators of sublethal changes, including indicators of ecosystem structure and where feasible, indicators of ecosystem functions such as primary production of periphyton. The benefits of using indicators may be seen by analogy with the proposed use of the hydrodynamic model for Lake Okeechobee, which is advocated partly because it contains a link between water quality and submerged vegetation that enables analysis "at a scale that is not possible using only controlled bioassay experiments" (Appendix L, 3.2.1.3). Collecting data on ecological indicators potentially could lead to similar links for other organisms at this larger scale.

Sampling of ecological indicators could be integrated with the monitoring scheme for contaminant screening described in Subtask 13.3. Addition of ecological indicators would increase the workload for this subtask, because measuring diversity and abundance of several taxa, for example, is more complicated than sampling for a particular species.

Bioassay studies will be conducted based on three scenarios (Appendix L, 3.2.3): discharge into unimpacted marsh waters, into receiving canals, and into STAs. If ecological indicators used in the bioassays also are used in the system-wide monitoring plan, it might be possible to increase the sampling area encompassed by the bioassay studies by using data from CERP monitoring stations, particularly for downstream sites. Ecological effects detected at monitoring sites near ASR wells are to be extrapolated system-wide through modeling. This is a reasonable approach, but success depends on the ability to determine how effects change as a function of concentration. A thorough understanding of concentration effects as a function of

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[5] See http://cfpub.epa.gov/ncer_abstracts/index.cfm/fuseaction/research.display/rpt/abs/rfa_id/137.

distance from initial discharge will be a critical issue in prediction of down-gradient effects. This may be particularly difficult in the case of ecological indicators.

Discrepancies in the timetable for ecological studies and monitoring of water quality need to be clarified. The schedule in Appendix C indicates that the first phase of Environmental Effects Evaluation (Task 10.4) will begin in 2006, but language elsewhere indicates it will begin earlier, in 2003. The duration of the three phases of water quality monitoring is indicated to be 6.5 years in one section (3.4.11), 8.5 years in another (7.9.3.3).

Finally, Appendix L states that screening level bioassays represent a "worst case" toxicity test. This is not accurate, because standard test organisms rather than endemic species will be used.

3

Other Topics

PROJECT CONSTRAINTS AND ASSUMPTIONS (SECTION 3.3)

The PMP acknowledges in section 3.3 that the "implementation schedule of the CERP limits study length which is critical for ecological assays." This is true, particularly for the additional assays suggested in the previous section of this report. For example, given the many sources of variation in species abundance, including climatic variability, it is unlikely that the Regional Study will be of sufficient duration to definitively demonstrate impacts of ASR on abundance of key species or on shifts in community composition and structure. But the study will provide a good start in that direction and provisions could be made for continuing the sampling under the auspices of the RECOVER plan of the CERP.

The PMP also notes that the schedule of the overall study is controlled, in part, by linkages to the schedules of the ASR pilot projects. Ideally, many of the aspects of the regional study should have preceded planning of the pilot site studies. This is particularly true with respect to characterization of the regional hydrogeology, determination of hydraulic parameters of the potential ASR target zones, and preliminary numerical modeling to evaluate possible pressure increases in the Upper Floridan aquifer (UFA) and overlying strata. Also, prior characterization of the quality of surface water sources for the ASR wells would help in determining level of pre-treatment required and in planning for geochemical reaction tests and some of the ecological field studies. Unfortunately, the pilot studies were funded and initiated before the plans for a regional study were outlined in the PMP that is the subject of this review. This unfortunate sequence may preclude optimal use of the regional study results in design and execution of the pilot studies. Nevertheless, consideration should be given to modest changes in schedules of pilot study or regional study tasks if initial results of either study suggest opportunities for enhanced understanding though improved coordination.

FUNCTIONAL AREA PLANS (SECTION 7)

Section 7.1 – Project Management

The PMP calls for the use of consultants for the execution of various tasks. Close and thorough coordination of these various consultants is required to ensure the continuity and integration of these separate efforts to avoid having them become disjointed parts of an overarching task.

In view of the stated importance of the fate and transport of microorganisms to the ASR project, an advisory committee should be formed to assist with these aspects of the project. Dr. Ron Harvey, who has extensive experience in this area, is one of the Project Delivery Team members. Such a committee would be helpful in making decisions on these issues.

The PMP calls for independent technical review. However, the Independent Technical Review Team is to be made up of only representatives of USACE, SFWMD, and contractors. This constitutes in-house review, which may be sufficient for many tasks. Independent technical review will be an important component of the major tasks. For example, in Appendix H, Quality Control Plan, there are provisions to include outside technical experts in review of the pilot studies, but not the regional study. Outside technical experts should also be included on the Independent Technical Review Team for the regional study in order to enhance credibility and acceptance of the quality of the study. A study of the peer review process at the USACE by the NRC (2002) should provide useful guidelines in this area.

Section 7.8 –Public Outreach and Involvement

Appropriately, public outreach is given high priority in the Regional Study, and the plan appears to be well conceived. Appropriate attention is given to environmental compliance as well (e.g., Endangered Species Act , National Environmental Policy Act), but this is generally not an issue because construction activities are a component of the various project implementation reports (PIR) rather than part of the Regional Study.

Section 7.9.6.2 –Monitoring During Cycle Testing

The plan to over-pump during the first cycle beyond water quality limits and all the way to near 100 percent recovery of injected water is a useful strategy. This will allow the entire recovery mixing-curve to be established and used as a baseline.

Section 7.11 –Operations and Maintenance

The Operations and Maintenance (O & M) plan to be developed through the regional ASR study apparently will cover only data logger systems for monitoring wells constructed as part of this study. However, additional O & M costs associated with these monitoring wells could be substantial depending on the level of monitoring undertaken during full scale ASR operation and the level of maintenance required for the monitoring wells. Even more substantial O & M costs will be associated with the operating ASR wells. For reference, the Las Vegas Valley Water District, with an average recovery cost of $191 per million gallons spends $13,000 per well per year in maintenance.

4

Conclusions and Recommendations

The Regional ASR Project Management Plan (PMP) clearly responds to the issues identified earlier by the South Florida Working Group ASR Issue Team and later by the CROGEE. The report recognizes the importance of acquiring information through the proposed Regional Study to resolve or better understand the issues that are involved with the consequences of implementation of ASR regionally in south Florida at the unprecedented scale of 1.7 billion gallons per day. The PMP goes a long way to providing the needed information. It is comprehensive, for the most part, and is linked well to the pilot ASR studies. The authors of the document should be commended for the effort that went into producing the plan and for the comprehensiveness of the proposed study.

The most important overall improvement to the document would be a greater attention to the CERP principle that "each incremental step [be] viewed as an experiment accompanied by one or more hypotheses that predict how that step will improve the system" (USACE, 1999), a concept generally termed adaptive management. Some of the task descriptions suggest that the study will be conducted as a relatively routine engineering exercise rather than a comprehensive and integrated scientific study to "investigate regional technical and regulatory issues governing the feasibility of full-scale ASR implementation…and develop tools to assess the feasibility and increase the level of certainty of successful ASR implementation," which is the stated objective of the study. This structure is of some concern given that results of the regional study may show that ASR at the scale being proposed is not feasible due to hydrogeological, geochemical, ecological, or other reasons. In such cases, the proposed plans to (1) apply the model (or collect the sample), (2) collect the results, and (3) move on to the next task will not be appropriate. Additional advanced consideration is warranted concerning what to do if the results of some phase(s) indicate that ASR, as originally planned, will not work.

The regional modeling described in Task 9 may come closest to this ideal; in this task the plan specifically discusses multiple model runs for a range of alternatives (in terms of well locations and numbers). Likewise, the flow chart of Figure 3, which shows "adaptive feedback" loops between water quality, ecological, and toxicological investigations, is a useful tool that might be more broadly applied elsewhere in the report. The PMP acknowledges the need for some flexibility in modification of the plan if early results warrant changes, and this is commendable. However, the question remains whether the overall study plan will be sufficiently flexible to allow for evaluation of alternative plans/procedures if a particular aspect of the original plan is problematical. Articulation of specific hypotheses within the PMP is highly desirable, and this approach should be coupled with a plan that ensures evaluation of results in each step in a timely manner to assure flexibility and implementation of alternative procedures or approaches in place of those that are problematical or do not work.

A moderate number of the tasks in the PMP are not described in enough detail to allow for a substantive critique of methods at this stage. While this is understandable given the scope of the effort, these include such important topics as tracer tests, numerical modeling, interpretation of bioassay results, packer test intervals, and sampling frequency. These topics deserve additional attention in later drafts.

Ecological and water quality studies are described both in descriptions of tasks 10 through 13 and, somewhat independently, in Appendix L. Unfortunately, the task descriptions and the appendix are not well integrated, and sometimes appear contradictory. The writers of the PMP are urged to make these sections more consistent with each other.

Based on the points raised in comments the specific tasks and functional area plans, the following recommendations are of particular importance:

- The proposed additional monitoring at the pilot sites is a good step, but probably still does not go far enough in terms of numbers of wells and well nests to characterize both hydraulic and biogeochemical processes. Vertical and horizontal heterogeneity of the aquifer system will make this a difficult task that will require extensive testing. Likewise, recharge of the ASR wells should continue, if at all possible, until some time after the injection water is detected at all of these monitor wells, to understand the physical and chemical behavior of the system as fully as possible.
- Likewise, improved understanding of potential geochemical reactions should be a priority all pilot sites. This may require additional monitoring during cycle testing beyond that anticipated in the PMP. Given the heterogeneity of the Florida Aquifer system (FAS) with respect to salinity and physical properties at existing ASR sites, there may be significant variability in these properties from site to site.
- Some of the funds necessary to expand such monitoring and sampling should come through de-emphasizing continuous coring. While coring can be useful, it is costly and may yield unreliable and non-representative data. Given these limitations, it might be prudent to reduce the coring program and use the savings to support installation of additional monitoring wells for field tests of hydraulic properties and for hydrogeochemical characterization.
- Column studies are proposed to assess interactions between microorganisms and the subsurface materials. Due to the presence of fractures and other features in the FAS, it will be difficult, if not impossible, to obtain representative, quantitative information on transport using column studies. Such results should be treated with caution.
- The proposed bioassays and mesocosm studies emphasize response of individual taxa rather than community- and ecosystem-level effects. However, these studies may reveal only sublethal effects (e.g., altered growth rates) of contaminants on the sampled organisms. Such results would be difficult to extend to impacts on the larger ecosystem (e.g., shifts in community composition or changes in frequencies of algal blooms), for which little monitoring is proposed. Thus, the ASR Regional Study's ecological monitoring and research components are poorly connected to the ecosystem- and community-level restoration objectives of CERP. This can be remedied by adding monitoring and assessment of ecological indicators to the proposed bioassays of Task 13. In coordination with other CERP science initiatives such as RECOVER, an opportunity exists to develop indicators that can be employed in both system-wide monitoring and the ASR Regional Study.

- The extended bioassay testing and monitoring of biological impacts are expected to occur over six- to twelve-month cycles. This sampling period may need to be longer to allow assessment of potential long-term effects on community composition, especially given interannual variability in factors such as rainfall, temperature, extreme events, etc.
- Surface water quality modeling and ecosystem modeling tends to focus on Lake Okeechobee. However, it appears more likely that negative effects of ASR-recovered water could occur within the Everglades itself. This is where surface waters are low in nutrients and dissolved solids, and where input, either directly or via pathways that include Lake Okeechobee, of recovered ASR water with relatively high ionic strength would represent a major ecological change. More emphasis should be placed on modeling of these more sensitive ecosystems and identifying water quality changes that could cause irreversible shifts in community composition.

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Appendix A

Executive Summary and Table of Contents from ASR Regional Study Draft Project Management Plan CERP, May 2002

Executive Summary

In April 1999, the Comprehensive Everglades Restoration Plan (CERP) proposed large-scale development of Aquifer Storage and Recovery (ASR) facilities as the preferred method of providing additional freshwater storage required for overall restoration success. Six ASR components will collectively form the proposed CERP ASR System, which includes a total of 333 ASR wells and related surface facilities at the general locations in attached Figure A. All proposed ASR wells have a target capacity of 5 mgd (million gallons per day). Water treatment facilities were also included in the conceptual CERP ASR components. Total cost of the proposed CERP ASR System is approximately $1,700,000,000. The United States Army Corps of Engineers (USACE), Jacksonville District and the South Florida Water Management District (SFWMD) are 50/50 cost sharing partners for design studies required prior to implementation of any large-scale CERP ASR facilities.

An independent scientific review of the conceptual CERP ASR System was completed in July 1999 by the ASR Issue Team, which was formed at the request of the South Florida Ecosystem Restoration Task Force's Working Group. Later the Working Group also engaged the National Academy of Sciences' Committee for the Restoration of the Greater Everglades Ecosystem (CROGEE) to review preliminary drafts of the project management plans (PMPs) for the Lake Okeechobee and Hillsboro ASR Pilot Projects, which resulted in their report dated February 2001. The ASR Issue Team identified seven broad technical uncertainties related to ASR implementation on the unprecedented scale proposed in the CERP. These seven issues are listed in Table 1, which also identifies proposed local-scale (pilot project) and regional-scale scientific studies required to address these issues. The CROGEE concluded that additional scientific studies are needed, including work to improve understanding of the regional hydrogeology, hydraulic properties, potential changes in water quality, and the effects, if any, of those changes on aquatic ecosystems.

Local-scale studies have been initiated in the form of three ASR Pilot Projects as recommended in the CERP. In general terms, these pilot project studies will develop site-specific data related to local water quality and hydrogeology, identify appropriate water treatment processes, and determine the feasibility of 5 mgd capacity ASR wells at each pilot locations. Figures in Appendix B of this PMP show the locations and summarize the details of the Lake Okeechobee, Hillsboro and Caloosahatchee ASR Pilot Projects. As noted above, the CROGEE ASR subcommittee previously reviewed the draft PMPs for the Lake Okeechobee and Hillsboro ASR Pilot Projects. Their report, dated February 2001, provided a technical critique of the ASR Pilot Project studies and strongly concurred with the Corps and SFWMD plan for a concurrent ASR Regional Study to address ASR Issues beyond the limited geographic scope of the pilot projects.

The attached draft PMP for the CERP ASR Regional Study has been prepared in response to the need for additional scientific studies to address potential regional impacts related to the unprecedented large scale of the proposed CERP ASR System (333 wells). This draft PMP represents the collective efforts of a large interagency project delivery team (PDT) with representatives from the following local, state and federal government agencies that actively participated in its development:

Broward County Water Resources Management
Miami-Dade County Water and Sewer Department
Palm Beach County Water Utilities Department
South Florida Water Management District
Florida Department of Environmental Protection
Florida Geological Survey
Florida Department of Agricultural and Community Services
U.S. Department of Interior, Everglades Ecosystem Restoration Task Force
U.S. Environmental Protection Agency
U.S. Fish and Wildlife Service
U.S. Geological Survey
U.S. Army Corps of Engineers

PDT members began PMP development by preparing the following mission statement:

"The ASR Regional Study will investigate regional technical and regulatory issues governing the feasibility of full-scale ASR implementation, as identified in the CERP, and develop tools to assess the feasibility and increase the level of certainty of successful ASR implementation."

Primary goals of the ASR Regional Study are to:

1. Address outstanding issues of a regional nature that cannot be adequately addressed by the authorized ASR Pilot Projects

Reduce uncertainties related to full-scale CERP ASR implementation by conducting scientific studies based on existing and newly acquired data and evaluate potential effects on water levels and water quality within the aquifer systems, and on existing users, surface-water bodies, and the flora and fauna that inhabit them.

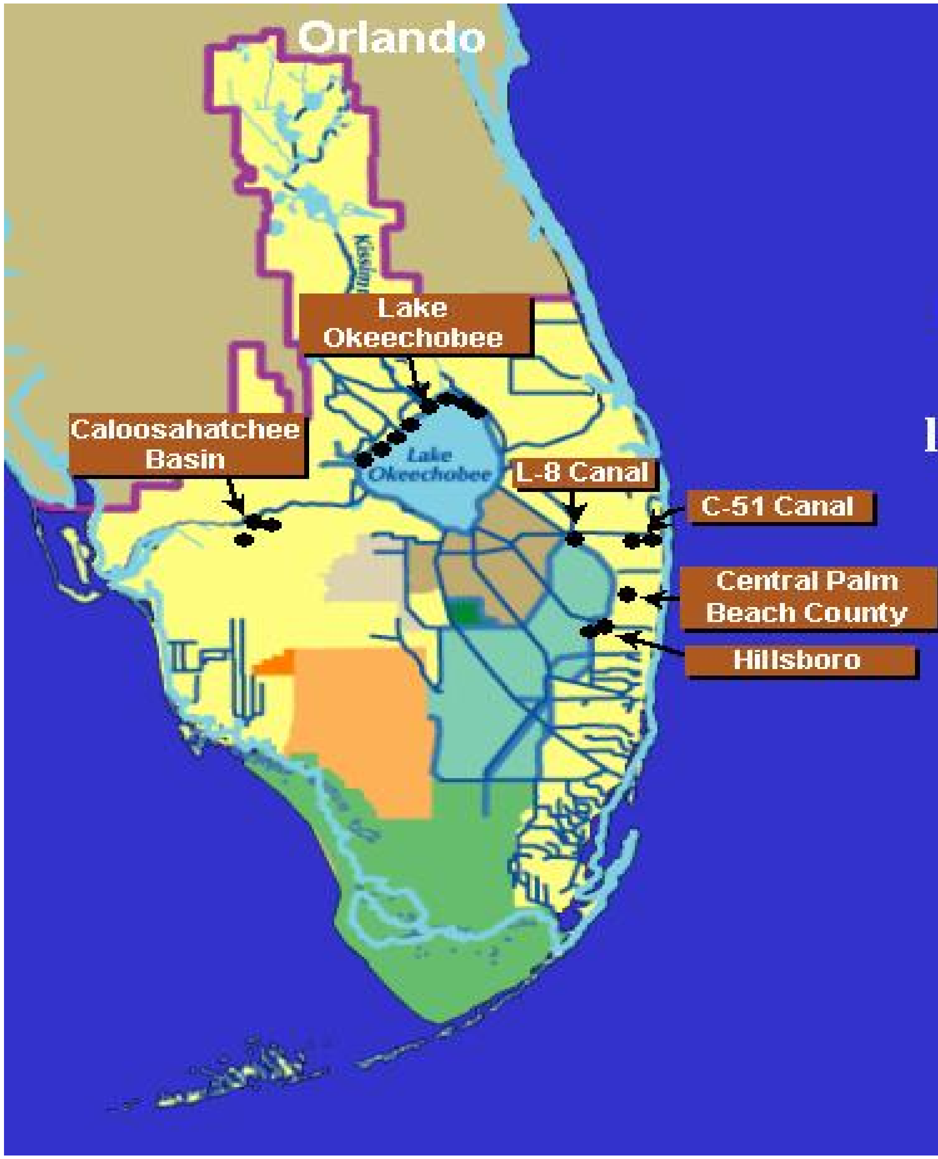
2. Develop a regional groundwater model of the Floridan Aquifer System (FAS) and conduct predictive simulations to evaluate the technical feasibility of the proposed 333-well CERP ASR system, or if determined to be infeasible, identify an appropriate magnitude of ASR capacity with minimal impact to the environment and existing users of the FAS.

The PDT's plan to achieve these goals, as described in this PMP, is to identify and conduct a series of tasks that will develop scientific data to address each of the issues of concern. Many of these tasks are inter-related, and assist in addressing multiple issues. Table 2 presents a summary of major tasks to be conducted in the ASR Regional Study, and cross-references these tasks with the issues raised by the ASR Issue Team.

While the CERP did not directly call for an ASR Regional Study, the Corps and SFWMD agree that a coordinated central data collection and regional modeling effort is required to address large-scale ASR implementation issues. In addition to budget amounts for the ASR Pilot Projects, the CERP April 1999 budget included a total of approximately $128,000,000 for ASR related Planning, Engineering and Design studies for the six (6) proposed ASR components identified on Figure A. Funds for the studies outlined in this document will be provided from the established CERP ASR design budget. The ASR Regional Study described in this PMP will take roughly 9 years to complete and has a budgeted cost including contingency funds of approximately $45,000,000. This study will conduct critical ASR related studies and develop scientific data required to help determine the engineering feasibility of large-scale ASR implementation as proposed in the CERP.

TABLE 1 Summary of ASR Issue Team Items

Issue Team Item	Pilots/Regional	Tasks
1. Characterization/Suitability of the Quality of Prospective Source Waters; Spatial and Temporal Variability	Pilot Projects	- Local Source Water Quality Characterization
	Regional Study	- Regional Water Quality Characterization
2. Characterization of the Regional Hydrogeology of the Upper Floridan Aquifer: Hydraulic Properties and Water Quality	Regional Study	- Regional Hydrogeologic Evaluation - Test/Monitor Well Drilling & Tests - Seismic Reflection Survey - Geochemistry Studies
	Pilot Projects	- ASR/Monitor Well Drilling, Background Water Quality
3. Analysis of Critical Pressure for Rock Fracturing	Regional Study	- Rock Fracturing Desk Top Analysis - Regional Groundwater Modeling
	Pilot Projects	- Laboratory Analysis of Cores
4. Analysis of Site and Regional Changes in Head and Patterns of Flow	Regional Study	- Regional Potentiometric Head (Literature Review) - Field Measurements - Regional Groundwater Modeling
	Pilot Projects	Potentiometric Head Measurements at ASR/Monitor Wells (Background and Cycle Testing)
5. Analysis of Water Quality Changes During Movement and Storage in the Aquifer	Pilot Projects	- Local Source Water Quality Characterization Program - Background Floridan Aquifer Water Quality - Cycle Testing Water Quality
	Regional Study	- Regional Groundwater Modeling - Geochemical Modeling
6. Aquifer Storage and Recovery Potential Effects on Mercury Bioaccumulation for South Florida Ecosystem Restoration Projects	Pilot Projects	- Local Source Water Quality Characterization Program - Cycle Testing Water Quality
	Regional Study	- Regional Water Quality Measurements
7. Relationship between ASR Storage Properties, Recovery Rates and Recharge Volume	Pilot Projects	- Specific Capacity Tests, Geophysical Logs, Cores - Cycle Testing Water Levels, Water Quality
	Regional Study	- Regional Groundwater Modeling - Geochemical Modeling



CERP ASR
Regional Study

Purpose: To evaluate potential regional impacts of proposed large scale ASR implementation.

CERP ASR Sites	Wells
Lake Okeechobee	200
Caloosahatchee	44
L-8 Basin	10
C-51 Basin	34
Central PBC	15
Hillsboro	30
TOTAL	**333**

Note: Design Capacity for each ASR well = 5 million gallons per day (mgd).

TABLE 2 Relationship of ASR Regional Study Tasks to ASR Issues

TASK	ASR Issues Addressed 1	2	3	4	5	6	7
1.0 Build Inventory of Existing Data and Information. Task includes a comprehensive search for published and unpublished literature on topics related to regional geology (lithology, structure, stratigraphy, etc.), hydrogeologic framework (flow zones, leakance, transmissivity, etc.), testing results from existing ASR wells and ambient Floridan Aquifer System (FAS) water quality. Available data will be evaluated, appropriate data collected, and a database compiled.	X	X	X	X	X		X
2.0 Evaluation of Methods. Scope includes a workshop plus expert assistance to evaluate available technologies for drilling, collection of core samples and downhole geophysical investigations.		X	X	X	X		X
3.0 Define Preliminary Hydrogeologic Framework. The overall scope is the synthesis and interpretation of existing data on the geologic and hydrogeologic framework of the Floridan Aquifer System (FAS), and identification of areas needing additional data analysis. The main objective is to identify, and where possible, rectify areas of inconsistency.		X		X			
4.0 Geochemistry. Scope includes literature/data search, characterization of all components in ASR hydrogeochemical system, laboratory geochemical bench tests, geochemical reaction modeling, investigation of water/rock/microorganism interactions, comprehensive evaluation and report preparation.	X	X		X	X	X	X
5.0 Pressure Induced Changes. Scope includes identification of engineering constraints and data gaps, model selection and development, and model runs for evaluation of potential pressure induced changes.		X	X				
6.0 Field Data Collection. Scope includes development of a data collection plan based data gaps identified in Task 3.0, drilling and testing of new wells, seismic reflection surveys, groundwater monitoring, tracer tests, testing of existing wells, and post cycle test logging and insitu dissolution experiments at 2 pilot project wells.		X	X	X	X		X
7.0 Laboratory Analyses. Scope includes geotechnical testing, analyses of existing and new core samples and cuttings, geochemical analyses of rock matrix, and fracture trace analysis.		X	X	X	X	X	
8.0 Finalize Conceptual Hydrogeologic Framework. Task will consist of a detailed review of all findings from the field program, and evaluation and synthesis of that data with previous work to build a regional interpretation of the hydrogeologic flow system.		X	X	X	X		X
9.0 Regional Groundwater Numerical Modeling. Scope includes selection of appropriate model code, development of regional and high resolution inset (subregional) hydrogeologic models, and model runs for analysis of potential site and regional changes in subsurface water pressures (heads) and patterns of flow for the conceptual CERP ASR System (333 wells) and, if needed, alternative ASR System configurations.				X			X

10.0 Surface Water Quality Data Analysis. Tasks will include identification of the study areas and relevant water quality criteria, characterization of potential ASR water supplies, compilation and evaluation of existing and new water quality data, and evaluation of potential environmental /health risk effects related to large-scale ASR implementation.

11.0 Water Quality Monitoring of Source/Receiving Water Bodies. Scope includes development of a surface water quality monitoring plan plus source/receiving water data gap monitoring at five (5) ASR pilot well intake/discharge sites.

12.0 Surface Water Quality Modeling. Tasks include Lake Okeechobee ecosystem modeling, ecological methylmercury modeling, pollutant fate/transport modeling, mass balance study and assessment of dissolved ions in recovered water.

13.0 Ecological & Toxilogical Field Studies. Scope includes screening bioassays, extended bioassay testing, biological monitoring of localized impacts (at ASR Pilot Projects), mercury methylation testing, fish/clam mesocosm studies, epidemiological study of fish consumption, and water treatment residuals management assessment.

14.0 PROJECT REPORTS. Scope includes preparation of two (2) interim reports and a final report. Tentative schedule is for the first report in about three (3) years with subsequent reports on roughly the same schedule.

ASR Regional Study Draft Project Management Plan
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Appendix C

Biographical Sketches of Members of the Committee on Restoration of the Greater Everglades Ecosystem and Outside Consultants

Committee Members

JEAN M. BAHR, CHAIR, is professor the Department of Geology and Geophysics at the University of Wisconsin-Madison where she has been a faculty member since 1987. She served as chair of the Water Resources Management Program, UW Institute for Environmental Studies, from 1995-99 and she is also a member of the Geological Engineering Program faculty. Her current research focuses on the interactions between physical and chemical processes that control mass transport in ground water. She earned a B.A in geology from Yale University and M.S. and Ph.D. degrees in applied earth sciences (hydrogeology) from Stanford University. She has served as a member of the National Research Council's Board on Radioactive Waste Management and several of its committees.

SCOTT W. NIXON, VICE-CHAIR, is professor of oceanography and director of the Rhode Island Sea Grant College Program at the University of Rhode Island. He currently teaches both graduate and undergraduate classes in oceanography and ecology. His current research interests include coastal ecology, with emphasis on estuaries, lagoons, and wetlands. He has served on three National Research Council committees including, most recently, the Committee on Coastal Oceans. Dr. Nixon received a B.A. in biology from the University of Delaware and a Ph.D. in botany/ecology from the University of North Carolina-Chapel Hill.

JOHN S. ADAMS is professor and chair of the Department of Geography at the University of Minnesota. He researches issues relating to North American cities, urban housing markets and housing policy, and regional economic development in the United States and the former Soviet Union. He has been a National Science Foundation Research Fellow at the Institute of Urban and Regional Development, University of California at Berkeley, and economic geographer in residence at the Bank of America World Headquarters in San Francisco. He was senior Fulbright Lecturer at the Institute for Raumordnung at the Economic University in Vienna and was on the geography faculty of Moscow State University. He has taught at Pennsylvania State University, the University of Washington, and the U.S. Military Academy at West Point. His most recent book, Minneapolis-St. Paul: People, Place, and Public Life, looks at the region's growth and at what factors may affect the metropolitan area's future. Adams holds two degree in economics and a doctorate in urban geography from the University of Minnesota.

LINDA K. BLUM is research associate professor in the Department of Environmental Sciences at the University of Virginia. Her current research projects include study of mechanisms controlling bacterial community abundance, productivity, and structure in tidal marsh creeks; impacts of microbial processes on water quality; organic matter accretion in salt marsh sediments; and rhizosphere effects on organic matter decay in anaerobic sediments. Dr. Blum earned a B.S. and M.S. in forestry from Michigan Technological University and a Ph.D. in soil science from Cornell University.

PATRICK L. BREZONIK is professor of environmental engineering and director of the Water Resources Research Center at the University of Minnesota. Prior to his appointment at the University of Minnesota in the mid-1980s, Dr. Brezonik was professor of water chemistry and environmental science at the University of Florida. His research interests focus on biogeochemical processes in aquatic systems, with special emphasis on the impacts of human activity on water quality and element cycles in lakes. He has served as a member of the National Research Council's Water Science and Technology Board and as a member of several of its committees. He earned a B.S. in chemistry from Marquette University and a M.S. and Ph.D. in water chemistry from the University of Wisconsin-Madison.

FRANK W. DAVIS is a Professor at the University of California Santa Barbara (USCB) with appointments in the Donald Bren School of Environmental Science and Management and the Department of Geography. He received his B.A. in biology from Williams College and a Ph.D. from the Department of Geography and Environmental Engineering at The Johns Hopkins University. He joined the Department of Geography at UCSB in 1983, and established the UCSB Biogeography Lab in 1991. His research focuses on the ecology and management of California chaparral and oak woodlands, landscape ecology, regional conservation planning, and spatial decision support systems. He was Deputy Director of the National Center for Ecological Analysis and Synthesis between 1995 and 1998, and currently directs the Sierra Nevada Network for Education and Research Page. Dr. Davis has been a member of three prior NRC committees.

WAYNE C. HUBER is professor and head of the Department of Civil, Construction, and Environmental Engineering at Oregon State University. Prior to moving to Oregon State in 1991, he served 23 years on the faculty of the Department of Environmental Engineering Sciences at the University of Florida where he engaged in several studies involving the hydrology and water quality of south Florida regions. His technical interests are principally in the areas of surface hydrology, stormwater management, nonpoint source pollution, and transport processes related to water quality. He is one of the original authors of the Environmental Protection Agency's Storm Water Management Model (SWMM) and continues to maintain the model for the EPA. Dr. Huber holds a B.S. in engineering from the California Institute of Technology and an M.S. and Ph.D. in civil engineering from the Massachusetts Institute of Technology. He is currently a member of the NRC's Committee on Causes and Management of Coastal Eutrophication.

STEPHEN R. HUMPHREY is dean of the College of Natural Resources and Environment at the University of Florida where he also serves as affiliate professor of Latin American studies, wildlife ecology, and zoology. He also has been the curator in ecology for the Florida Museum of Natural History since 1980. Dr. Humphrey has authored and co-authored numerous articles and books on the effects of urbanization on wildlife. He holds B.A. in biology from Earlham College in Richmond, Indiana and a Ph.D. in zoology from Oklahoma State University. He is former chair of the Environmental Regulatory Commission of the Florida Department of Environmental Regulation and a member of the Florida Panther Technical Advisory Council of the Florida Game Commission.

DANIEL P. LOUCKS is professor of civil and environmental engineering at Cornell University. His research, teaching, and consulting interests are in the application of economics, engineering, and systems theory to problems involving environmental and water resources development and management. Dr. Loucks has taught at a number of universities in the United States and abroad and has worked for the World Bank, and the International Institute for Applied Systems Analysis. He also served as a consultant to a variety of government and international organizations concerned with resource development and management. He is a member of the National Academy of Engineering and is currently a member of the National Research Council's Committee on Risk-Based Analyses for Flood Damage Reduction Studies.

KENNETH W. POTTER is professor of civil and environmental engineering at the University of Wisconsin-Madison. His expertise is in hydrology and water resources, including hydrologic modeling, estimation of hydrologic risk, estimation of hydrologic budgets, watershed monitoring and assessment, and aquatic ecosystem restoration. He received his B.S. in geology from Louisiana State University and his Ph.D. in geography and environmental engineering from The Johns Hopkins University. He has served as a member of the NRC's Water Science and Technology Board and several of its committees.

LARRY ROBINSON is director of the Environmental Sciences Institute at Florida A&M University where he is also a professor. At Florida A&M University he has led efforts to establish B.S. and Ph.D. programs in environmental science in 1998 and 1999, respectively. His research interests include environmental chemistry and the application of nuclear methods to detect trace elements in environmental matrices and environmental policy and management. Previously he was group leader of a neutron activation analysis laboratory at Oak Ridge National Laboratory (ORNL). At ORNL he served on the National Laboratory Diversity Council and was President of the Oak Ridge Branch of the NAACP. Dr. Robinson earned a B.S. in chemistry, summa cum laude, from Memphis State University and a Ph.D. in nuclear chemistry from Washington University in St. Louis, Missouri.

REBECCA R. SHARITZ is professor of botany at the University of Georgia and senior scientist at the Savannah River Ecology Laboratory in Aiken, South Carolina, where she has been the Head of the Division of Wetlands Ecology. Her research focuses on ecological processes in wetlands, including factors affecting the structure and function of bottomland hardwood and swamp forest ecosystems, responses of wetland communities to environmental disturbances, and effects of land management practices on nearby wetland systems. Dr. Sharitz has served on several NRC committees including, The Committee on Restoration of Aquatic Ecosystems: Science, Technology and Public Policy. She received a B.S. in biology from Roanoke College and a Ph.D. in botany and plant ecology from the University of North Carolina.

HENRY J. VAUX, JR. is professor of resource economics at the University of California, Riverside. He currently serves as Associate Vice President - Agricultural and Natural Resource Programs for the University of California system. He previously served as Director of the University of California Water Resource Center. His principal research interests are the economics of water use and water quality. Prior to joining the University of California he worked at the Office of Management and Budget and served on the staff of the National Water Commission. He received a Ph.D. in economics from the University of Michigan in 1973. He recently served as chair of the National Research Council's Water Science and Technology Board.

JOHN VECCHIOLI recently retired as a hydrologist with the U.S. Geological Survey's Water Resources Division in Tallahassee, Florida and as chief of the Florida District Program. Previously, he was responsible for quality assurance of all technical aspects of ground water programs in Florida. His research interests have included study of hydraulic and geochemical aspects of waste injection in Florida and of artificial recharge in Long Island, N.Y. He has also done research on ground water-surface water interactions in New Jersey and Florida. Mr. Vecchioli received his B.S. and M.S. in geology from Rutgers University. Mr. Vecchioli previously served on the NRC's Committee on Ground Water Recharge.

JEFFREY R. WALTERS is Bailey Professor of Biology at Virginia Polytechnic Institute and State University, a position he has held since 1994. His professional experience includes assistant, associate, and full professorships at North Carolina State University from 1980 until 1994. Dr. Walters has done extensive research and published many articles on the red-cockaded woodpeckers in North Carolina and Florida and he chaired an American Ornithologists Union Conservation Committee Review that looked at the biology, status, and management of the Cape Sable Seaside Sparrow, a bird native to the Everglades. He is a fellow of the American Ornithologist Union, a member of Sigma Xi, American Society of Naturalists, Animal Behavior Society, Audubon Society, Cooper Ornithological Society, Ecological Society of America, Phi Beta Kappa, and many other scientific organizations. His research interests are in cooperative breeding in birds; reproductive biology of precocial birds; primate intragroup social behavior; evolution of cooperative breeding in birds; ecological basis of sensitivity to habitat fragmentation; kinship effects on behavior; and parental behavior on precocial birds. He holds a B.A. from West Virginia University and a Ph.D. from the University of Chicago.

Consultants

TOM M. MORRIS is a staff Hydrologist with the Operations Department Maintenance Engineering Division. He currently oversees the operation and maintenance of 108 groundwater production and injection wells for the Las Vegas Valley Water District. He has been closely involved with the groundwater injection program for the 14 years of operation. He drilled and designed the majority of the ASR wells, designed and custom tailored the injection equipment, tracked their efficiency of operation, and made the necessary adjustments to optimize the performance of the wellfield injection program. He specializes in the hydraulic impacts in the wellfield and the hydraulic actions around the well head that effect the injection performance.

MICHAEL C. NEWMAN is Dean of Graduate Studies, School of Marine Science, and Professor of Marine Science, Department of Environmental Sciences, College of William and Mary. Dr. Newman has diverse research interests which include ecotoxicology, general and applied aquatic ecology, contaminant effects on populations, bioaccumulation, factors modifying inorganic contaminant toxicity, fate of inorganic contaminants in aquatic systems, quantitative methods for ecological risk assessment, toxicity models, and water quality. His current projects include population genetics of PAH-exposed fish, stochastic modeling of contaminant exposure from fish consumption, predicting metal bioavailability for risk assessments, improving prediction of lethal effects with time-to-death methods, improving species sensitivity distribution methods for ecological risk assessment, and fate and effects of crop protectants from tomato cultivation on living resources in tidal creeks. He received a B.A. in biology and an M.S. in zoology from the University of Connecticut, and an M.S. and Ph.D. in Environmental Sciences from Rutgers University.

MARYLYNN V. YATES is a professor of environmental microbiology in the Department of Environmental Sciences and associate executive vice chancellor at the University of California, Riverside. Dr. Yates conducts research in the area of water and wastewater microbiology. Current research focuses on contamination of water by human pathogenic microorganisms, especially through the use of reclaimed water and biosolids; developing and improving methods to detect microorganisms in environmental samples; persistence of pathogenic microorganisms in the environment; and efficacy of water, wastewater, and biosolids treatment processes to inactivate pathogenic microorganisms. Dr. Yates previously served on the NRC Committee on Groundwater Recharge. She received a B.S. in nursing from the University of Wisconsin, Madison, an M.S. in chemistry from the New Mexico Institute of Mining and Technology, and a Ph.D. in microbiology from the University of Arizona.

Appendix D

Acronyms

ASR	Aquifer Storage and Recovery
CERP	Comprehensive Everglades Restoration Plan
CROGEE	Committee on Restoration of the Greater Everglades Ecosystem
DBPs	disinfection byproducts
FAS	Floridan Aquifer System
LVVWD	Las Vegas Valley Water District
NRC	National Research Council
PIR	Project Implementation Review
PMP	Project Management Plan
RECOVER	Restoration Coordination and Verification
SAS	Surficial Aquifer System
SAV	submerged aquatic vegetation
SFWMD	South Florida Water Management District
STA	stormwater treatment area
TDS	total dissolved solids
UFA	Upper Floridan aquifer
UIC	underground injection control
USACE	U.S. Army Corps of Engineers