REGIONAL APPLICATIONS OF AQUIFER STORAGE AND RECOVERY

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Background

Faced with diverse, controversial and oftentimes competing demands, the engineering profession continues to be challenged with the development of innovative solutions to meet our future water needs. Demand to push technology to the limit to resolve complex issues that have never been dealt with before are becoming routine occurrences. Assistance and teamwork will be needed by all to encourage and allow innovation. One of the most challenging issues facing south Florida for future years is the development of water supplies to meet urban, agriculture and environmental demands.

The State of Florida, and in particular south Florida and the Lower East Coast, continue to experience rapid population growth with an attendant increase in demand for water. South Florida's population has grown from 30,000 in 1890 to over 5 million in 1990, and is projected to increase to about 8 million by the year 2010. This rapid growth represents a significant increase in demand for fresh water as shown in Table 1.

TABLE 1 - Overall Water Demands in the Lower East Coast of Florida (MGY)[1]

Category	Estimated Demands for 1990 [2]	Projected Demands for 2010	Percent Change 1990-2010
Agriculture	258,800	183,000	-29.3
Public Water Supply	278,500	385,400	38.4
Industrial	7,600	7,600	0.0
Golf	22,100	33,000	49.3
Landscape	136,200	203,400	49.3
TOTAL	703,200	812,400	N/A

1 - From Revised Draft Preview Document, Lower East Coast Regional Water Supply Plan, SFWMD Feb. 1995.
2 - Public water supply is based upon 1989 pumpage data rather than 1990 pumpage data which was influenced by water restrictions in place due to drought conditions that year. All others are based upon calculated 1990 demands and represent self-supplied users.

Although South Florida receives an average annual rainfall of approximately 53 inches, much of this rainfall is lost by evapotranspiration and drainage (flood control). Only the State of Louisiana receives more rainfall on an annual basis (54 inches a year). Rainfall is highly variable in the Lower East Coast region with about two-thirds of annual rainfall occurring during the wet season months (June-October). The remaining third occurs during the dry season (November-May) when demand for supplemental surface water is the highest. During the wet months, coastal flood protection requires that large quantities of fresh water be discharged to tide and lost to the ocean to prevent flooding of developed areas. For example, in the Lower East Coast region, approximately 2,500,000 acre-feet (2,230 MGD) of stormwater are lost to tide on an annual basis. During prolonged dry periods, restrictions on water consumption and pumpage are often required to prevent saltwater contamination of coastal wellfields and the inland migration of seawater.

The Everglades Agricultural Area and other agricultural areas around Lake Okeechobee also exert a demand for fresh water which is provided by rainfall and supplemented by surface water deliveries from the Lake. Additionally, demands on some of Florida's most important natural resources, including the Everglades National Park, have been recognized as significant users and are included in future demand projections; e.g., Everglades Protection Project.

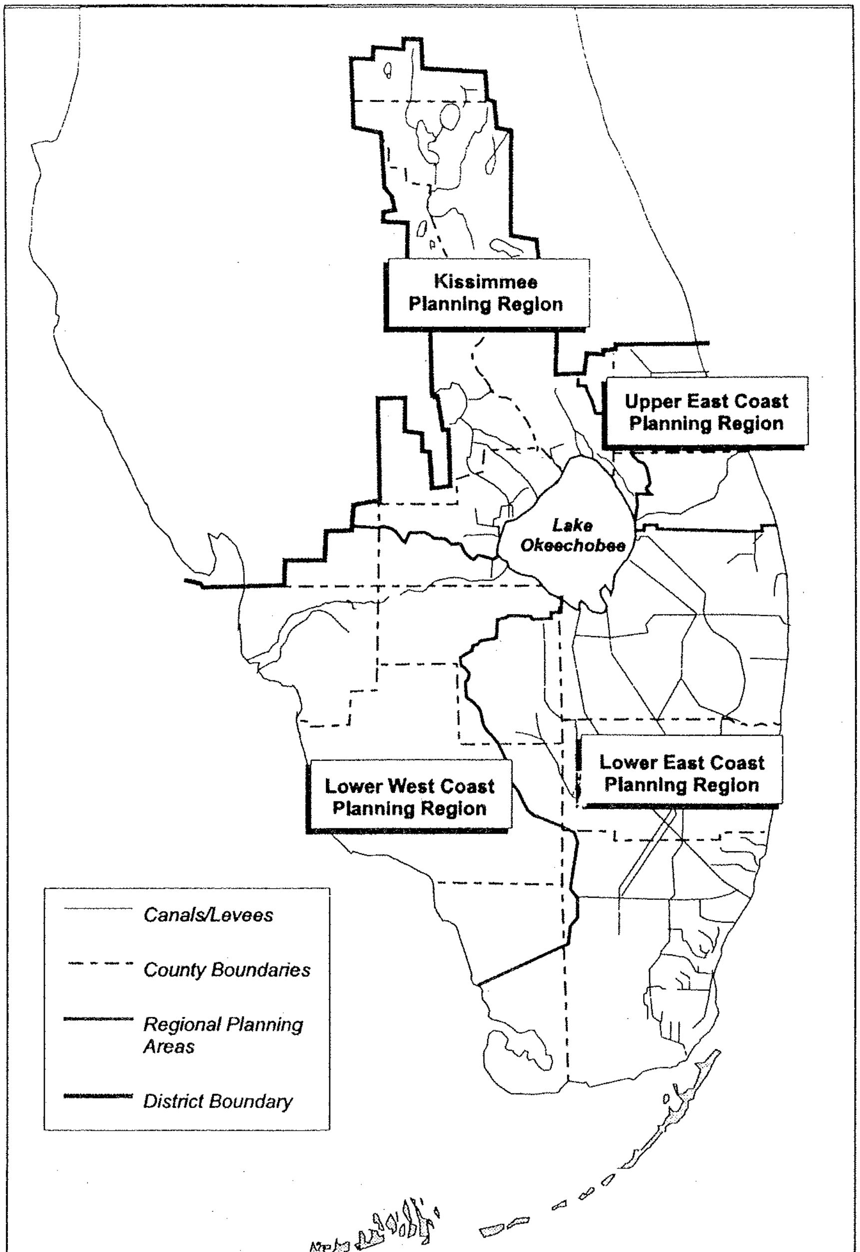

Figure 1

The South Florida Water Management District (SFWMD) is a regulatory agency that is responsible for the management of the water resources in South Florida. Their geographical area of responsibility including the Lower East Coast is shown in Figure 1. The SFWMD's mission includes the four general areas of responsibility as shown below:

- Water Supply
- Flood Protection
- Water Quality
- Natural Systems Management

These areas are all inter-related and sometimes in conflict with one another. Issues involving each of these four areas of responsibility are diverse, complex, and controversial. In many situations, issues related to environmental restoration and water supply can be in direct conflict with each other. Water quality is also problematic since some natural systems require waters of much higher quality than other categories of demand (i.e., recharge to Everglades Natural Park versus recharge to the Biscayne Aquifer).

One of the efforts currently underway is the development of a comprehensive water supply plan for the Lower East Coast. This planning effort is consistent with the State of Florida's Comprehensive

Plan goal for the management of water resources and has been studied for over 7 years. The plan, known as the Lower East Coast Regional Water Supply Plan, is nearing completion and will provide valuable insight for regional water supply planning for the Lower East Coast of Florida.

The Lower East Coast Regional Water Supply Plan attempts to identify future (year 2010) water resource problems, and evaluate potential cost-effective solutions in Palm Beach, Broward, and Dade counties and portions of Monroe, Collier, Lee, Glades, Okeechobee, Martin, and Hendry counties. The major analytical tool used in this planning process is a regional-scale integrated surface-groundwater model that simulates the hydrology and water management of most southeastern Florida affected by the Central and Southern Florida Flood Control Project. This model allows the analysis of various water resource options to evaluate their effectiveness in addressing previously identified problem areas. A few objectives identified during the initial phases of the planning process include the following:

1. Protect and enhance the environment including federal, state, and locally identified natural resource areas.

2. Protect and conserve the water resources of South Florida to ensure their availability for future generations.

3. Provide for the equitable, orderly, cost effective, and economical development of water supplies to meet South Florida's environmental, agricultural, urban and industrial needs.

4. Improve resource management through the integration of regional and local water supply plans and land use planning.

Each option modeled consisted of features such as increased storage to assist in restoration of the Everglades National Park. Results of the modeling effort led to a series of preferred options such as shown in Figure 2. Option No. 5 was considered advantageous as it improved many of the existing man-made management practices by increasing storage. For example, Option No. 5 which utilizes ASR as the primary tool to increase system storage increases water supply to the Everglades National Park from 310 ac-ft/yr (MGD) to 1,033 ac-ft/yr (MGD).

Problem Definition

After several model runs, it was apparent that the ability to store water in the system during times of surplus for later use during times of need was an effective means of improving deliveries to the natural system and reducing projected future water shortages to the urban communities. This was particularly true along the coast and in the inland agricultural areas. A significant benefit of this approach was that it allowed for addressing the needs of the Everglades. Evaluation of traditional and innovative options led to the consideration of underground storage to augment existing and traditional storage methods.

Underground storage was considered a promising option due to the topography of Florida. South Florida is very flat with only a few feet of natural hydraulic gradient between the head waters (Lake Okeechobee) and the southern reaches of the Everglades National Park. Lakes and/or reservoirs are shallow and evapotranspiration rates are high making them inefficient mechanisms for water storage. Land costs are also relatively high.

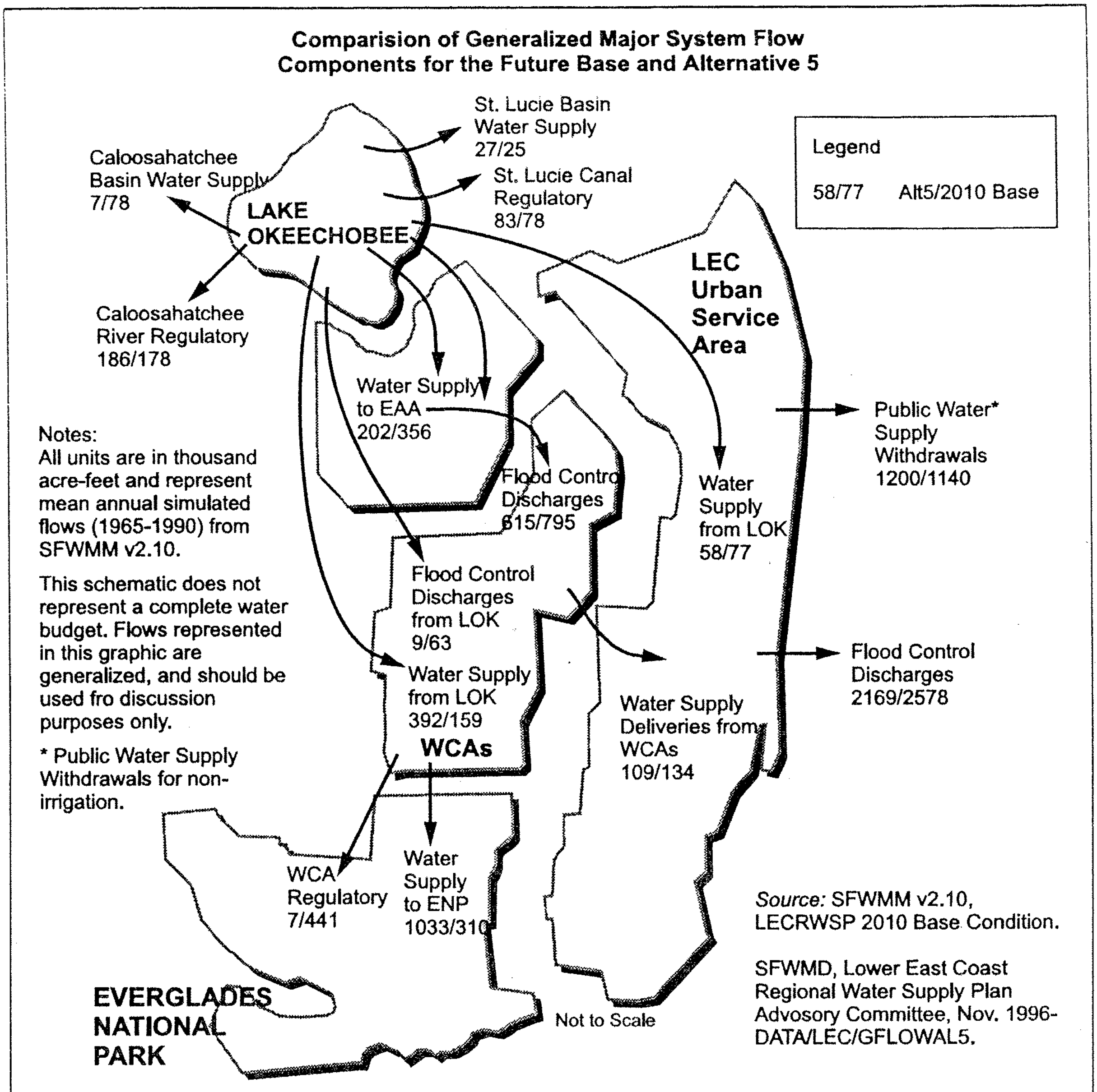

Figure 2

Application of storage concepts such as the aquifer storage and recovery (ASR) technology for storing surplus water has been evaluated and proposed as a regional option in the Lower East Coast Regional Water Supply Plan to help in reducing predicted future water shortages in the Lower East Coast area of South Florida. One of the regional ASR options considered in the Lower East Coast planning effort consists of two hundred twenty-five 5 MGD ASR wells, each with a conservative 5 MGD capacity, located in clusters located along some of the SFWMD's major conveyance canals. Each well cluster consists of two 2.5 MGD surficial groundwater wells as the source of water for a single 5 MGD ASR well which is completed in the upper Floridan Aquifer. This option would use canals as temporary storage features and would withdraw from and recharge to the canals during operation.

Another application consist of using ASR to expand the storage potential of Lake Okeechobee. Under this option, approximately 750 MGD of recovery capacity by ASR wells would be strategically located around the Lake, withdrawing water for underground storage when water levels are above a target stage elevation. Stored water would then be recovered and the Lake would be recharged during the dry season to ensure adequate supplies. This paper focuses on the latter option.

The proposed operating scheme for the Lake Okeechobee ASR system would be to recharge the aquifer when surface waters are released to tide for flood control. Intercepted surface water would be injected and stored into the upper Floridan Aquifer System for future use (i.e., recovery). The recovered water would then be re-introduced into the Lake and/or adjacent canals during periods of need to aid in maintaining and managing canal and water table elevations.

Preliminary model runs indicate that this option appears to provide significant water resource benefits including a reduction of deliveries from the regional system to the coastal areas and a reduction of tidal discharges. This concept may incorporate untreated groundwater and/or surface water as a source. The SFWMD has conceptually proposed an untreated surface water ASR pilot facility that would be located near the southern portion of Lake Okeechobee. This facility would utilize untreated surface water from Lake Okeechobee for injection into the upper Florida Aquifer System. The Florida Department of Environmental Protection (FDEP) and the United States Environmental Protection Agency (EPA), Region IV, are currently evaluating the merits of this proposal.

Concept

The proposed ASR application will be a first of a kind. While storage of treated water, raw groundwater, and some surface water ASR systems have been initiated, no ASR system of this magnitude has ever been attempted. Storage of massive volumes of untreated surface water, with huge variations in availability makes this application unique. In addition, the water quality issues related to storage, and recovery create new regulatory challenges.

Some preliminary testing has been performed to provide a level on comfort regarding the proposed ASR plan. Preliminary testing and modeling have been conducted at the Lake Okeechobee Taylor Creek/Nubbin Slough ASR test well. The results have been used during development of the conceptual plan. In addition, many coastal communities have initiated potable and raw water ASR systems.

Design criteria for the Lake Okeechobee ASR system is based on knowledge of the upper Floridan Aquifer System. Specific features of the design include definition of success. While most utility systems strive for near 100% recovery, this system will be considered successful if 50% of the stored water is recovered. Storage of appropriate volumes and testing at the correct scale are critical factors for success. Approximately 90% of the deliveries from Lake Okeechobee to the Lower East Coast are estimated to be loss due to high ET and system inefficiencies. Other design criteria include:

- 60-80% recovery efficiency
- 10 MGD per well capacity
- 24-inch diameter casing (could be 30-inch diameter)
- Cased to 1,200 feet
- Open hole to 1,600 feet
- Target storage volume of 1 to 1.5 billion gallons per well

Table 2 presents a summary of the various design parameters for potable water, raw water, and reclaimed water. Design of raw water ASR systems differ significantly when compared to potable water designs. In addition, raw water and reclaimed water systems have unique requirements that are specific to the use of recovered water. Raw water ASR systems (either groundwater or surface water) for example, are designed to capture excess water within a short frame and store much larger volumes than reclaimed or treated water ASR systems. One or more production horizons may be selected, causing final completion to be deeper than other systems. Storage volumes may be in excess of 1 billion gallons per ASR well which is considerably higher that volumes stored in reclaimed water systems. Since the recovered water will be fully treated prior to consumption, recovery efficiencies may be low. Low recovery efficiencies allow additional flexibility in recovery rates. High or low rates could be acceptable depending on demands and the treatment process. Recovery rates as high as 15-24 MGD are possible for raw water ASR systems.

TABLE 2 - Technical Comparisons of Aquifer Storage and Recovery (ASR) Systems

Criteria	Treated Water	Untreated Water	Reclaimed Water
Recharge Rate (MGD)	Low to medium	Medium to very high	Low to medium
Water Quality of Recharge Fluid	Meets drinking water stds.	Meets most primary, but not all secondary stds.	Meets most primary, but not all secondary stds.
Water Quality of Receiving Zone(s)	Good to fair	Fair to very poor	Good to fair
Storage Period	3-9 months	6-24 months	3-6 months
Storage Volume	30-150 million gallons	250-1,500 million gallons	10-50 million gallons
Recovery Rate (MGD)	Low to medium	Medium to very high	Low
Recovery Efficiency	75% or higher	25% or higher	75% or higher
Development Time	Moderate	Short to moderate	Moderate to high
Monitoring	Minimal	Extensive	Extensive

Typical costs for ASR wells completed into the upper Floridan Aquifer System range from $1 to $1.5m. The total time required to design, construct and develop and ASR well is about two years. Design may take 3-6 months, but permitting may require over 12 months to complete for untreated water systems. Development of the storage horizon will vary for numerous reasons including native water quality, recharge/recovery rates, hydraulic characteristics of the horizon chosen and desired recovery efficiency. Repetitive cycles of similar volumes will improve recovery efficiency (6-18 months may be required to fully develop a storage horizon).

Constraints

An ASR well permit application using surface water as a source has never been permitted. This concept, which is under discussion with a variety of regulatory agencies, will require an open mind set to move forward. Permitting a concept that has never been permitted may be the biggest challenge facing this application of ASR.

The application and development of the ASR technology has been constrained by current Federal and State regulations. A major obstacle to using untreated ground and surface water as a source for ASR systems lies in the regulatory interpretation of the federal Underground Injection Control (UIC) regulations. Both the EPA and FDEP interpret the UIC regulations as prohibiting the injection of fluids into an Underground Source of Drinking Water (USDW) aquifer if the fluid contains contaminants which exceed the primary drinking water standards. Under this current policy, any ASR project which would exceed these standards would be required to obtain an aquifer exemption.

Federal regulations applicable to UIC include 40CFR Part 144 (UIC Program), Part 145 (State UIC Program Requirements) and Part 147 (State UIC Programs). In Florida, EPA has delegated primacy to the State for enforcement of the Federal regulations. The State of Florida has additional requirements pertaining to injection practices which are outlined in Chapter 62-528. These regulations are even more stringent than the Federal regulations and require that injected fluids meet both primary and secondary drinking water standards. The State also has restrictions regarding movement of injected fluids outside the designated injection zone depending on the classification of the injection well. In South Florida, surface water directly recharges the surficial (water table) drinking water aquifers via canals.

Legal issues surrounding the adequacy of EPA's and FDEP's interpretation of regulations for requiring pre-treatment of injected waters (untreated ground or surface water) can be raised. In fact, the plain language of the EPA regulations support a contrary interpretation of the regulations. It could be argued that as long as the injected water is of a quality that can be treated to meet drinking water standards upon withdrawal, then water not meeting primary and/or secondary drinking water standards could be injected. Changes to the current regulatory framework are needed if the full potential of ASR technology is to be realized. The ability to utilize high quality sources of water that may not fully meet some primary drinking water standards such as the standard for coliform bacteria, will allow large scale ASR technology to move forward in South Florida.

Some progress has been made recently regarding regulatory classification of ASR under the State's UIC program. Chapter 62-528 F.A.C. reclassified ASR wells separately as Class V, Group 7 wells. This new classification should assist to promote ASR as a storage tool in Florida. Table 3 provides a summary of the criteria governing the new Group 7.

Conclusions

This paper begins to discuss some innovative ideas of the ASR concept for applications other than treated water systems. Benefits associated with treated water systems have been well documented and demonstrated during the past 20 years. Additional applications and benefits can be realized with the expanded use of the ASR concept. Untreated or raw water systems have tremendous advantages over traditional applications. These benefits are beginning to surface as the technology gains popularity. Another application has been the use of ASR for storage of reclaimed waters. Benefits with this application are vast and are also being tested for large scale implementation.

The main benefit of raw water ASR systems is that these systems allow augmentation of raw water supply by taking advantage of variations in demand. In Florida for example, production wells can be pumped at almost unlimited amounts during wet periods with excess water stored underground for later use to meet peak demands. Monitoring of raw water ASR systems are reasonable since regulators recognize that recovered waters will be fully treated to drinking water standards prior to consumption. Regulatory concerns are generally related to the quality of the receiving zone and the consistency and reliability of the raw water. Raw water ASR systems have been tested, or constructed, or under construction at various sites in Florida including Lake Okeechobee, Dade County, Broward County, Palm Beach County and the City of West Palm Beach.

TABLE 3 - Aquifer Storage and Recovery (ASR) System Permitting Matrix

Exemption Required	Mechanical Integrity Required	Monitoring Overlying Zones/Injection Zone/ & ASR Supply Zone	Class I Standards	Monitor Injected Fluid	Permit
ASR Category 7A - Meets primary and secondary standards and was treated at WTP.					
No	No	No No No	No	No	Auth.
ASR Category 7B - Meets primary and secondary standards.					
No	Maybe[1]	Maybe[1] Yes Yes	No	Maybe[1]	Auth.[1] w/more restrictions
ASR Category 7C - Meets primary, but does not meet all secondary standards.					
Water Quality Exemption (Maybe)	Yes	Yes Yes Yes	Maybe[2]	Yes	Yes
ASR Category 7D -Does not meet primary standards.					
Aquifer Exemption	Yes	Yes Yes Yes	Yes	Yes	Yes

1 - Depends if Department has reasonable assurance that the ASR supply water quality will continue to meet water quality standards over time.

2 - Class I standards may not be required if certain parameters contained in the secondary drinking water standards are exceeded by a small amount.

Applications of raw water and reclaimed water ASR have lagged primarily due to regulatory restrictions which guide underground injection and storage of fluids in potential sources of underground drinking water. There have been significant changes in the regulatory community during the last two years as evident by the new classification of ASR systems into a separate grouping. This reclassification has helped promote more widespread use of ASR in the State and will allow regulators to monitor ASR systems based on intended uses.

The technical issues related to design of raw water ASR systems expand the potential storage horizon. Raw water ASR systems are generally designed to store very large volumes underground (500,000,000 to 1,500,000,000 gallons), and recharge and recover at high rates. Potable ASR systems store volumes are designed with significantly less capacity than raw water systems and must be designed to maximize recovery efficiency depending on the intended use. Recharge rates may be much higher for raw water ASR systems.

Continued use of innovative applications will enable the SFWMD and others to more prudently manage water resources. These applications are consistent with SFWMD's long range planning initiatives and should be allowed to be fully tested to confirm feasibility for future use. Regulators will play a major role in the development of new and innovative applications such as ASR. Their support is essential to allow utilities to seriously consider new approaches to water management problems. Use of the ASR technology in conserving fresh water resources such as stormwater and reclaimed water can be an important component in any water resource planning effort.