WATER SUPPLY BENEFITS OF STORMWATER ASR IN SOUTH FLORIDA

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ABSTRACT: Aquifer storage and recovery (ASR) of stormwater was evaluated to assess its potential to augment water supply in southeast Florida. A feasibility study was conducted which included hydrologic analyses, water quality evaluations, treatment requirements, permitting feasibility, and cost comparisons for different treatment technologies. Results indicated that stormwater ASR can reliably and cost-effectively capture large volumes of stormwater during wet periods to meet demand during dry periods. It can be readily integrated into the existing water supply systems at a minimum cost and can significantly increase yield and maintain reliability during dry periods.

INTRODUCTION

Southeast Florida is extensively developed from the coast to the edge of the Everglades. Growth in the area continues at a fast pace and is expected to increase demands on the water resources of the area. Projections are that population will increase by over 50 percent in the next 20 years, and public water supply demand will increase by 38 percent.

In addition to urban growth, Everglades restoration efforts will reduce the amount of regional water available for urban supplies. As a result, water demands are projected to exceed the existing capacity of the natural system to supply water during droughts. With average rainfall of about 55 inches per year in southeast Florida, water is plentiful during the wet season. However, dry periods can stress the system as experienced during recent droughts (1980-1981 and 1988-1989) which highlighted the vulnerability of the system.

High annual rainfall coupled with the large volumes of surface waters discharged to the ocean during the wet season indicates that water is abundant. The water supply shortfall could be resolved by providing adequate storage capacity to capture water during wet periods for use during dry periods.

Surface water storage reservoirs are a costly proposition because of limited land availability in the developed areas. Existing storage available in Lake Okeechobee and the Water Conservation Areas are currently fully utilized to the extent allowed by existing policy that seeks to balance urban water needs with environmental restoration and flood control.

Aquifer Storage and Recovery (ASR) is one of the solutions currently under consideration for meeting the current and future water supply needs of southeast Florida. ASR is a proven and cost-effective technology for storing large volumes water in an underground aquifer during periods when water is available, and recovering the water from the same well when it is needed.

Study Area

The study area for this project was Palm Beach County, specifically the service area of the Palm Beach County Water Utilities Department (**Figure 1**). Site specific data used in this study included water use demand, canal flow data, and surface water quality data. However, since the hydrologic, water quality, and demand characteristics are comparable to other areas in southeast Florida, the results and conclusions presented herein may be applicable throughout southeast Florida.

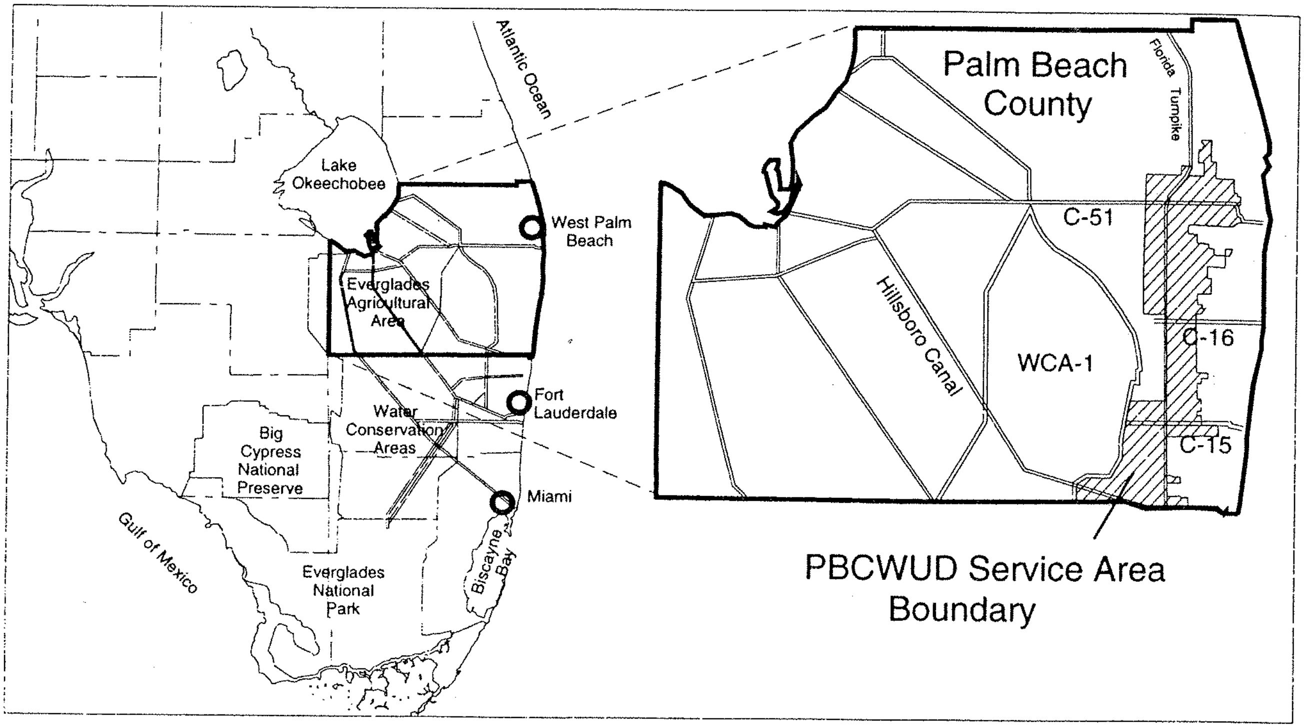


Figure 1
Palm Beach County Service Area Map

Southeast Florida is characterized by low topographic relief with ground surface elevations ranging from sea level to about 20 feet NGVD. Surficial soils are generally composed of sandy materials that allow for direct recharge of the surficial aquifer by rainfall and provide a connection between the aquifer and surface water features such as lakes and canals.

Surface water runoff is drained by tertiary and secondary canal systems that ultimately discharge to the Atlantic Ocean via primary canals managed by the South Florida Water Management District. The primary canals extend from Lake Okeechobee to the coast and serve to drain flood waters from the Lake, the Water Conservation Areas, the Everglades National Park, and urban areas along the coast (Figure 1).

A surficial aquifer composed of sand and shelly limestone is the primary source of water supply in southeast Florida. Because the Surficial Aquifer System is interconnected with the canal system, the primary canals are also used to recharge the aquifer with waters from regional storage during dry periods.

Underlying the surficial aquifer is a confining unit that separates the surficial aquifer system from the Floridan aquifer. The Floridan aquifer system is composed of alternating layers of high and low permeability limestone with three distinct water production zones. Although not used extensively as a water supply source because of the brackish nature of the water, the Floridan aquifer is selectively used to supply water to reverse osmosis treatment plants in certain areas. In addition, the Floridan aquifer is the aquifer of choice for municipalities using ASR.

Stormwater ASR

The concept of stormwater ASR is to capture excess stormwater and surficial groundwater that would normally be discharged to the ocean. Waters captured through direct withdrawal from canals or from wells recharged by canals, would undergo treatment prior to distribution for public water supply. During wet periods, excess stormwater of acceptable quality would be injected into the Upper Floridan aquifer using ASR wells. Stored ASR water would be withdrawn during dry periods to augment water supply needs.

The goal of stormwater ASR is the conservation of urban stormwater and its use as an alternate source of water supply that reduces dependence on the surficial aquifer system, the primary source of water supply in Palm Beach County. Benefits of stormwater ASR include conservation of stormwater and ground water, increased aquifer recharge, and reduced dependence on the regional system.

ASR is one of the components of an integrated water resource plan under implementation by the Palm Beach County Water Utilities Department (PBCWUD) to provide long-term water supply solutions for the County. Other components of the plan include conservation, created wetlands, reclaimed water, and indirect reuse.

WATER AVAILABILITY

A water availability analysis was conducted to determine the effectiveness of ASR at capturing excess stormwater from the canals. A spreadsheet model simulated the daily operation of a stormwater ASR system, including canal flow, water use demand, treatment plant capacity, and ASR injection, storage, and recovery. Results indicated that stormwater ASR can reliably capture large volumes of stormwater during wet periods to meet demand during dry periods.

The concept of stormwater ASR was found to be more effective than initially anticipated because storage cycles were found to be of shorter duration, and should result in higher recovery rates of injected water. Hydrologic analyses of historic canal flows revealed that dry periods (zero flow) were generally of short duration, albeit occurring more frequently during the dry season (November to April). As indicated in Table 1, dry periods averaged from 20 to 30 episodes per year, with durations averaging from 3 to 7 days, and extending up to 30 or 100 days under severe drought conditions (the period of analysis included the 1988-89, 100-year drought).

The spreadsheet model was used to estimate ASR and treatment plant capacity requirements as a function of maximum day demand for both raw and treated stormwater ASR. The model was run over a range of values of maximum day demand using source water from each major canal.

Table 1
Analysis of Zero Flow Events[1]

Parameter	Flow Station/Canal				
	S5A_P C-51 Canal	S155_S C-51 Canal	S41_S C-16 Canal	S40_S C-15 Canal	G56_S Hillsboro Canal
Zero Flow Summary					
Number of Days of Period of Record	3,617	6,403	3,545	3,666	1,603
Number of Zero Flow Days	2,308	1,177	2,027	1,039	449
Percent Zero Flow Days	63.8%	18.4%	57.2%	28.3%	28.0%
Event[1] Duration Statistics					
Average number of events per year	39.3	12.5	30.8	29.8	20.7
Mean Duration (days)	5.9	5.4	6.8	3.5	4.9
Median Duration (days)	3.0	2.0	3.0	2.0	3.0
Minimum Duration (days)	1.0	1.0	1.0	1.0	1.0
Maximum Duration (days)	77.0	101.0	60.0	39.0	35.0
Standard Deviation of Duration (days)	7.9	10.5	9.6	4.6	6.8
Coefficient of Variation[2] of Duration	1.3	2.0	1.4	1.3	1.4

[1] Zero flow event is defined as one or more consecutive days of zero canal flow.

[2] Coefficient of variation is defined as the standard deviation divided by the mean.

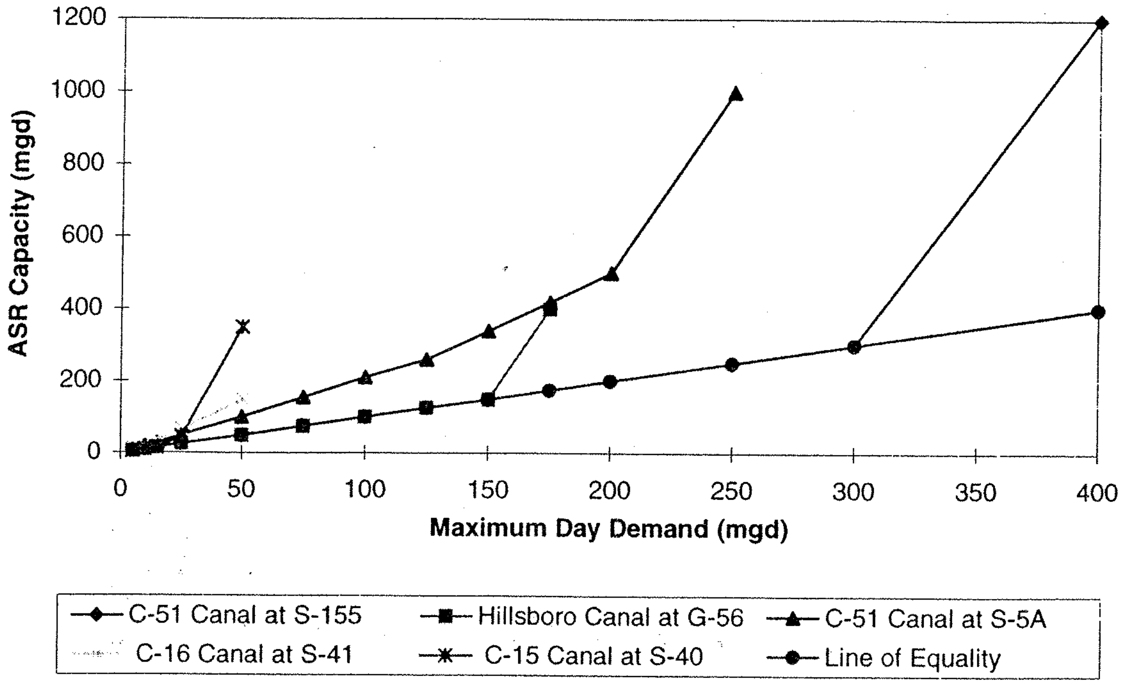
Figure 2 shows the relationship between maximum day demand and raw stormwater ASR capacity for each of the major canals in the study area. The figure also shows the "line of equality," which defines the points where ASR capacity is equal to maximum day demand. The line of equality represents the minimum ASR capacity required to meet the indicated demand. All things equal, it is desirable for ASR capacities to follow the line of equality to minimize ASR capacity and related costs for a given level of demand.

A review of Figure 2 shows that most canals follow the line of equality at low levels of demand but deviate from that line as demand begins to outstrip stormwater availability. Generally, canals with higher average flows and lower occurrences of zero flow periods displayed a greater potential to meet high levels of demand with a minimum of ASR capacity. Once demands begin to exceed stormwater availability, ASR capacity requirements increase exponentially up to a maximum level beyond which additional ASR capacity cannot meet demand

In the case of treated water ASR, the ability to inject treated water into ASR storage is a function of the difference between plant capacity and average day demand. Assuming that enough water is available in the canal to supply the plant, the plant would be operated at maximum capacity and water produced in excess of demand would be injected into ASR storage. Using a peaking factor of 1.52, about one third of plant capacity could go into ASR storage, on average. Therefore, the required ASR capacity during injection is about one third of maximum day demand. During recovery, however, ASR capacity has to be equal to maximum day demand to meet demand during periods when no canal flows are available to feed the plant.

Figures 3 and 4 summarize the relationship between demand, plant capacity, and treated stormwater ASR capacity for the two major canals in the study area. The figures show that at low levels of demand, ASR and plant capacity are close to or equal to maximum day demand. However, as demand grows and begins to exceed canal water availability, plant capacity must be higher than maximum day demand to meet total demand. For very high levels of plant capacity, ASR capacity must also be increased to satisfy demand.

Figure 2
Raw Stormwater ASR Capacity Needed to Meet Maximum Day Demand



In summary, both raw and treated stormwater ASR systems were found to be feasible at small system capacities. However, at high capacities, a raw stormwater ASR system proved more efficient at capturing excess stormwater, yielding up to 3 times more water than a treated stormwater ASR system. Using a raw stormwater ASR system, for example, the C-51 and Hillsboro canals were capable of yielding up to 300 mgd and 150 mgd of firm yield, respectively. For treated stormwater ASR, however, the same canals could only yield up to 100 mgd and 50 mgd of firm yield, respectively.

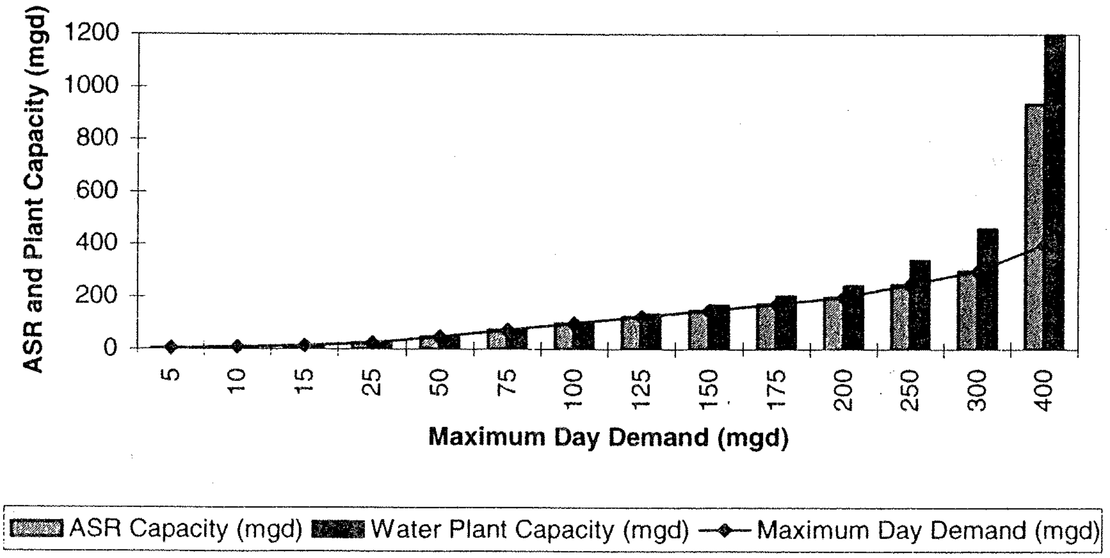
Other critical advantages of raw stormwater ASR include the avoidance of plant shutdowns and startups during prolonged dry periods, and more reliable performance that is less sensitive to changes in water availability and/or ASR recovery efficiency.

SOURCE WATER DEVELOPMENT ALTERNATIVES

A number of alternatives were considered for withdrawing excess stormwater from the canal system, including the following:

1. Direct canal intake
2. Shallow Well
    - Vertical well (open hole from 40 to 60 feet deep) in close proximity to canals
    - Horizontal well aligned along the canal banks (20 feet deep)
3. Deep groundwater well (open hole from 100 to 140 feet deep) in the vicinity of the canal, similar to the supply wells currently used by PBCWUD.

Figure 3
Treated Stormwater ASR and Plant Capacity
for C-51 Canal at S-155

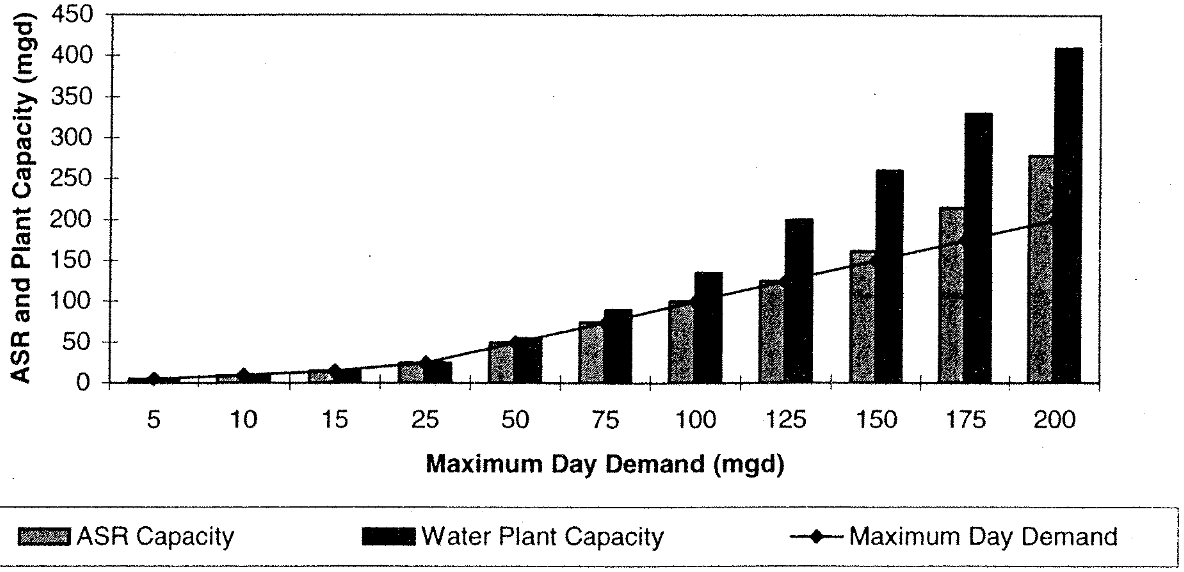


Each of these alternatives can capture stormwater from adjacent canals either directly or indirectly, by induced aquifer recharge. Local canals can also be supplemented with stormwater diverted from larger canals to provide the required recharge.

A shallow or deep groundwater well system (either horizontal or vertical) adjacent to a canal is expected to provide a more consistent source of quality water compared to a direct canal intake.

A review of canal water quality within the study area indicated that the parameters for which data were available were found in compliance with existing primary drinking water standards. The secondary standards of color and zinc, however, were typically exceeded. Turbidity, hardness, and water temperature were somewhat variable between canals, and chlorophyll and algae were present in samples analyzed for those parameters. The water also had relatively high concentrations of total organic carbon, which indicated that it may have a high disinfection byproduct formation potential.

Figure 4
Treated Stormwater ASR and Plant Capacity for Hillsboro Canal at G-56



TREATMENT ALTERNATIVES

The method of source water development (canal intake, shallow well, or deep well) and related water quality characteristics were the primary factors influencing the selection of treatment processes required to achieve the desired water quality objectives. Source waters were subdivided into the following two major categories for treatment purposes:

1. Low to Moderate Hardness (less than 150 mg/L as calcium carbonate);
2. Moderate to High Hardness (greater than 150 mg/L as calcium carbonate).

For waters of low to moderate hardness it was assumed that softening would not be required. For options involving a canal intake, it was assumed that coagulation, flocculation, sedimentation and filtration (collectively referred to as enhanced conventional treatment) would be suitable process components. For options that utilize wells, where consistently low turbidity levels are anticipated, it is expected that the sedimentation process component may not be required (i.e., direct filtration may be suitable).

For waters with higher hardness levels, it was assumed that softening would be required as a component of the treatment process. For options that utilize wells, lime softening was assumed to be used instead of conventional treatment or direct filtration. For the canal intake alternative which is expected to be characterized by elevated and variable levels of turbidity and particulates, it was assumed that lime softening would be implemented in addition to conventional treatment.

As the sources considered were all characterized by elevated total organic carbon levels, all treatment options were configured with the objective of complying with the anticipated Enhanced Surface Water Treatment Rule and the Disinfectant/Disinfection By Product (D/DBP) rule, as well as all existing Safe Drinking Water Act (SDWA) regulations.

The various source water alternatives and treatment processes were combined into five process alternatives. Planning level cost estimates were developed for each of these alternatives to provide a basis for their evaluation. The five alternatives are described as follows:

1. Canal Intake, Low Hardness - direct canal intake followed by raw water equalization, pre-ozonation, flash mixing, flocculation, sedimentation, post-ozonation (pre-filters), deep bed filtration and treated water ASR. Provisions are made for future addition of Granular Activated Carbon (GAC), if required.
2. Shallow Well, Low Hardness - shallow well intake, pre-ozonation, and direct filtration (flush mixing, flocculation, filtration). Raw stormwater and treated water ASR are both options for this alternative. Provisions are also made for future additions of GAC if required.
3. Canal Intake, High Hardness - direct canal intake followed by raw water equalization, pre-ozonation, flash mixing, flocculation, sedimentation, softening, post-ozonation and filtration. Treated water, ASR is assumed for this option and provision is made for the future addition of GAC contractors if required.
4. Shallow Well, High Hardness - Shallow well followed by raw water ASR wells, softening, post-softening ozonation, deep bed filtration and treated water ASR. Provisions are made for future additions of GAC contractors if required.
5. Deep Well, High Hardness - Groundwater well followed by raw water ASR, lime softening, post-softening ozonation, filtration and treated water ASR.

ASR WELL SYSTEMS

A review of existing ASR systems in Florida, coupled with an assessment of the hydrogeology of the study area, indicated that suitable hydrogeologic conditions exist for the successful construction and operation of Floridan Aquifer ASR wells in the PBCWUD service area.

There are approximately 20 operational ASR systems within the United States. Six are located in Florida, storing water in fresh, brackish, and seawater aquifers. ASR Systems located in Florida include the Boynton Beach, Manatee County, Peace River, Cocoa, Port Malabar, and Marathon. The ASR system in Boynton Beach is the only operational system located within Palm Beach and Broward county area.

The PBCWUD service area has a suitable hydrogeologic environment for ASR application. This is supported by the successful operation of the Boynton Beach ASR well, located within the PBCWUD service area. The Boynton Beach well is operated at a rate of over 1.5 mgd, stores water for periods of

30 to 60 days, and recovery efficiencies presently vary between 60 to 80 percent. It is expected that total dissolved solids (TDS) concentrations will be approximately 5,000 mg/L within the Upper Floridan aquifer storage zones, based on water quality data from the Boynton Beach, Deerfield Beach, and deep well sites within the PBCWUD service area.

ASR wells within PBCWUD can be expected to inject and recover stored water at conservative rates of up to 2 mgd per well. Recovery efficiencies will be highly dependent upon site-specific aquifer characteristics, however, operational data from several facilities in the south Florida area indicates that a 75% recovery efficiency for water stored for brief periods appears to be a reasonable target.

Recovery efficiencies may be improved by installing multiple wells within close proximity to each other (perhaps between 500 to 1000 feet, as at the successful Cocoa ASR facility) to create ASR well "clusters". Over time, the "cylinders" of stored water would overlap and coalesce, hence aiding in the dilution and dispersion of brackish ambient waters away from the ASR wells.

The construction and operation of an ASR system requires compliance with certain regulatory requirements. The key agencies involved in ASR permitting in Palm Beach County include the Florida Department of Environmental Protection (FDEP), the United States Environmental Protection Agency (EPA), the SFWMD, and the Palm Beach County Public Health Unit (PBCPHU). ASR projects are typically evaluated in terms of technical, environmental, and economic feasibility. Effects on existing uses, adverse impacts on nearby surface waters, saltwater intrusion, and the lateral and vertical extent of the water quality impacts are all considered during the permitting process.

Based on numerous treated water ASR systems permitted in South Florida, no problems are anticipated with permitting treated stormwater ASR systems. While permitting of raw water ASR injection is expected to be somewhat more involved, no major problems are anticipated with permitting the injection of raw groundwater (from shallow or deep wells). Based on available water quality data, groundwater quality is in compliance with existing drinking water quality standards except for color, zinc, and copper. These are all secondary standards which can be addressed by obtaining a water quality criteria exemption from the FDEP. A criteria exemption was granted to ASR wells in Dade County, and applications for criteria exemptions are currently under review for ASR wells in Broward County, West Palm Beach, Fort Lauderdale, and Manatee County.

Permitting the injection of raw stormwater extracted via direct canal intake is expected to meet with greater difficulty. Raw canal water is expected to have greater variability in turbidity, algae, pathogens, total organic carbon, taste, color, and odor; possibly exceeding primary water quality standards depending on weather conditions. Of the parameters for which canal water quality data were available, historic exceedances were observed for iron, zinc, and color. In addition, maximum values of total chloride, copper, and dissolved sodium were close to exceeding standard at some locations.

Exceedances of primary standards would require a minor aquifer exemption. Only one minor aquifer exemption has been granted for an ASR well in the state of Florida (the Lake Okeechobee ASR well). Other minor aquifer exemptions have been granted for deep injection wells, such as those granted to Monsanto and American Cyanamid. While minor aquifer exemptions are difficult to obtain under current regulations, proposed procedures under discussion with the EPA may facilitate this process in the future.

COST ESTIMATES

Planning level cost estimates were prepared to aid in the evaluation of stormwater ASR alternatives. Individual capital and operation costs were prepared for the ASR wells, three source water alternatives, and five treatment process alternatives.

The different options for source water, ASR wells, and treatment process were consolidated into five stormwater ASR alternatives, and cost estimates prepared for all five. The five stormwater ASR options were as follow:

- Canal Intake, Low Hardness
- Shallow Well, Low Hardness
- Canal Intake, High Hardness
- Shallow Well, High Hardness
- Deep Well, High Hardness

Each of these alternatives can be used in conjunction with either raw or treated stormwater ASR.

Figure 5 compares the total (capital and operation) annual costs of the five alternatives in dollars per thousand gallons for system capacities ranging from 10 to 50 mgd. The least cost alternative involves the use of conventional deep groundwater wells as the means to capture stormwater for ASR storage, followed closely by the shallow well (low hardness) alternative. The direct canal intake alternative was the highest cost, primarily because of the need for raw water equalization and conventional treatment.

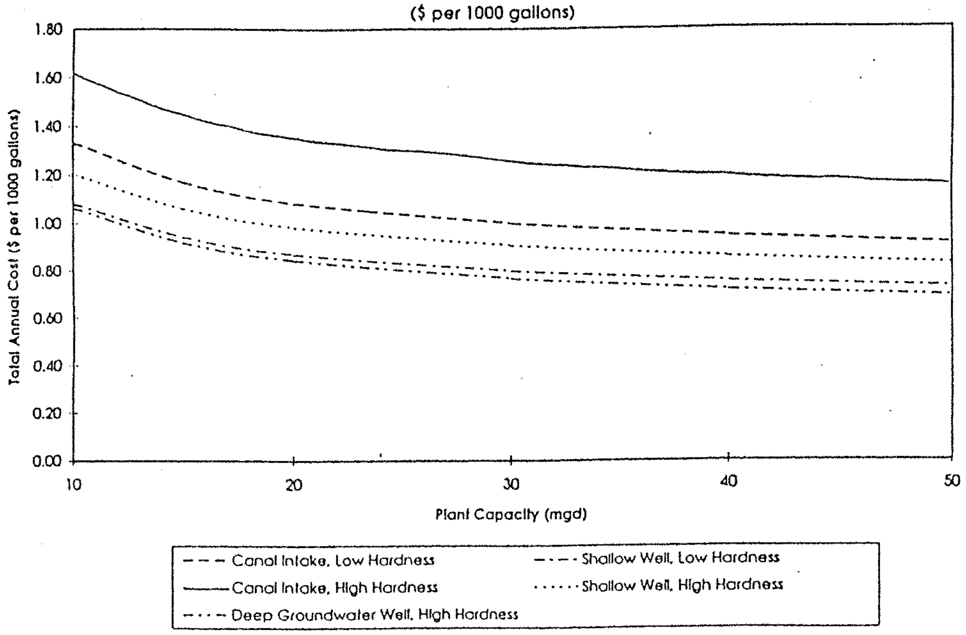


Figure 5
Annual Capital and Operation Cost
($ per 1000 gallons)

* Total Annual Cost includes Treatment Plant Capital Cost (including Land and ASR Well Cost), Chemical, Electrical and Labor Cost
** Based on Maximum Daily Flow

Estimated cost for construction and testing of a 2 mgd ASR well is $1,200,000. Expanding an ASR facility beyond a single ASR well reduces the overall construction cost by $250,000 because of the already completed monitor well and testing program. Therefore, the marginal cost of each additional 2 mgd well is approximately $1,000,000. The cost of ASR represents approximately 13% of the total annualized cost (capital and operation) of a complete stormwater ASR facility (source water, treatment plant, and ASR).

ACKNOWLEDGMENT AND REFERENCES

This project was funded jointly by the Palm Beach County Water Utilities Department and the South Florida Water Management District.

Montgomery Watson. 1996. Feasibility Study of regional Aquifer Storage and Recovery - Final Report. Lake Worth, Florida