Aquifer Storage and Recovery System Enhancement Through Reduced Operating and Capital Costs

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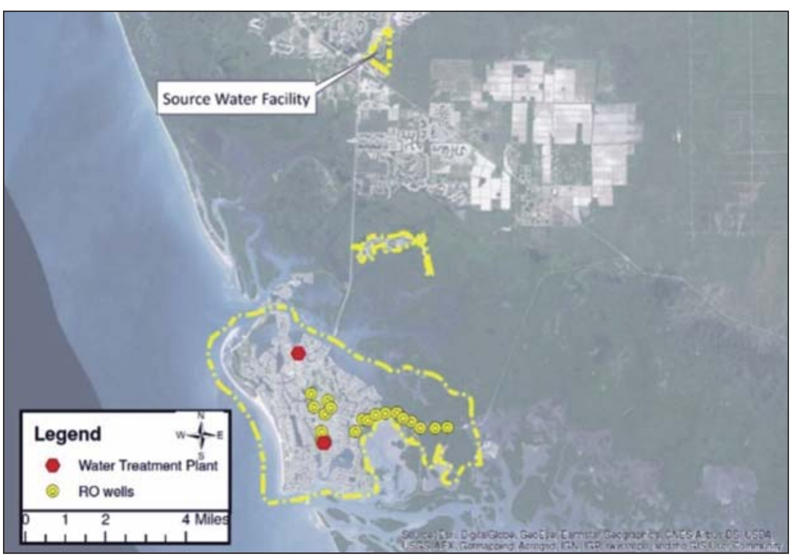
History of the Aquifer Storage and Recovery System

Marco Island Utilities (MIU) was purchased by the City of Marco Island (island) from Florida Water Service (FWS) in November 2003. The MIU provides potable water, reclaimed water, and sanitary sewer service for all of the residences and businesses on the island and two small communities two miles north of it. Marco Island is 24 sq mi in area and is one-half mi off the coast of Florida in the Gulf of Mexico, about 15 mi south of the City of Naples.

On the island there is no developable fresh water; potable water is produced at two water treatment plants (WTP): the North Water Treatment Plant (NWTP) and the South Water Treatment Plant (SWTP). The NWTP currently uses a lime softening process to soften fresh water (i.e., salt concentration about 500 parts per million [ppm]) from the source water facility (SWF), formerly known as Marco Lakes, located nine mi north of the island. Figure 1 is an aerial view from the SWF to Marco Island showing the main facilities of MIU, including the two WTPs and the Marco Island wellfield, also known as the reverse osmosis (RO) wellfield. The 208-acre SWF has two lakes and seven aquifer storage and recovery (ASR) wells that provide the fresh water for treatment at the NWTP to produce potable water and to supplement reclaimed water at two golf courses.

Figure 2 shows an aerial view of the ASR wellfield. Table 1 summarizes the phases of development of the ASR wellfield to its current size of seven wells. The ASR well No. 1 began operation in 1997, and on Oct. 2, 2001, it was issued a Class V operating permit from the Florida Department of Environmental Protection (FDEP), the first ASR well in Florida to receive such a permit. The ASR wells located on the north side of the lake are set on a grid with 400-ft spacing. The ASR wellfield received a Class V operating permit in June 2010 (plus a construction permit for ASR wells No. 4 and No. 7 to be built). New groundwater modeling results showed that ASR wells No. 4 and No. 7 would not have to be constructed because the existing seven wells can successfully operate at higher flow rates to meet the planned capacity of 13.5 mil gal per day (mgd).

The ASR system is a nationally recognized project and has won the 2010 grand prize for environmental sustainability from the American Academy of Environmental Engineers, the National Ground Water Association's 2010 outstanding groundwater project award, and the 2011 president's award for environmental sustainability from the National Association of Environmental Professionals.



Above: Figure 1. Map Showing Service Area and Features of the Water Supply System

At right: Figure 2. Aquifer Storage and Recovery Wellfield at the Source Water Facility

Wellfield Operations

Pretreatment of Water Stored in the Aquifer Storage and Recovery Wellfield

The stored water is pretreated to protect the wells from plugging and meet regulatory requirements; however, when the water is recovered it is essentially raw water, since it must undergo full treatment at the NWTP, just like the water withdrawn from the lakes and pumped to the NWTP to produce potable water.

The 9 mgd (or more) injected in the ASR wellfield is pumped through a pretreatment plant before injection into the ASR wells. Figure 3 shows the pretreatment plant that consists of two 12-ft-diameter and four 8-ft-diameter pressure filters with filtration beds of sand and charcoal. After the water is filtered, sodium hypochlorite and ammonium sulfate are added to produce a concentration of about 0.7 ppm of monochloramine disinfectant, and then the pH is reduced from about 7.5 to 7 with carbon dioxide gas to prevent precipitation of calcium carbonate on the borehole walls in the storage zone.

Aquifer Storage and Recovery Wellfield Operation

During the rainy season (typically mid-June to the end of November) Henderson Creek Canal (HCC), which borders the east side of the SWF, has a high inflow of stormwater runoff. Correspondingly, bank infiltration from the HCC into the two lakes is sufficiently high during the rainy season to allow the withdrawal from the two lakes to simultaneously meet the demand of about 6 mgd to the NWTP and about nine 9 mgd to fill the ASR wellfield. The maximum realistic storage rate is 13.5 mgd. The ASR wellfield storage zone is between two clay layers at 730 and 780 ft below ground surface and the native water has a chloride content of about 2,900 ppm. The stored water (with a chloride content of 70 to 150 ppm) is maintained at about one bil gal in a bubble shape with a diameter of about 4,000 ft. During the dry season (December to June) the water elevation in the lakes is often low and it limits the water withdrawal rate. The additional flow (2 to 5 mgd) needed to meet the demand is made up by recovering water from the ASR wellfield.

Good Geology Contributes to the Success of the Wellfield

The storage zone between 730 to 780 ft below grade is homogenous limestone that ranges from vary pale orange to yellowish gray. This limestone has a sponge-type structure, with good to excellent apparent moldic porosity. Fractures that would conduct stored water far from the wells and make it difficult to recover were not evident.

No Long-Term Issue With Arsenic in Recovered Water

The release of arsenic into the recovered water causes the oxygen in the water to react with the small amount of pyrite (about 0.23 wt percent) that contains the arsenic (about 0.14 wt percent of the pyrite) and forms ferric oxyhydroxide. During recovery, ions in the water flow over and react with the oxyhydroxide to form iron sulfide and also release the arsenic into the water.

Figure 4 shows the trend of arsenic in the recovered water from the ASR wells No. 2 and No. 3 (typical of all the wells). The reason the arsenic reduces to nondetect concentration after three cycles in MIU's ASR wellfield is a result of the relatively high concentration of dissolved organic compounds (about 15 ppm) compared to the dissolved oxygen concentration of about 5 to 6 ppm. The oxygen in the water most likely forms an aerobic zone near the well; however,

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the high organic concentration will react with all the oxygen to limit the size of the aerobic zone. Without oxygen, the arsenic in the pyrite does not dissolve into the water.

Benefits of the Aquifer Storage and Recovery Wellfield: A Third Water Supply

Marco Island's population ranges from 15,000 in the summer months to more than 40,000 during the winter months. Such a large variation in population causes the monthly daily average water demand in the summer months to be as low as 5.5 mgd and for the winter months to be 9 mgd. This variation in water demand would be greater by about 2 mgd if it were not for the reclaimed water distribution system that provides irrigation water to customers. Table 2 lists the benefits to customers of MIU by having the ASR wellfield as a third water supply, which during the dryer months, allows MIU to meet the high demand without having to increase the withdrawal from the wellfield on the island to the point where the salt concentrations increase. A previously published paper (FWRJ, March 2013) showed that the supply wells for the SWTP had a long history of ever-increasing dissolved salt concentrations, with a few wells exceeding 18,000 ppm salt. The ASR wellfield allows MIU to reduce the annual withdrawal from the brackish water wellfield wells by 50 percent (from 4 mgd to 2 mgd), thereby stopping and even reversing the upward trend in salt concentrations, making the brackish wellfield sustainable.

The large volume of stored water in the ASR wellfield has allowed the island to obtain exemptions from the South Florida Water Management District (SFWMD) from irrigation restrictions. The additional water from the ASR wellfield allows MIU to have sufficient water to provide about 60 mil gal per year (mgy) to the golf courses to supplement reclaimed water.

The additional water provided by the ASR wellfield also allows MIU to send about 45 mgy into the chlorine chambers at the reclaimed water production facility (i.e., the wastewater plant on the island), which blends with the treated wastewater, thereby increasing the amount of reclaimed water available for distribution. The raw water from the Marco Lakes site must meet suspended solids standards of 5 ppm. Figure 5 shows the suspended solids meter and piping that delivers the raw water to the chlorine contact chamber.

Goals of Upgrades to the System for the Future

The ASR system has a 20-year operating history, going back to when upgrades were needed to ensure continued high performance and relatively low operating costs with high reliability for the next 20 years (and longer). The goals that the upgrades need to achieve are listed in Table 3.

Maintain Stable Operating Performance of the Wells

The most important goal of any upgrade to an ASR system is to be certain that stable operation of the ASR wells is not compromised. For example, if the filtration equipment is not inspected on a regular basis, with the goal of reducing labor costs, the potential for fouling the borehole of the wells dramatically increases.

Reduce Annual Operating Cost

Modifications (i.e., upgrades) to operating

Table 1. Aquifer Storage and Recovery Development History

Table 1 – Development of Marco Island ASR System	
1997	Installed ASR Test Well, Monitoring Well, and Pretreatment (2 8-ft dia. Pressure filters, chlorination w/ Bleach and HCL)
1998	ASR test well became ASR-1
2001	ASR-1 received operating permit
2002	Wells ASR-2, ASR-3, and Monitor well DZ-2 Installed; Added 2 8-ft dia. Pressure Filters and CO2 system
2006	Wells ASR-5, 6, and 8 Installed; Added 2 12-ft dia. Pressure Filters and Ammonia system
2007	Installed Well ASR-9
2010	Existing Wells received Operating Permit with Administrative Order
2010	Wells ASR-4 and 7 Construction and Testing Permit Renewed
2015	Well Field received Operational Permit

Figure 3. Pretreatment System

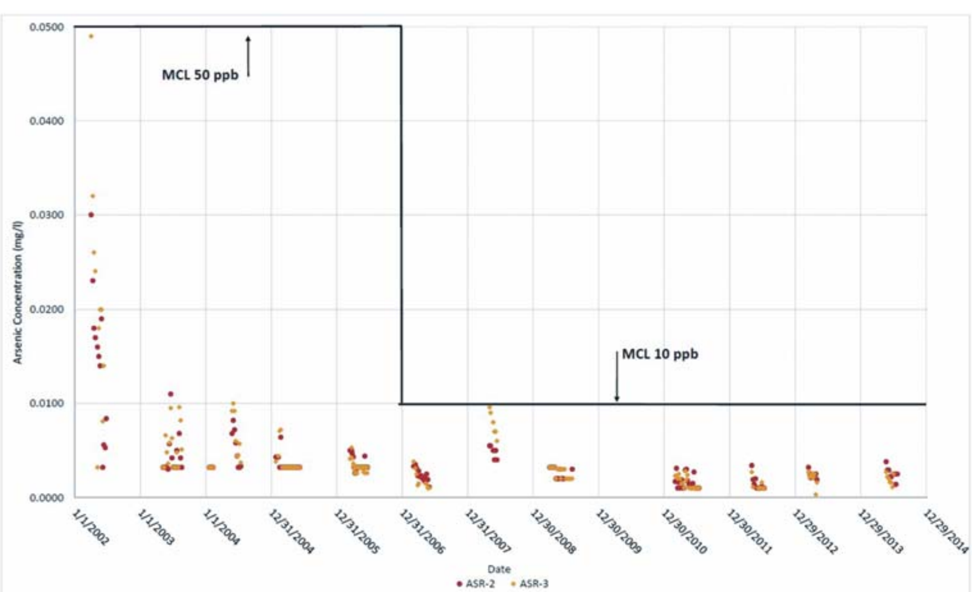

Figure 4. Arsenic Recovery (2002-2014)

Figure 5. Suspended Solids Meter and Chlorine Contact Chambers

Benefits of the ASR Wellfield – A Third Water Supply
Meeting Demand for Potable Water Production while maintaining low withdrawal from the Wellfield on Marco Island
Available Raw Water to Supplement Reclaimed Water for Irrigation at Golf Courses
Available Raw Water to Produce Additional Reclaimed Water when Wastewater Generation is Greatly Reduced by the Drop in Population on the Island
Large volume of Stored Water to get the though Drought Conditions without having to Implement Water Restrictions

Table 2. Benefits of a Third Wellfield

Table 3. Goals of Upgrades to Aquifer Storage and Recovery System

Maintain Stable Operating Performance of the Wells
Properly pretreat the raw water injected into the ASR Wells
Reduce Average Annual Costs (as $/1000 gallons recovered water)
Reduce Power Costs
Optimize/Limit the Amount of Stored Water (i.e., Increase Recovery Efficiency)
Reduce Maintenance Costs
Reduce Monitoring Requirements
Increase Recovery Efficiency
Know the amount and location of the stored water (i.e., where is the raw water bubble)
Increase the allowable concentration of chlorides in recovered water
Improve Reliability to Meet Demand for Recovered Water
Backup critical components such as Feed Pumps
Have parallel process components
Multiple ASR Wells

protocols should have the net effect of reducing overall costs. For example, the use of ammonium sulfate solutions to replace gaseous ammonia for formation of monochloramine in the injected water actually increases the cost of chemicals, but it decreases maintenance costs, with a net effect of a reduction in annual operating costs. Another example is the reduction in analytical sampling needed to meet FDEP permit requirements.

Increase Recovery Efficiency

The ASR wellfield must provide a sufficiently high recovery efficiency of the stored water for the operation to be financially viable (i.e., justified). Any upgrade that could compromise the recovery efficiency needs to be carefully assessed before being implemented.

Improve Reliability to Meet Demand for Recovered Water

Any upgrade should not have a negative impact on the reliability of the ASR system to be able to meet the demand of recovered water. For example, backup pumps for storing water in the ASR wellfield improve the reliability to recover water since it can't be recovered if the pumps fail to store water.

Upgrades Implemented for the Wellfield

Improvements to the Pressure Filters

The main components of the pretreatment system are the pressure filters, which were installed in pairs. The first two 8-ft-diameter filters were installed in 1997 when ASR well No. 1 started operation; one filter was operating and one was in standby mode. After about 20 hours of operation, the pressure in a filter increased from 4 to 15 pounds per sq in. gauge (psig), which automatically took that filter offline for a five-minute backwash with unfiltered water, and switched the flow to the standby filter for the next 20 hours. When ASR wells No. 2 and No. 3 were installed, another pair of 8-ft-diameter filters where installed. When ASR wells No. 5, No. 6, and No. 8 were installed in 2006, the two 12-ft-diameter filters were also installed. Table 4 provides the approximate completion of each of the upgrades completed at the ASR wellfield.

The backwashing continued to occur with filtered water. The backwashing of the filters was still triggered when the pressured drop across a filter reached 15 psig. The problem with the backwashing protocol was that each of the three pairs of filters, in theory, could have one filter in the backwash mode at the same time. With high flow rates of 6,000 gal per minute (gpm), the other filters online could have almost all the sand and charcoal blown out to the drainage area for the backwash water. This scenario did occur and resulted in two upgrades to the filters.

This first upgrade was to have a process control consultant recode and make the necessary wiring modification so that all six filters communicated with each other; then, only one filter would be in a backwash mode no matter what the flow rate was for the injected water. This eliminated the potential to blow out the sand and charcoal in the filters. The second modification was to change the programming sequence (on-off setting) of the control valves for each filter so that the backwashing was done with filtered water. This last change slightly reduces the volume of filtered water produced each day, but it increased the time for backwash cycles.

Using Ammonium Sulfate Solution Instead of Gaseous Ammonia

In 2006, when ASR wells No. 5, No. 6, and No. 8 were installed, a gaseous ammonia feed system was installed to create the disinfectant monochloramine in the injected water instead of hypochlorite, which caused the formation of trihalomethanes (THMs). In 2012, the gaseous ammonia feed system was replaced with an ammonium sulfate solution that has a much higher chemical cost (by a factor of more than three), but much lower maintenance costs and higher reliability.

Reduce Annual Losses of Carbon Dioxide

Installation of a second refrigeration unit on the carbon dioxide storage tank essentially eliminated losses of carbon dioxide, thereby reducing operating costs.

New Aquifer Storage and Recovery Feed Pumps and Building

The existing two 49-year-old, 200-horsepower (hp) ASR feed pumps (Figure 6) were replace with two new 400-hp pumps (Figure 7), with each equal to the combined flow (6,000 gpm) of the older pumps. This provided 100 percent redundancy. Each pump can also can pump more than 5,000 gpm of lake water directly to the

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Figure 6. Aquifer Storage and Recovery Pumps During Deconstruction

Figure 7. New 400-hp Aquifer Storage and Recovery Feed Pumps

Figure 8. New Aquifer Storage and Recovery Feed Pump Building

Table 4. Upgrades to Aquifer Storage and Recovery System

Upgrades to ASR System	
1997	Modified Control System of Pretreatment Plant Pressure Filters
2006	Backwash Pressure Filters with Filtered Water Instead of Raw Water
2012	Replace Ammonia Gas Feed System with Ammonium Sulfate Solution
2013	Replaced the two, 49 year old ASR Feed Pumps with Two New Pumps
2014	Completed Updated Modeling Study of the Fresh Water Bubble
	Installed Second Refrigeration Unit on Carbon Dioxide Storage Tank
2015	Modifications to Renewed ASR Wellfield Permit
TBD	Replace Lime Softening at NWTP with Low Pressure Reverse Osmosis

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NWTP in the event the adjacent 37-year-old pump house that normally pumps lake water to the NWTP is damaged. To improve the reliability and reduce the maintenance costs of the new pumps, a new pump house (Figure 8) for the 400-hp pumps was built, which is designed to withstand wind loads of 180 mi per hour (mph).

Modeling Study Reduces Capital Costs and Optimizes Stored Water

A modeling study of the bubble of fresh water stored at the ASR wellfield was completed in 2014 and provided an updated estimate of the fresh water shape of the bubble. A result of the modeling was that the existing seven wells had the ability to store the maximum daily stored water of 13.5 mgd, and that the last two ASR wells No. 4 and No.7 did not have to be built, resulting in a capital savings of about $3 million in well construction and ancillary costs.

Modification of the Permit Requirements for Modeling

In 2015 the permit for the ASR wellfield was renewed. Given the long history of compliance, the monitoring and associated analytical costs have been reduced. Table 5 shows the reductions monitoring compared to the monitoring required before the permit was renewed. Generally, the water quality testing and monitoring increased by about 50 percent in the ASR and monitoring wells tapping the injection/production zone, and by about 75 percent in the upper monitoring zone.

Planned Upgrade to Replace Lime Softening at the North Water Treatment Plant

Pilot testing will soon begin to obtain the data to design the lime softening process at the NWTP with low-pressure RO membrane trains. This will have an impact on the ASR wellfield because the recovery is currently cut off at a maximum chloride concentration of 250 ppm. The RO will essentially remove about 99 percent of all the dissolved salts so the recovery limit can be increased to 500 ppm of chlorides. The net effect is that less water would have to be injected to store the same volume of recoverable water, thereby saving on injection costs.

Summary of the Results of the Upgrades

Table 6 is a summary of the operating cost savings associated with the upgrades to the ASR system. Table 7 gives the operating costs for the five-year injection period (2006-2010) and the five-year recovery period (2007-2011) for the ASR system before the upgrades and what the cost would have been had all the upgrades been available. The net result is that the operating costs are reduced by about 20 percent. The power cost for storing water with the new pumps was estimated at 85 percent of the power consumption of the old pumps, but the power for recovery is unchanged. The analytical and associated labor costs for sampling were reduced based on the percentage reduction in the permit requirements. The chemical costs have

Table 5. Water Quality Monitoring Reductions

Water Quality Parameter(s)	Well ID (Precentage Reduction)				
	ASR	DZ-1/2	SZ-1	ASR-9	Tamiami
Gross Alpha (pCi/L)	No Change	No Change			
Cryptosporidium and Giardia lamblia	No Change				
E. coli and Enterococci	No Change				
Total Trihalomethanes (mg/L)	50%	50%	75%	100%	
Dissolved Oxygen (mg/L)	50%	50%	75%	100%	
Total Dissolved Iron (mg/L)	50%	50%	75%	100%	
Total Dissolved Sulfide (mg/L)	50%	50%	Sampling Added		
Total Organic Carbon (mg/L)	50%	50%	Sampling Added		
Manganese (mg/L)	50%	50%	100%		
Nitrate as N (mg/L)	50%	50%	Sampling Added		
Arsenic (µg/L)	50%	50%	75%	100%	
Total Dissolved Solids (mg/L)	50%	50%	75%	100%	
Specific Conductivity (µmhos/cm)	50%	50%	75%	100%	100%
Total Alkalinity (mg/L)	50%	50%	100%	100%	
pH (SU)	50%	50%	75%	100%	100%
Chloride (mg/L)	50%	50%	75%	100%	100%
Sulfate (mg/L)	50%	50%	75%	100%	
Field Temperature (°C)	50%	50%	75%	100%	100%
Color (color units)	50%	50%	75%	100%	
Fecal Coliform (# per 100 ml)	50%	50%	75%	100%	
Total Coliform (# per 100 ml)	50%	50%	75%	100%	
Oxidation-Reduction Potential	50%	50%	75%	100%	
Primary and Secondary Drinking Water Standards (Injectate Only)	No Change				

a slight increase from the higher cost of ammonium sulfate compared to ammonia and salt. The two greatest maintenance issues had been the yearly repairs to the old feed pumps and ammonia feed system, which have been mostly eliminated with the upgrades; however, while the operating cost savings is good, the real benefit is the improved reliability, since the ASR wellfield often provides 20 percent of the raw water needed by MIU.

Results

A summary of the results of the upgrades, including the reduction of planned capital expenses and increased reliability, is as follows:

- Modeling work showed two additional ASR wells were not needed to meet future demand ($3 million savings).
- Changes to monitoring requirements and chemical feed systems reduced operating costs by about 20 percent.
- Reliability to store water at high flow rates was greatly increased, which is critical since available storage time is limited.
- Greatly improved reliability of the ASR feed pump.

Table 6. Operation Cost Analysis

Cost Item	Before Upgrades		After Upgrades	
	Storage	Recovery	Storage	Recovery
Water Stored 2006 to 2010, 1000 gal	3,198,691			
Water Recovered 2007 to 2011, 1000 gal		1,453,400		
Power Cost, Storage	$154,636		$131,441	
Power Cost, Recovery		$30,297		$30,297
Analytical Cost, Storage	$56,080		$33,648	
Labor for Sampling	$16,000		$9,600	
Analytical Cost Recovery		$109,100		$65,460
Labor for Sampling		$18,821		$11,293
Chemical Costs				
Carbon Dioxide, $	$206,374		$206,374	
Bleach, $	$24,351		$24,351	
Ammonia, $	$1,605		$0	
Salt (softener), $	$4,270		$0	
Ammonium Sulfate Solution			$6,420	
Total Chemicals, $	$236,600		$237,145	
Media/Filter Repairs	$50,000		$50,000	
Maintenance	$100,000	$40,000	$40,000	$40,000
Total Operating Cost over five years	$613,316	$198,218	$501,834	$147,050
Total Savings			$111,482	$51,168
Total Operating Cost, $/1000 recovered (1)(2)	$0.26	$0.14	$0.21	$0.10
Total Savings per 1000 gal			**$0.05**	**$0.04**

(1) Assumes 1.33 gal stored for 1 gal recovered
(2) In one year there was no recovery but 430 mil gal were stored.