A Cautious Look at Aquifer Storage Recovery in South Florida from a Public Health Viewpoint

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Aquifer Storage Recovery (ASR) has been routinely touted as a great water management tool and is becoming more popular as utilities realize that it can be an inexpensive way to store water. It has been stated that "The major driving force in ASR has been economics" [Pyne, p. 13].

An ASR well is used to recharge the Upper Floridan aquifer with either treated water or raw water from a surficial aquifer, which is the Biscayne aquifer in Broward County, Dade County, and the southern part of Palm Beach County, during a period of having excess water supply such as the rainy season. The recharge water is stored in the injection zone as a fresh water bubble surrounded by brackish water until needed during an emergency, a period of peak demand, or a drought. The stored and supposedly fresh water from the bubble will then be pumped up or recovered to meet water demands.

Regulations

The Underground Injection Control (UIC) sections of EPA and DEP are in charge of issuing construction permits for ASR wells. Their rules are designed "to protect the quality of the state's underground sources of drinking water and to prevent degradation of the quality of other aquifers adjacent to the injection zone" [Meyer, p. 10].

The Drinking Water Sections of EPA, DEP, and the Approved County Public Health Units are left with the permitting responsibilities to assure that drinking water standards are met when the ASR recovery stream is pumped up from the fresh water bubble in the Upper Floridan aquifer and either partially/fully treated, or blended directly with the treated water in a ground storage tank before being pumped into the distribution system.

Benefits

On the surface, ASR looks like a simple, straightforward, and economical technique for storing excess water and enhancing flexibility in managing water resources. It has been promoted with the claim of providing some major benefits including the following:

1. "Increase the efficiency of system operation" [Bloetscher, Walker, Martin & Vaughn, p. 36].
2. "Smaller increments of water treatment facility expansions can be constructed and the system operated closer to average day demand" [Bloetscher, Walker, Martin & Vaughn, p. 36].
3. "ASR is a low cost water management alternative to augment potable water supply in south Florida" [Pyne, p. 13].
4. "Because the water is stored underground, typical ASR storage quantities are orders of magnitude greater than other conventional storage methods" [CH2M HILL, p. 5-18].
5. "Evaporative losses, which can be significant in above ground reservoir systems, are non-existent in ASR systems" [CH2M HILL, p. 5-18].

Concerns and Issues

A closer look at what would happen to the fresh water bubble in the Upper Floridan aquifer and what should be done to the recovery stream reveals many critical technical and public health concerns and issues.

Bubble Stability: ASR can be seen to have a good chance to succeed under certain limiting geologic conditions, such as a natural pocket of clay or rock having minimal or ideally no water movement. According to CH2M HILL (1995), "a suitable aquifer storage zone must have adequate confinement and permeability" [p. 5-18]. However, the Upper Floridan aquifer in south Florida is known to be an open aquifer (having no vertical surrounding protective walls) with brackish water moving "generally from the area of highest head in the central Florida, eastward to the Straits of Florida, westward to the Gulf of Mexico, and, to a lesser extent, southward" [Meyer, p. 1]. Under such conditions, the fresh water bubble being stored at the bottom of an ASR well will almost certainly migrate away from the well over time, which will ultimately affect the recovery efficiency adversely.

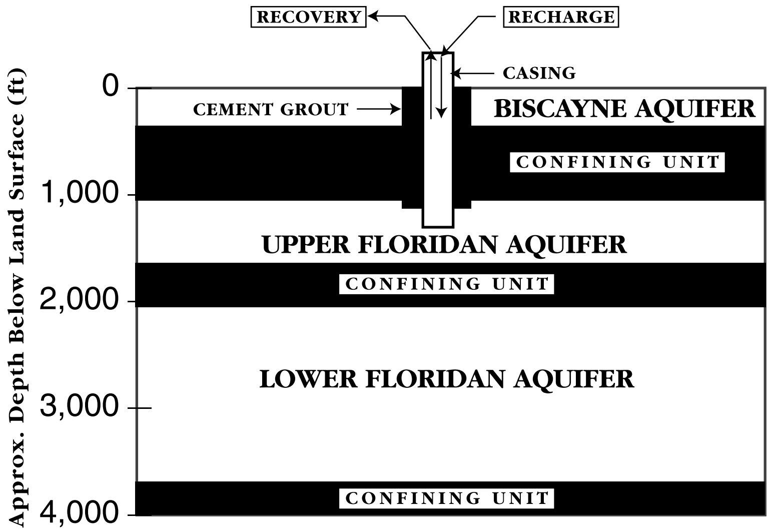
The possibility of bubble migration has become definitely more certain because the Upper Floridan aquifer can no longer remain in its former virgin conditions and its environment will become even more dynamic as more and more ASR and reverse osmosis wells are constructed to meet growing water demands. RO supply wells should have a higher priority than ASR applications because of RO's versatility and effectiveness as a water treatment technology. However, ASR can be seen as a hindering factor for RO because "nearby competing water users are limited in the ASR zone" [CH2M HILL, p. 5-18].

Recovery Efficiency vs. Quality: Based on a chloride concentration of 250 mg/l as the maximum limit for the recovery stream, the recovery efficiencies at four ASR sites in Dade County, Lee County, Palm Beach County, and St. Lucie County ranged from 2.76% to 47.8% [Meyer, p. 20]. The transmissivities at those four test sites following the order of the counties listed above are: 11,000 ft^2/d, 700 to 800 ft^2/d, unknown, and 6,000 ft^2/d [p. 20]. It can be reasonably assumed that the higher the transmissivity of the injection/storage zone, the lower the recovery efficiency. The transmissivity at an Upper Floridan aquifer test site in Broward County was estimated at 24,064 ft^2/d [CDM, p. 9], which does not project a promising sign for future ASR applications in the county.

The recovery efficiency can be increased by raising the maximum limits of sodium, chloride, and other contaminants for the recovery stream up to or above their maximum contaminant levels (MCL's), which represents a degradation of finished water quality, a hardly acceptable practice from the public health viewpoint!

Lack of Data: ASR is a risky business involving a trial and error process in the case of Broward County because there is a current lack of adequate hydrogeological/aquifer characteristics data such as transmissivity, storage coefficient, velocity, and direction of water movement. Each ASR well is a one-shot deal (a hit or miss attempt) with a high degree of uncertainty compared to the use of aboveground storage tanks because "until the well is drilled, the suitability of the aquifer confining zone and permeability can not be confirmed" [CH2M HILL, p. 5-20].

Potential Misuse: The widespread applications of ASR has the potential to cause public water systems to be blinded by their interpreting it as a "cure-all" for saving money through circumventing regulatory requirements (e.g., putting off needed plant expansions and additions to ground storage capacity; failing to provide emergency interconnections with neighboring water systems; delaying implementation of advanced water treatment technology whereby water quality goals/ improvements are not met; reducing the use of chemicals to provide less than optimally treated lime softened water to customers which impacts on stability/ corrosivity; and degrading finished water quality through ASR blending that may also cause the exceedance of certain primary/secondary MCL's).



Typical ASR Well and Associated Aquifers

Contamination of Floridan Aquifer: ASR blending is a particularly serious public health concern because of numerous data indicating that the Florida aquifer has been subjected to many contamination incidents. Accordingly to Meyer (1988, p. 1):

The principal use of the Floridan aquifer system in south Florida is for subsurface storage of liquid waste. The Boulder Zone of the Lower Floridan aquifer is extensively used as a receptacle for injected treated municipal wastewater, oil-field brine and, to a lesser extent, industrial wastewater.

These facts are also cited by William A. J. Pitt [Pitt, p. 29-30]. Meyer (1988, pp. 1,23) also presented many other interesting facts such as:

Chloride concentrations for the brine ranged from 108,000 to 164,570 mg/l, compared to about 19,200 mg/l for sea water [p. 10]... During 1943-83 ,about 7.1 billion gallons [of oil-field brine] were injected into the Floridan aquifer system. During 1959-83, about 112.1 billion gallons of nontoxic liquid waste were injected into the Floridan aquifer system by municipal wastewater treatment systems and industry... Injection of nontoxic liquid waste chiefly is into the Boulder Zone of the Lower Floridan aquiver although small amounts have been injected into the Upper Floridan aquifer.

Recently, a sinkhole in Mulberry, about 30 miles southeast of Tampa, "swallowed more than 18 million pounds of phosphoric acid, threatening the Floridan aquifer" [McClure, 1996].

Hydraulic Connection: It has been stated that:

Hydraulic connection between the upper and lower aquifers by sinkholes and fractures that transect the middle confining unit is inferred. Groundwater movement in south Florida is estimated to be chiefly upward from the Lower Floridan aquifer through the middle confining unit, then laterally toward the ocean through the Upper Floridan aquifer [Meyer, p. 5].

Mixing: There is also evidence showing that mixing had occurred between injected treated municipal effluent and native water in the injection zone [McKenzie and Irwin, p. 11].

Potential Sanitary Hazard and Cross-Connection: Existing data for the Upper Floridan aquifer in Broward County show detection of some critical contaminants causing serious concern: BOD (50 mg/l); COD (480-510 mg/l); gross alpha particle activity (90 pCi/l); combined radium-226 and radium-228 (20.1 pCi/l);sodium (890-1,000 mg/l); chloride (1,600-4,500 mg/l); and TDS (3,800-8,347 mg/l). There is also a detection of 375 pCi/L of gross alpha particle activity in the Lower Floridan aquifer in Broward County.

The detected range of COD for the native water of the Upper Floridan aquifer would put it right into the same category as domestic wastewater [Salvato, p. 479], and the BOD of 50 mg/l reveals a very poor quality of water because "public health authorities object to runoff entering streams if the BOD of the runoff exceeds 20 ppm [mg/l]" [Stoker & Seager, p. 121]. The MCLs of gross alpha particle activity (15 pCi/l), combined radium-226 and radium-228 (5 pCi/l), and sodium (160 mg/l) are primary drinking water standards that can adversely affect public health if exceeded.

Based on the above-mentioned data, an ARS well can be safely defined as a potential sanitary hazard according to Chapter 62-550.200 (55), FAC, which requires a backflow preventer to separate it from the finished water of any potable water system to prevent a cross-connection as defined by Chapter 62-550.200 (16), FAC

Blending: Blending lower quality ASR well water with treated water from a lime-softening water treatment plant is a risky business requiring fully automatic and continuous monitoring of the ASR well water for such critical parameters as the levels of BOD, COD, sodium, chloride, and TDS, especially when the stability of the ASR well water quality can not be guaranteed, which may also cause an adverse effect on the maintenance of optimized corrosion control and possible lead/ copper MCL exceedances at consumer's taps.

Multiple Protective Barriers: Past memos from high ranking public health and environmental officials dictated requirement of multiple protective barriers for potable water treatment [Berkowitz, 1973; Landers, 1976], which can only make a lot of sense in light of currently heightened public awareness about drinking water problems such as the waterborne cryptosporidiosis outbreak affecting an estimated 400,000 people and possibly causing as many as 112 deaths in Milwaukee, Wisconsin in April, 1993 [Miller, p. 8] [Fox & Lytle, p. 87]; a case of mistaken use of reclaimed water for making lemonade in Boca Raton (Shifrel, 1996]; and more stringent future federal regulations such as the Information Collection Rule (ICR), Under Direct Influence (UDI) requirements, and the proposed requirement for annual public notification of contaminants in potable water by utilities.

Cryptosporidiosis: The entire September 1996 issue of "Journal AWWA" is devoted to cryptosporidiosis and the concern for protecting public health. In the article "US Outbreaks of Cryptosporidiosis," Solo-Gabriele and Neumeister (1996, pp. 76, 81) stated that:

> *Drinking water has been implicated as the mode of transmission in several outbreaks of cryptosporidiosis throughout the United States.... Of the total number of outbreaks, roughly half were associated with groundwater sources.... Wastewater was implicated as the source of contamination of raw or treated water.... Each case emphasizes the importance of raw water protection and maintenance of optimal water treatment at all times.*

It stands to reason to require that existing ASR facilities be more closely monitored for contaminants in the recovery stream and future ASR applications be approached with utmost caution.

Information Collection Rule (ICR): All of the above-mentioned rules should force public water systems to be much more cautions in the management and operation of their water treatment plants. According to Logsdon and Harms (1996, p. 8), "the ICR mandates an extensive monitoring and reporting effort covering raw and treated water quality, information on watersheds affecting surface supplies, water system data, and detailed information on treatment processes." ASR applications will probably be scrutinized more closely due to the ICR requirements, and "any HCL violation or any data that could be used to indicate possible water quality problems will be targeted by lobby groups wanting stricter environmental standards."

Of course, public water systems should realize that their credibility, Logsdon and Harms (1996, p. 8) goes on to say:

> *Will be on the line as ICR data are reported to USEPA. [Thus], before, during, and after implementation of the ICR, water systems must be candid and open with the public. When problems arise, it is important that the public hear about them from the water system first, rather than from environmental groups or regulatory authorities.*

Logsdon and Harms (1996) also advocate that "the key to avoiding problems with lobby groups is sound operation and management practices that ensure continuous production of the best-quality drinking water" [p. 8].

Enhancement vs. Degradation: The quality of treated water should always be enhanced rather than degraded, especially now when consumers are demanding higher quality drinking water and abandoning the use of tap water for consumption in favor of bottled water because they are losing confidence in the public water systems. Data from different sources can lend support to the facts that "Americans worry about their tap water [and] it's bottoms up for bottled water" [Zaneski, p. BSE 8]. In a report of the Rocky Mountain Institute from Snowmass, Colorado, sponsored by EPA, a scenario was envisioned in which a "lack of confidence in the public water supply leads to a boom in the bottled water markets and in the point of use/point of entry home cleaning technologies" [Rasmussen, p. 67].

Recommendations

Proposed ASR projects have been reviewed with a high degree of caution by the Broward County Public Health Unit. From a public health viewpoint, ASR can represent a regulatory nightmare with complicated, unintended consequences. Once blending is allowed and becomes an accepted norm, there will no longer be an incentive to enhance water quality, which will be further degraded for the sake of budget savings. The philosophy behind the adage "The solution to pollution is dilution" seems to be practical but, in actuality, can be irresponsible and disastrous if and when mishaps occur.

ASR requires additional investigations and cautious thinking instead of the current promotional activities from the various involved interests. As a minimum, the following issues should be kept in mind by all involved parties when considering an ASR application:

1. An ASR well represents a potential sanitary hazard and cross-connection with recoverable water of questionable and/or possible poor quality. Therefore, full treatment of the recovery stream must be provided including lime softening, which has been known to be effective in substantially removing bacteria and virus [Salvato, p. 394], filtration, and disinfection to protect public health.

2. All ASR projects should be considered only on an experimental basis in the initial phase to allow collection of valuable data to assess the aquifer characteristics and the quality of the native water in the injection/storage zone.

3. Monitoring wells must be a requirement for better control and data collection.

4. The recovery of water from an ASR well must have built-in safeguards such as limits of sodium and chloride ions and other critical contaminants at about half of their MCL's to avoid and minimize a chance for runaway contamination.

5. A sound capital investment depends on a long-term beneficial solution. ASR appears to be only a temporary, half-measure solution at best to the problem of limited water supply, compared to RO technology, which can treat brackish water from the Upper and Lower Floridan aquifers and even sea water.

6. It can not be said often enough that:

> *Public water systems [should] protect public health by maintaining constant vigilance over all aspects of their operations... [And] optimizing treatment will benefit the community and will position water systems to do their best at providing drinking water of the best possible quality. The time to optimize is now [Logsdon & Harms, p. 8].*

Conclusions

The above-stated goal of UIC rules (i.e., "to protect the quality of the State's underground sources of drinking water and to prevent degradation of the quality of other aquifers adjacent to the injection zone") is recommendable and worthy. However, the protection of public health and welfare should be the ultimate goal of drinking water rules. Logsdon and Harms

(1996, p. 8) considered "the water system's duty to protect the health of the community" as the first reason among those needed by water systems managers to justify spending of funds.

All regulatory agencies will ultimately have to answer to the public/taxpayers/consumers regarding their actions and responsibilities. Therefore, they should always keep in mind the adage "It is always better to be safe than sorry" in considering matters involving public health.

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Present-Day Operating Conditions of Older Reverse Osmosis Facilities

Helen Bennett and O.J. Morin

Some of Florida's earliest reverse osmosis facilities were built at Venice Gardens in Sarasota County. Since the first units were constructed, a number have been added. Currently, the Sarasota County operates 6 RO units at two sites: at Jacaranda (often referred to as the Venice Gardens site) and at Plantation. In addition to the RO facilities a 14-MGD electrodialysis reversal (EDR) unit has been added to the system.

As part of the master plan completed by Black & Veatch, the operation of the RO facilities was investigated to determine their condition and to make recommendations for future operation. The following primary goals were included in the work:

- Measure the performance of each plant.
- Estimate operational flexibility.
- Determine plant reliability.
- Estimate remaining life of these systems.

The combination of high concentrations of calcium and sulfate in the feedwater to the facilities has required operation at relatively low recovery rates. Typically, plant recoveries have been kept at about 50 percent. Plant operation, however, has been quite good. No problems have been experienced with scaling or fouling of the membrane surfaces and membrane replacement has been infrequent. One unit, located at the Plantation site is still in operation with its original DOW low pressure hollow fiber membranes.

Plant Descriptions

The Jacaranda site is composed of seven units composing two plants. Plant No. 1 has five units and plant No. 2 two units. The design capacities of each of the units composing plant 1 is 250,000 gpd and each of the units making up plant 2, is 330,000 gpd. The Plantation site has two units, each at a design capacity of 250,000 gpd.

Each plant is similarly designed. Figure 1 gives the diagrammatic arrangement of each.

Source water is from a well supply and brine disposal is to a deep injection well. The feedwater to be treated is quite high in total dissolved solids concentration, averaging between 2,000 and 3,000 mg/l. The supplies are also high in calcium, barium, and sulfate: about 400, 1200, and 0.07 - 0.11 mg/l, respectively.

The constituent that limits the recovery to about 50 percent is calcium sulfate. This solubility is kept at about 100 - 110 percent of solubility. Pretreatment includes the use of sulfuric acid, and a scale inhibitor manufactured by B.F. Goodrich (AF-600). Sulfuric acid addition is on the order of 90 - 100 mg/l (pH is lowered to 6.5) and the scale inhibitor addition is 10 to 15 mg/l. Post treatment from the plants includes degassification and chlorine, caustic, and corrosion inhibitor addition. Blending of the raw water with permeate is also carried out at each site. The finished water quality (after blending the raw water with permeate) goal is a TDS of between 150 and 250 mg/l.

The process characteristics of the plants are given in Table 1. All plants are fitted with DOW (Filmtec) membranes.

Figure 1. Process Diagrammatic

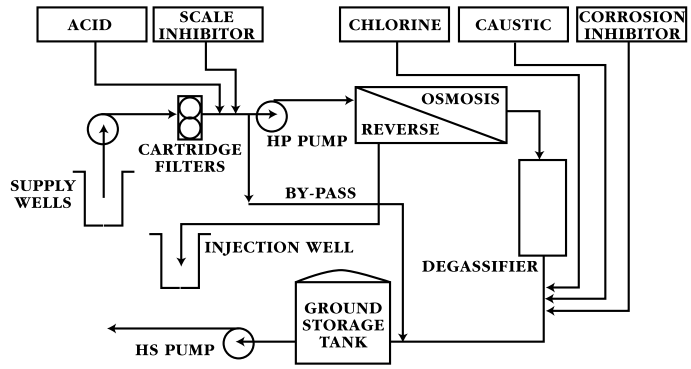

Table 1. Process Characteristics

Item	*Jacaranda Site*		*Plantation Site*	
	Plant 1	*Plant 2*	*Unit 1*	*Unit 2*
Number of Stages	1	1	1	1
Number of Pressure Vessels	9	10	12	9
Number of Membranes	54	60	12	54
Operating Pressure, (psig)	220	210	250	200
Flowrates, (gpm)				
• Feedwater	350	458	347	347
• Permeate	174	229	173	173
• Brine	174	229	173	173
Fluxrate, (gfd)	14.0	16.5	—	14.0
Recovery, (%)	46	50	45	55

Plant Performance

The plant performance can be measured by a number of methods. Key among these are:

- Production capacity trends.
- Operating pressure trends.
- Salt rejection trend.
- Process recovery.

For the RO process, the production capacity should remain constant over time. As membranes foul or scale, production will decrease. But decrease in capacity can be compensated for by increasing the operating pressure which increases production. Thus, normal RO operation, is to increase pressure over time to maintain production. To measure the production performance of membranes, pressure changes over time are monitored.

The rejection of minerals from the feedwater is the inverse of salt passage. Salt passage is a function of the difference in the brine bulk TDS and the permeate TDS: the higher the difference, the greater the salt passage. Salt passage is monitored by the rejection rate, measured as percentage removal. If the permeate quality decreases, (i.e., TDS increases) it is an indication that the membranes may be failing. It could also indicate that the recovery is too high (the concentration of the brine stream is too high). Thus, to evaluate salt passage, the recovery and rejection rates are monitored.

The operating pressure can also have an effect on the quality of the permeate. Because the operating pressure determines

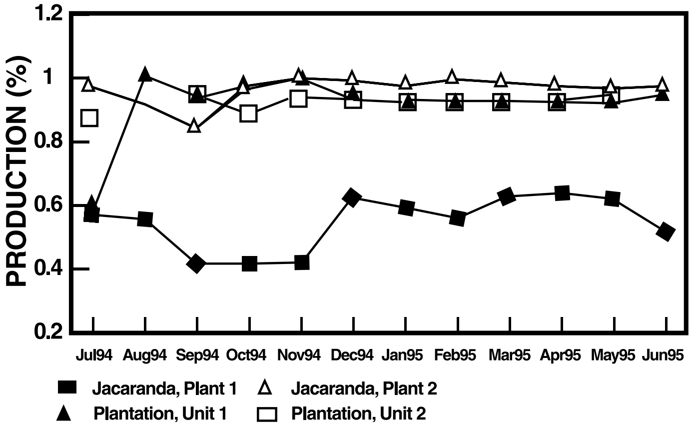

Figure 2. Production (% of Design)

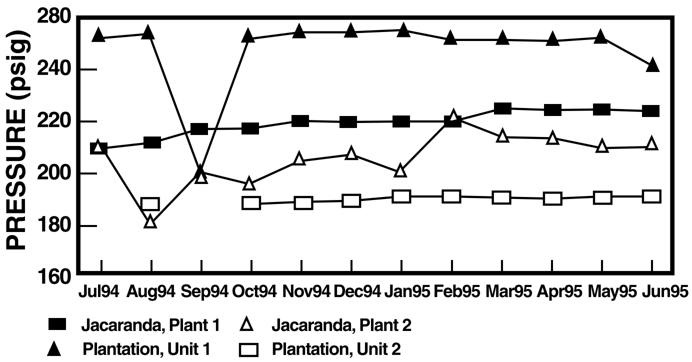

Figure 3. Operating Pressure (psig)

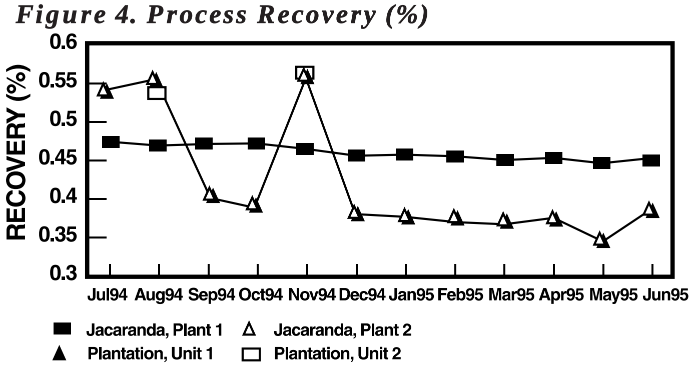

Figure 4. Process Recovery (%)

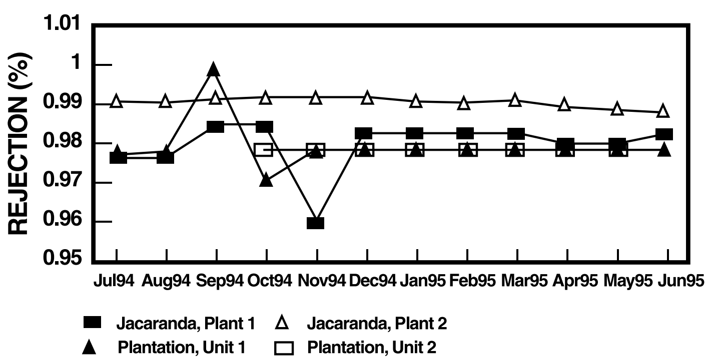

Figure 5. Process Rejection (%)

the amount of water produced, high operating pressures at constant rejection rates result in reductions of the TDS of the stream.

For the Sarasota plants, the performance factors are plotted in Figures 2 - 5 for the period July 1994 through June 1995. Figure 2 gives the production rates for each plant, Figure 3 the operating pressures, Figure 4 the recovery rates, and Figure 5 the rejection rates.

Inspection of Figure 2 shows that the plant's production rates, plotted as the percent of design capacity, are fairly constant. Note that the Jacaranda Plant 2 and both units at the Plantation site are at 90 percent of design capacity, which is considered to be very good production performance considering that the plants have been in service for some time without the need to replace membranes—the oldest unit at Plantation is approaching 10 years of service.

A review of the operating pressure in conjunction with the production yielded the following results.

- Plant 1 at Jacaranda shows an increase in operating pressure of about 2 to 3 percent over the one-year period. Average pressure over the study period was 220 psig.
- Plant 2 at Jacaranda shows an increase in operating pressure of about 7 percent over the period, which indicates that the membranes are approaching the time when they will require cleaning. Although operating pressure alone is not the determining factor for cleaning, an increase of more than about 10 percent should not be allowed before cleaning. The average pressure over the year was 220 psig.
- Unit 1 at the Plantation site operated at about 100 percent capacity throughout the reported period, and operating pressure was steady at 225 psig. This is higher than the other RO units because of the membranes used—DOW hollow fiber membranes that require a higher operating pressure than the Thin Film Composite (TFC) spiral wound membranes fitted in the other plants. The average pressure for the one year period was 248 psig.
- Unit 2 at Plantation also showed a steady production capacity near the design capacity point. The operating pressures during the period were constant at about 185 psig. Note that the pressure trend is increasing only slightly over the period. Average pressure was 190 psig. The average production capacities over the reported period were 56 percent for Jacaranda plant 1, 97 percent for Jacaranda plant 2, 92 percent for Plantation unit 1, and 93 percent for Plantation unit 2.

A review of the recovery and rejection rates for each of the units gave the following results:

- Inspection of figure 4 indicates that the recovery rate for Jacaranda plant 1 decreased slightly over the one year period and averaged 46 percent for the year. Figure 5 shows that the rejection rate increased slightly during the period, from 97 percent to 98 percent, indicating that the membrane condition is not deteriorating.
- Jacaranda plant 2 recovery trend held steady. During the period it achieved a recovery of about 50 percent. Rejection was quite steady at 99 percent. Recovery at Plantation Unit 1 declined from 54 to 38 percent, averaging 42 percent for the period. However, feedwater TDS increased from 2,400 mg/l to 2,600 mg/l which would account for some of the decline. The rejection held quite steady at 98 percent.
- Unit 2 at Plantation did not report the recovery factor during the study period. However, rejection was good at 97.9 percent.

Modeling

A further check was made to verify operation of the membranes by comparing the operation against the membrane manufacturer's modeling programs. This work did not include the hollow fiber membranes. The results of this investigation. shown in Table 2, indicate that the units were operating quite close to the projected values.

Table 2. Modeling Results

Process Item	Jacaranda Plant 1		Jacaranda Plant 2		Plantation Unit 2	
	Model Results	Actual Operation	Model Results	Actual Operation	Model Results	Actual Operation
Permeate Production (gpd)	262,566	196,016[1]	300,517	290,880	251,573	231,264
Operating Pressure (psig)	212	220	208.2	206.0	195.7	189.8
Rejection Rate (%)	98.6	98.1	98.5	99.0	98.4	97.9
Flux Rate (gfd)	14.7	14.7	15.2	15.2	14.1	14.1
Flowrates (gpm)						
• Feedwater	395.7	220	420	412.2	319.1	295.4
• Permeate	182.3	101.4	208.7	202.0	174.7	160.6
• Brine	213.3	119.3	211.3	218.2	144.4	134.8
Water Quality (mg/l)						
• Feedwater	2,764	2,758	2,063	2,050	2,596	2,594
• Permeate	40.0	53.6	30	20.0	42	55
• Brine	5,092	5,058[2]	4,071	4,055[3]	5,686	5,664

[1] All Units not in operation simultaneously.
[2] Calculated value.
[3] Calculated value.

Conclusions

- All membranes are functioning normally, including the hollow fiber membrane which has been in service for over eight years. The data indicate that they are all in good condition.
- Plant reliability has been good.
- The number of units available at each site offers increased operational flexibility.
- The plants can be expected to offer a further service life of 15 years or more.

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