Pembroke Pines Explores Aquifer Recharge as a Cost-Effective Alternative Water Supply Strategy

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In early 2007, the governing board of the South Florida Water Management District (SFWMD) adopted the Regional Water Availability Rule. The salient features of the rule require that future water demands over and above the "base condition water use" must be provided from alternative water supply sources (AWS) or offset with reuse or stormwater (also considered AWS). The base condition water use was defined as the five-year historical, highest twelve-month pumpage from the wellfield of concern. Utilities needing water supplies above their base condition are required to seek sources that are not dependent upon the Everglades for recharge. This includes the Biscayne Aquifer and therefore has significant implications for southeast Florida residents. Given that reuse is a goal of the state's comprehensive water plan, and a major goal of the Florida Department of Environmental Protection (FDEP) and the state's water management districts, finding a cost-effective and useful reuse alternative was desired. Irrigation options, as well as indirect potable reuse, were analyzed, given the results of test data. This project focused on the potential to turn wastewater into a high-quality water supply that meets all applicable state and stringent local standards for groundwater recharge to supplement potable water supply sources.

Because few existing undeveloped or underutilized high-quality water sources exist in the United States, many utilities are considering impaired water sources to meet increasing demands and regulations requiring the investigation of alternative water supply sources. Utilities are increasingly expressing interest in utilizing reclaimed water sources for aquifer recharge and land application projects, as well as desalination technologies, in an effort to offset potable water withdrawals. The evolution of these processes offers significant promise to meet future water supply needs.

The Regional Water Availability Rule impacts future water supplies for southeast Florida utilities. The "base condition water use" must be provided from AWS, which is designated as including:

- Acquiring water from someone who has sufficient supplies
- Aquifer storage and recovery (ASR)
- Alternative water sources using saline sources (specifically Floridan Aquifer or seawater sources)
- Alternative water supply options that will provide recharge to current wellfields (meaning reuse of reclaimed water to standards for indirect potable reuse, FAC 62-610 Part V)
- Alternative water supply options that will provide a reduction in pumpage from the Biscayne Aquifer (meaning reuse of reclaimed water to standards for land application systems FAC, 62-610 Part III)

Based on ongoing investigations in southeast Florida, ASR has not yet proven to be an effective method of AWS and does not create additional water. The remaining three options have limited opportunity in the City of Pembroke Pines without significant investment.

The City has long been interested in reclaimed water options. Historically, however, residential irrigation was perceived as being too expensive to pursue. This is a result of the absence of costly piping infrastructure and limited open space for irrigation. In addition, the availability of disposal options such as injection wells and ocean outfalls have been a disincentive in the past. Because of cost, and the need to acquire added potable raw water supplies, the City considered the use of reclaimed wastewater to offset water use, including the option of aquifer recharge. Four other local utilities have reviewed opportunities with aquifer recharge in southeast Florida (Sunrise, Davie, Plantation, and Miami-Dade County) with the intent of recovering this water downstream of the injection point, but none has done so to date, for a variety of reasons.

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Need for Research

Treating wastewater for recharge standards requires reverse osmosis (RO) membranes to treat the water to acceptable standards in Broward County due to very low nutrient criteria. The standard-bearer for such recharge projects is Water Factory 21 in Orange County, Calif. (Bloetscher, et al, 2011). Water Factory 21 has been operating for over 40 years and was part of one of the most important epidemiological studies on the health impacts of recharging the aquifer with reclaimed wastewater. The study, performed in 1988-1991, found no measurable differences in the incidence of diseases between Orange County and the Los Angeles basin where the water supply is not recharged with reclaimed water (Bloetscher, et al, 2011).

Pembroke Pines investigated the technical feasibility of using RO as a part of a multi-barrier system, as seen in Figure 1, to treat domestic wastewater to drinking water standards and use it to recharge groundwater with the goal of enhancing source water recovery. The RO will precede the ultraviolet/advanced oxidation process (UV/AOP) in the pilot study and in the full-scale AWS facility. Recovery of wastewater to supplement potable supplies is a major conservation initiative in water-limited environments.

The following are the pilot study objectives:

- Characterize the secondary treated wastewater, RO concentrate, and reclaimed water quality for use in developing the design/build package, supplement permitting, and provide data on necessary additional treatment and concentrate issues.
- Develop a program to select and test RO membranes for use by the City of Pembroke Pines as a part of its AWS upgrade at the existing wastewater treatment plant.
- Conduct bench testing of water quality results compared to claims of membrane manufacturers.
- Conduct pilot testing of candidate membranes provided by proposed suppliers.
- Analyze the water quality of the permeate for post-treatment needs.
- Maximize the recovery of concentrate and develop methods to address disposal of concentrate that cannot be used for other purposes.

Description of the Reverse Osmosis Systems

Preliminary pilot testing was performed using a Florida Atlantic University (FAU) RO pilot skid built in 2005 by Harn R/O Systems Inc., in Venice, Fla. The skid, as shown in Figure 2, was delivered to the pilot site in September 2010 and has a capacity of approximately 4 gpm, using 4-in. diameter DOW Filmtec BW30-4040 membranes (Bloetscher, et al, 2011).

The FAU Harn RO pilot system is composed of:

- A 2 HP, 240 volt, three-phase RO pump rated for a flow of 6 gpm at 250 psi
- A skid assembly for a two-stage 1/1 array with 4-in. diameter single element pressure vessels for a nominal permeate production rate of 1.5 gpm at 75 percent recovery with recycle
- Concentrate and pump discharge control valves
- Pressure gauges
- Flow meters
- Samples taps for monitoring water quality
- Pretreatment consisted of a chemical dose to reduce feed water pH and one single-element pretreatment cartridge filter housing

Major testing was conducted using a two-stage, three-element-per-vessel Osmonics RO pilot skid, as seen in Figure 3. The Osmonics RO skid was delivered to the pilot site in October 2010 (Bloetscher, et al 2011). The two stage 2:1 configuration is made of stainless steel with a dual cartridge pretreatment filter system. Previously used DOW Filmtec BW 30-4040 membranes were loaded in all vessels initially. The skid has a capacity of up to 30 gpm at 300 psi pressure. The Osmonics RO pilot system is composed of:

- Stainless steel vessels that house three 4-in. diameter, 40 inch long membranes
- A 7.5 hp 208-230 volt, three phase horizontal split case feed pump
- Feed pump variable frequency drive (VFD)
- A 2.0 hp 208-230 volt, three-phase horizontal split case clean-in-place (CIP) system pump
- A 1.5 hp, 230 volt, 3 phase Dayton 20 gpm/20 psi booster pump
- Concentrate and pump discharge control valves
- Pressure gauges
- Flow meters
- Samples taps for monitoring water quality
- Pretreatment consisted of chemical dosing of 5.7 mg/L of dispersant and a dual-element pretreatment cartridge filter housing with no acid required

The RO pilot performance was monitored on a daily basis, and feed, permeate, and concentrate flow rates were recorded. The recycle stream was not used. Two positive displacement meters were installed to measure the permeate and concentrate flow rate. After the Osmonics RO pilot skid was delivered to the site and placed in service, the Harn RO skid was connected as a third stage. Supplementary testing was performed to determine the efficiency of recovering additional water from the first- and second-stage concentrate streams.

The Osmonics RO skid contains a CIP system, hard-piped to the skid. The CIP sys-

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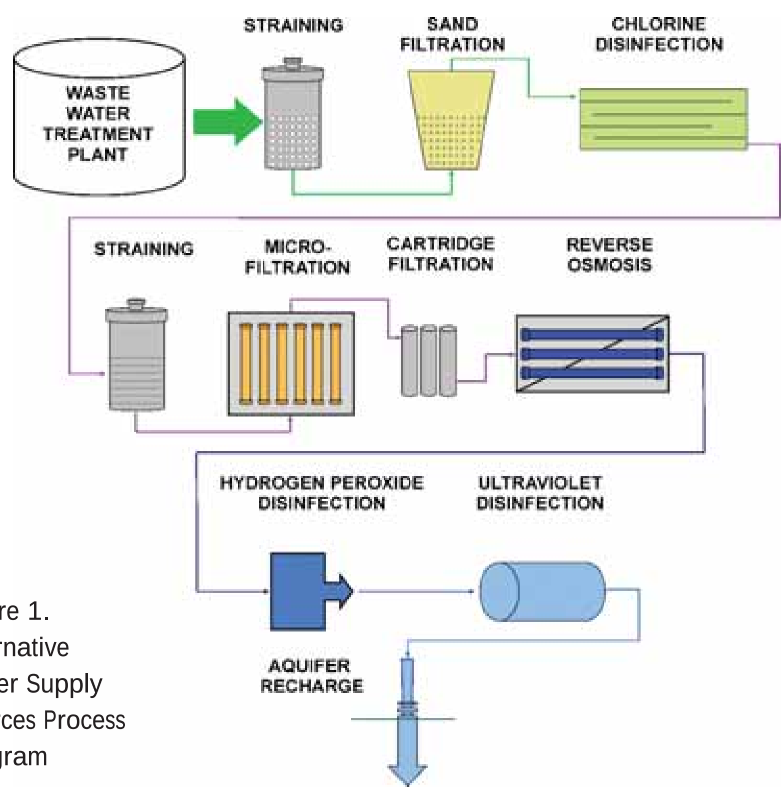

Figure 1. Alternative Water Supply Sources Process Diagram

Figure 2. Florida Atlantic University Reverse Osmosis Skid

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tem includes a 150-gal polyethylene tank and a 2.0 hp horizontal split case, 208-230 volt, three-phase pump. The system is piped to utilize RO permeate for chemical cleaning solution preparation by allowing permeate to discharge into the polyethylene tank where it can be mixed with chemicals for the cleaning. The CIP process typically requires one to four hours (depending on the severity of the membrane fouling) of circulating a chemical cleaning solution on the feed side of the membranes. The cleaning solution in the polyethylene tank could then be discharged to the pilot plant backwash water collection system and transferred to the existing sanitary sewer system (Bloetscher, et al, 2011).

Figure 3. Osmonics Reverse Osmosis Skid 2:1 Configuration

Table 1. Feed Water Parameters for Reverse Osmosis System

Constituent	Feed (mg/L)
NH4	13.9
K	12.7
Na	24.6*
Mg	6.1
Ca	48
Sr	0.44
Ba	0.2
CO3	0.05**
HCO3	136.75
NO3	18
Cl	29.94
F	0.7
SO4	79.85
SiO2	11
Boron	0.27

* *value adjusts based on balancing cations*
** *calculated value based on pH*

Results

Water Quality Monitoring

Test cocks were located on both skids for test purposes. In the field, general water quality data, including pH, specific conductance, temperature, dissolved oxygen and ORP, were measured using two handheld probes. A 556 multi-parameter probe from YSI Inc. was calibrated weekly and a Hach MP6P handheld probe was calibrated several times each week.

For pH, a three-point calibration was performed with pH standard solutions of 4.0, 7.0, and 10.0. For specific conductance, a standard solution of 10,000 mS/cm was used for calibrations. For dissolved oxygen, a water-saturated air calibration method was used as follows: 3 mm (1/8 in.) of water was placed in the bottom of the calibration cup. After 10 minutes, the air in the calibration cup was considered water-saturated and the dissolved oxygen was calibrated to 100 percent.

Feed Water Quality

The water quality characteristics of the wastewater are an important factor to consider when determining the efficiency of a membrane system. The water quality parameters summarized in Table 1 were measured to provide the necessary insight to evaluate and design the proposed pilot and full-scale treatment plants. These water quality results are from samples collected after the MF system in the pilot. For preliminary analysis, estimates of finished water and concentrate quality were made using DOW Filmtec's reverse osmosis system analysis (ROSA) software. The ROSA was used to determine pretreatment requirements and project permeate and concentrate water quality characteristics, as well as the potential treatment needs involving disposal of the concentrate solution. The results were verified through field testing.

Methods

The initial task of evaluating membranes was to determine the pressure, membrane types, and potential fouling mechanisms for the proposed process. The initial investigation used the Harn single-stage RO skid loaded with a used DOW Filmtec BW30-4040 membrane. The BW30-4040 membrane is designed to remove salts from brackish water; however, the salt content in the RO feed water for this application was very low, so salt removal was not a goal of the project. These membranes were selected with the primary goal of removing phosphorus from the water in order to meet local nutrient limits.

The Harn RO skid can be configured for parallel (single-stage) or successive-stage op-

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eration. Initially, the goal was to find the fouling mechanism and operational parameters, so only one vessel was used without any acid or antiscalant. The goal was to force fouling quickly in order to determine what antifoulants would be needed. The Harn RO skid operated with at a precartridge filter pressure of 150 psi, which was slightly below expected conditions. A series of operational trials were run to establish the baseline conditions.

After the Harn RO testing was complete, the Osmonics skid was loaded with used DOW Filmtec BW30-4040 membranes for testing and was connected to receive feed water that had received pretreatment from the upstream processes. The Osmonics skid was operated at various precartridge filter pressures to evaluate the performance. Figure 4 shows the permeate flow rates for the initial performance optimization runs for the Osmonics RO skid.

Run 1 operated at a precartridge filter pressure of 190 psi from Nov. 9-15, 2010, using no antiscalant and no acid. The permeate performance lost over 20 percent of the initial permeate flow rate. Temperatures and pressures were relatively constant during this period. The flow rate was less than anticipated, and since the flux decreased, the precartridge filter pressure was increased for Run 2 in order to restore flows. A CIP was not performed after Run 1.

Run 2 operated at 290 psi from Nov. 15-24, 2010, using no antiscalant and no acid. There was a small increase in the flow rate; however, after nine days of operation, a 30 percent decrease in the permeate flow rate was observed. The 3 percent loss per day was similar to Run 1. Temperatures and pressures were relatively constant during this period. The membranes were cleaned after Run 2 with a citric acid solution, with only a slight improvement to the permeate flow rate.

Run 3 was initiated with the same precartridge filter pressure as Run 2 (290 psi) with no antiscalant or acid used for pretreatment. The permeate flow rate quickly deteriorated between Nov. 25 and Dec. 6, 2010, as with the prior runs. This was an indication that increasing the precartridge filter pressure was not the solution to regain capacity. At the conclusion of Run 3, the membranes were cleaned with a high pH, caustic soda solution. This cleaning restored much of the lost capacity of the system and permitted the precartridge filter pressure to be reduced to 190-200 psi for Run 4, since the higher pressure in Run 2 provided no increase in the permeate flow rate.

For Run 4, new DOW Filmtec BW30-4040 membranes were installed in the first stage only. Run 4 operated with no antiscalant or acid for pretreatment. Temperatures and pressures were relatively constant during this period, from Dec. 12-29, 2010. There was an immediate decrease in the permeate flow rate, as had been experienced in Runs 1, 2, and 3. Data on the potential fouling mechanisms were gathered and evaluated by FAU. Based on visual inspection of the membranes and cartridge filters, the success of the caustic soda cleaning solution, and high organic constituents of the secondary effluent, the fouling mechanism was determined to be dissolved organic matter (DOM). Based on this deter-

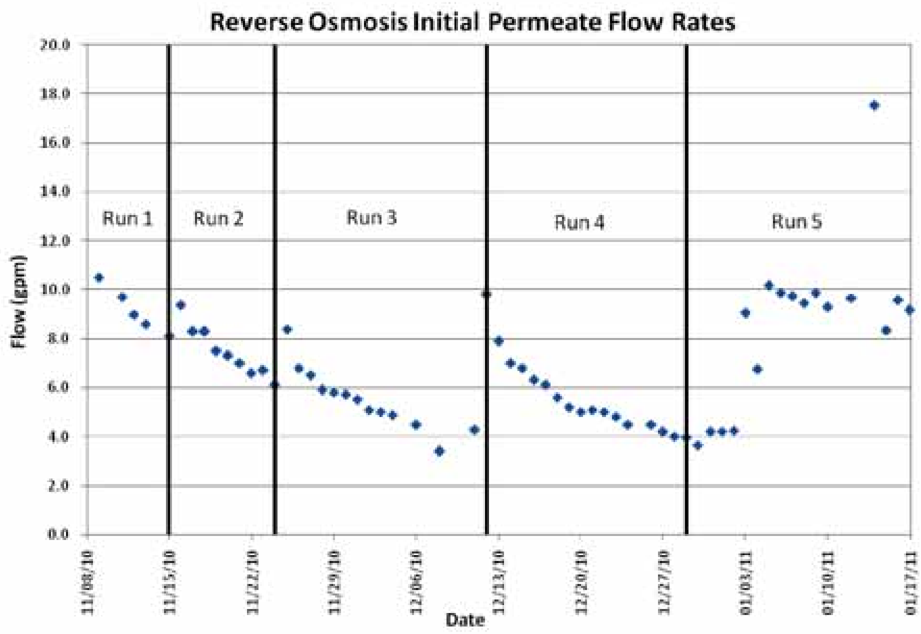

Figure 4. Summary of Permeate Flows for Five Initial Reverse Osmosis Skid Test Runs (Bloetscher, et al, 2011a)

Table 2. Summary of Membrane Operating Parameters (Bloetscher, et al, 2011a)

Issue	DOW Filmtec	Hydranautics	Koch
Membrane Type	Polyamide TFC	Composite Polyamide	TFC Polyamide
Maximum Operating Temperature	113°F	113°F	113°F
Maximum Operating Pressure	600 psi	600 psi	600 psi
Maximum Feed Flow Rate	16 gpm	16 gpm	
Maximum Pressure Drop	15 psi	10 psi	10 psi
pH Range, Continuous Operation	2 - 11	2 - 11	4 - 11
pH Range, Short-Term Cleaning	1 - 13	1 - 13	2.5 - 11
Maximum Feed Silt Density Index for wastewater applications	5.0	5.0	5.0
Free Chlorine Tolerance	<0.1 ppm	<0.1 ppm	<0.1 ppm
Nominal Active Surface Area	78 ft2	80 ft2	85 ft2
Recovery Rate	15 percent	15 percent	15 percent
Permeate Flow Rate	2,400 gpd	2,000 gpd	2,370 gpd
Maximum Feedwater Turbidity		1.0 NTU	0.2 NTU
Stabilized Salt Rejection	99.5 percent	99.6 percent	99.55 percent
Membrane specified	BW30-4040	ESPA2-LD-4040	TFC-4040-HR

Notes
DOW Filmtec Test Operating Conditions: 2,000 ppm NaCl, 225 psig, 77°F, and 15 percent recovery
Hydranautics Test Operating Conditions: 1,500 ppm NaCl, 225 psig, 77°F , and 15 percent recovery
Koch Test Operating Conditions: 2,000 ppm NaCl, 225 psig, 77°F, and 15 percent recovery

mination, it was recommended to inject a dispersant in the feed water to prevent fouling; Avista Vitec® 3000 dispersant was utilized to resolve this problem. The dispersant was placed in service on Dec. 29, 2010, and set at a dose rate of 5.7 mg/L for Run 5. In addition, new DOW Filmtec BW 30-4040NF (non-fouling) membranes were installed in the second stage for Run 5. The Run 5 operated at a pre-cartridge filter pressure of 235 psi. The permeate flow rate remained constant after these additions. The Osmonics RO skid appears to have operated well with the dispersant in Run 5, so the use of the dispersant was continued for the rest of the pilot program.

Membrane Testing

Three membrane manufacturers were tested in Phase II, based on their recognized experience with RO systems in the water treatment industry. Each manufacturer's membranes were allowed at least four weeks of runtime in Phase II. After consulting various membrane manufacturers, candidate membrane technical specifications were reviewed and the following were selected for pilot testing:

- BW30-4040 (used in first-stage) and BW30-4040NF (used in second-stage) from DOW Filmtec
- ESPA2- LD-4040 from Hydranautics
- TFC-4040HR from Koch

Table 2 outlines the operating parameters of each membrane. All are very similar and should be appropriate for this application. It should be noted that the permeate flow rate

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Table 3. Summary of Membrane Performance (Bloetscher, et al, 2011)

Parameter	DOW BW30-4040	Hydranautics ESPA2 4040HR	Koch TFC-4040HR
Rejection (percent)	98	97.6	97.5
Recovery (percent)	66.4	72.8	70.5
Concentration Factor	3.1	3.7	3.4
Flux (gpd/sf)	15.7	16.7	21.5
Normalized Specific Flux (gpd/sf/psi)	0.072	0.072	0.103
Change in Flux: peak to end after startup (percent)	17	21	0
Crossflow Velocity (ft/d)	19.3	21.1	20

Table 4. Summary of Nutrient and Coliform Average Results Post-Reverse Osmosis and UV-Advanced Oxidation Processes

Analyte	Units	BC Limit	FAC Limit	Filmtec	Hydranautics	Koch
Phosphorous	mg/L	0.01	NS	U	U	U
Turbidity	NTU	10	NS	U	U	U
Total Coliforms	CFU/100 mL	1000	4	U	U	U
Fecal Coliforms	CFU/100 mL	800	1	U	U	U
TSS	mg/L	*	NS	U	U	U

Table 5 - Summary of Post-Reverse Osmosis and UV-Advanced Oxidation Processes Average Water Analysis Characteristics

Analyte	Units	BC Limit	FAC Limit	Filmtec	Hydranautics	Koch
BOD	mg/L	5	NS	U	U	U
COD	mg/L	10	NS	U	U	I
Oil & Grease	mg/L	10	4	U	U	U
Phenolics	mg/L	0.0001	NS	U	U	U
TOC	mg/L	NS	3	U	U	U

Notes
NS = No standard
U = Undetected based on method detection limit
I = Result is between lab method detection limit and practical quantification limit
** = None attributable to wastes*

Table 6 - Summary of Pesticide, Pathogen, and Unregulated Contaminant Monitoring Rule Average Results Post-Reverse Osmosis and UV-Advanced Oxidation Processes

Analyte	Units	BC Limit	FAC Limit	Filmtec	Hydranautics	Koch
Pesticides						
Azinphos-methyl (guthion)	ug/L	0.1	NS	U	NT	U
Demeton	ug/L	0.1	NS	U	NT	U
Ethyl Parathion	ug/L	42	NS	U	NT	U
Malathion	ug/L	0.1	NS	U	NT	U
Chlorinated Hydrocarbons						
Hexachlorobutadiene	ug/L	10	NS	U	NT	U
Hexachloroethane	ug/L	10	NS	U	NT	U
Pathogens						
Enterovirus	Infectious units/100 L	1/gal	<1	U	NT	U
Enumerated Cryptosporidium Oocysts	oocysts/100 L	1/gal	<1	U	NT	U
Enumerated Giardia Cysts	cysts/100 L	1/gal	<1	U	NT	U
Enumerated Giardia Cysts, Potentially Viable	cysts/100 L	1/gal	<1	U	NT	U
Total Enumerated Helminth Ova	ova	1/gal	<1	U	NT	U
Viable Helminth Ova	ova/100 L	1/gal	<1	U	NT	U
Unregulated Contaminants Monitoring Rule 2 (UCMR2)						
BB	NR	NR	NR	U	NT	NT
BDE-100	NR	NR	NR	U	NT	NT
BDE-153	NR	NR	NR	U	NT	NT
BDE-47	NR	NR	NR	U	NT	NT
BDE-99	NR	NR	NR	U	NT	NT
Dimethoate	NR	NR	NR	U	NT	NT
Terbufos Sulfone	NR	NR	NR	U	NT	NT
1,3-Dinitrobenzene	NR	NR	NR	U	NT	NT
2,4,6-Trinitrotoluene (TNT)	NR	NR	NR	U	NT	NT
RDX	NR	NR	NR	U	NT	NT
N-Nitrosodiethylamine	NR	NR	NR	U	NT	NT
N-Nitrosodimethylamine	NR	NR	NR	U	NT	NT
N-Nitroso-di-n propylamine	NR	NR	NR	U	NT	NT
N-Nitrosodi-n-butylamine	NR	NR	NR	U	NT	NT
N-Nitrosomethylethylamine	NR	NR	NR	U	NT	NT
N-Nitrosopyrollidine	NR	NR	NR	U	NT	NT
Acetochlor ESA	NR	NR	NR	U	NT	NT
Acetochlor OA	NR	NR	NR	U	NT	NT
Alachlor ESA	NR	NR	NR	U	NT	NT
Alachlor OA	NR	NR	NR	U	NT	NT
Metolachlor ESA	NR	NR	NR	U	NT	NT
Metolachlor OA	NR	NR	NR	U	NT	NT

Notes
NS = No standard, U = Undetected based on method detection limit
I = Results is between lab method detection limit and practical quantification limit; NT = Not tested

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for all membranes is roughly 1.3 gpm, which resulted in a total flow rate of approximately 12 gpm for the entire system.

Table 3 lists the performance measurement results for each membrane. All the membranes rejected over 97 percent of salts, had recoveries approaching or exceeding 70 percent with two stages, and were capable of having their flux at or above the maximum recommended, while still providing good water quality. Since salt is not the issue of concern, other parameters such as phosphorous must be evaluated to determine if the process was sufficient. The DOW Filmtec, Hydranautics, and Koch membranes exceeded desired removal of phosphorous throughout the official testing in Phase II of the pilot study.

Meeting Regulatory Requirements

All three of the membranes appear to be satisfactory for the purposes of this project, pending assurance and demonstration in the full-scale of meeting water quality parameters associated with phosphorous. Tables 4 to 7 indicate that all the membranes were successful at removing the regulated constituent when compared with the local (Broward County) and state regulatory requirements.

Reuse Alternatives

The pilot study results in Tables 4 through 7 demonstrate that RO is an effective tool to meet the regulatory requirements needed for aquifer recharge in Broward County. Since the expected capital and annual expenses associated with RO treatment are significant, prudence dictates that a complete review of AWS alternatives be performed prior to commitment to this option.

The following provides an analysis of multiple AWS alternatives and their respective 20-year present-worth values. In addition, each alternative was measured for environmental impact, efficiency, and effectiveness. This comparison allowed insight into the total relative value of the AWS options.

Cost Comparison of Alternatives

Table 8 outlines the City's proposed RO equipment parameters for 6-mgd capacity. The assumptions made in Table 8 extend to the cost comparisons in Table 9, including construction cost, and operation and maintenance cost, based on a 20-year present worth. Table 9 also outlines the cost comparisons for the alternative water supply projects available to the City. They are:

1. Biscayne Aquifer injection of reclaimed water with lime softening potable water

treatment (study)
2. Residential irrigation reuse system
3. Commercial irrigation reuse system (golf courses and parks)
4. Floridan Aquifer as a potable water supply
5. Floridan Aquifer injection of reclaimed water with RO potable water system

As can be seen in Table 9, a review of the initial capital investment leads to the commercial irrigation reuse alternative having the least capital cost, with the majority of costs tied up in piping infrastructure. The second- and third-ranking capital projects are Biscayne Aquifer injection of reclaimed water and Floridan potable water supply. This is intuitive, as the treatment trains are similar but for the necessity of multi-barrier pretreatment and post-treatment on the wastewater side. This also is somewhat subjective as about 24 percent of the Floridan Aquifer costs are tied to concentrate disposal wells which, under other circumstances, may be shared with the wastewater treatment plant. The fourth-ranking option is the injection of reclaimed water to the Floridan Aquifer with RO potable treatment. This option requires RO prior to injection, as well as RO for potable water treatment (due to the saline nature of the aquifer). This "RO in/RO out" scenario is thus twice the cost of either the RO injection or treatment options. Finally, the most capital-intensive option is the residential reuse option, which requires installation of reclaimed water pipelines throughout the City. This analysis confirms the utility perspective that the construction costs for residential reuse are much higher than costs for other options.

In comparing the present worth of these options, we find that commercial irrigation reuse remains the lowest total cost. Once the infrastructure is constructed, this type of reuse has very low operational cost, relative to the other options. Whereas Biscayne injection and Floridan withdrawal are essentially the same in capital cost, the RO of wastewater in aquifer injection yields a $10 million lead over Florida withdrawal. This is again due to the necessary operational costs of a RO multi-barrier system, including membrane filtration (MF) and post treatment with UVAOP. Both of these processes carry a significant electricity burden and neither is required for Floridan Aquifer withdrawal. The remaining options of Floridan injection, RO in/RO out, and residential reuse, have a ranking consistent with the capital cost ranking

If further consideration of alternatives is made beyond initial capital cost and present worth to include environmental impact, some significant issues precipitate regarding the efficiency and effectiveness of AWS alternatives. As identified in the 2003 FDEP Reclaimed Water Strategies Report, two categories are identified as a measurement of implementation:

1. Potable quality water offset (offset) – The amount of potable quality water saved through the use of reclaimed water expressed as a percentage of the total reclaimed water used.
2. Recharge fraction (fraction) – The portion of reclaimed water used in a reuse system that recharges an underlying potable quality groundwater.

Table 10 is an attempt to utilize these principals and apply them to AWS alternatives. Note that modification of the table presented in the FDEP 2010 Reuse Inventory was required to achieve this.

In the case of irrigation reuse, it is determined that the offset and fraction are much

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Table 7. Summary of Post-Reverse Osmosis and UV-Advanced Oxidation Processes Non-Organic Average Results

Analyte	Units	BC Limit	FAC Limit	Filmtec	Hydranautics	Koch
Sodium	ug/L	160000	160000	BL	BL	BL
Antimony	ug/L	6	6	U	U	U
Arsenic	ug/L	50	10	U	U	U
Barium	ug/L	2000	2000	U	U	U
Beryllium	ug/L	4	4	U	U	U
Cadmium	ug/L	5	5	U	U	U
Chromium	ug/L	100	100	U	U	U
Lead	ug/L	15	15	I	I	I
Mercury	ug/L	2	2	U	U	U
Nickel	ug/L	100	100	U	U	U
Selenium	ug/L	50	50	U	I	U
Thallium	ug/L	2	2	U	U	U
Cyanide, Total	mg/L	0.2	0.2	U	U	U
Fluoride	mg/L	2	4	U	U	U
Nitrate as N	mg/L	10	10	BL	BL	BL
Nitrate Nitrite as N	mg/L	10	10	BL	BL	BL
Nitrite as N	mg/L	1	1	I	U	U

Notes
NS = No standard, U = Undetected based on method detection limit
I = Results is between lab method detection limit and practical quantification limit
BL = Below regulatory limit

Table 8. Cost Comparison Assumptions (Bloetscher, et al, 2011a)

Permeate capacity (total):	6 mgd
Number of membrane skids:	3
Permeate capacity of each skid:	2 mgd
Maximum skid average flux at 3 mgd permeate capacity:	17gfd
Maximum first stage permeate flow at design conditions:	2.5 mgd
Design and maximum recovery:	80 percent
Minimum recovery:	75 percent
Number of concentrate stages per skid:	2
Configuration	2:1
Maximum first stage feed pressure (year five) (250 psig maximum):	Proposed guaranteed max. Feed press.
Maximum first year applied pressure (any stage):	225 psi
Maximum second stage (overall skid) permeate pressure:	20 psig

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less than those values for aquifer injection. This is due to a variety of reasons, including reclaimed water availability, evapotranspiration, and, in southeast Florida, tidal influences on local groundwater by canal systems. Therefore, the replenishment credit is always less than one for these methods of reuse. This translates into less than 1:1 CUP credit expectations from the SFWMD. Table 11 translates the present values of each option into the actual CUP credit cost and cost per mgd using the offset value. Table 12 performs a similar function using the fractional values. Note that the Floridan options have no recharge credit as no regulatory framework is currently in place; the current regulatory climate is centered on the Biscayne Aquifer and impacts to Everglades restoration. As studies of the Floridan progress, future regulations may credit Floridan recharge. This is especially true in light of the recent Floridan modeling performed by Broward County, which indicates that the aquifer is not sustainable.

In summary, the actual costs of these AWS systems are greatly impacted when

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Table 9. Cost Comparison of Alternative Water Supply Sources Options for Pembroke Pines (Bloetscher, et al, 2011a)

Components for 6.0 MGD of Finished Product Water	1. Biscayne Aquifer Injection of Reclaimed Water with Lime Softening Potable Water Treatment [1]	2. Residential Irrigation Reuse System	3. Commercial Irrigation Reuse System	4. Floridan Potable Water Supply	5. Floridan Aquifer Injection of Reclaimed Water with Reverse Osmosis Potable Water Treatment
Pretreatment Acid/Degasifier	$ -	$ -	$ -	$ 2,500,000	$ 2,500,000
Automatic Strainer	$ 340,000	$ 340,000	$ 340,000	$ -	$ 340,000
Media Filters	$ 1,960,000	$ 1,370,000	$ 1,370,000	$ -	$ 1,960,000
Chlorine Disinfection	$ 440,000	$ 310,000	$ 310,000	$ 310,000	$ 750,000
Microfiltration	$ 6,180,000	$ -	$ -	$ -	$ 6,180,000
Dechlor/Break Tank	$ 100,000	$ -	$ -	$ -	$ 100,000
Reverse Osmosis	$ 10,000,000	$ -	$ -	$ 10,000,000	$ 20,000,000
UV-AOP Disinfection System	$ 2,180,000	$ -	$ -	$ -	$ 2,180,000
Buildings	$ 1,980,000	$ -	$ -	$ 1,980,000	$ 3,960,000
Yard Piping	$ 4,030,000	$ 650,000	$ 650,000	$ 750,000	$ 4,780,000
Electrical & Instrumentation	$ 4,680,000	$ 390,000	$ 390,000	$ 4,680,000	$ 9,360,000
Existing WWTP Modification	$ 590,000	$ 590,000	$ 590,000	$ -	$ 590,000
Sitework	$ 780,000	$ 330,000	$ 330,000	$ 780,000	$ 1,560,000
Post Treatment Stabilization	$ 470,000	$ -	$ -	$ 470,000	$ 940,000
Recharge Pumps	$ 390,000	$ -	$ -	$ -	$ 390,000
High Service Pumps	$ -	$ 1,300,000	$ 1,300,000	$ 1,300,000	$ 1,300,000
Floridan Withdrawal Wells	$ -	$ -	$ -	$ 2,700,000	$ 2,700,000
Reuse Pipelines (est)	$ -	$ 108,000,000	$ 19,640,000	$ -	$ -
Storage tank	$ -	$ 1,000,000	$ 1,000,000	$ 1,000,000	$ 1,000,000
Injection Well - class V	$ 1,300,000	$ -	$ -	$ -	$ 5,400,000
Injection Well - class I	$ -	$ -	$ -	$ 10,000,000	$ 10,000,000
SUBTOTAL	**$ 35,420,000**	**$ 114,280,000**	**$ 25,920,000**	**$ 36,470,000**	**$ 75,990,000**
Soft Costs - 20%	$ 7,090,000	$ 22,860,000	$ 5,190,000	$ 7,300,000	$ 15,200,000
CAPITAL COST TOTAL	**$ 42,510,000**	**$ 137,140,000**	**$ 31,110,000**	**$ 43,770,000**	**$ 91,190,000**
Estimated Annual Operation Costs					
Labor	$ 490,000	$ 179,000	$ 179,000	$ 490,000	$ 980,000
Power	$ 1,010,000	$ 78,000	$ 78,000	$ 550,000	$ 1,560,000
Chemicals	$ 399,000	$ 200,000	$ 200,000	$ 120,000	$ 519,000
UV Lamps	$ 95,000	$ -	$ -	$ -	$ 95,000
Total Annual Cost	**$ 2,000,000**	**$ 460,000**	**$ 460,000**	**$ 1,160,000**	**$ 3,160,000**
20-Year PW of Annual Costs	**$ 26,300,000**	**$ 6,100,000**	**$ 6,100,000**	**$ 15,300,000**	**$ 41,600,000**
i = 4.375%					
Present Worth Comparison [2]	**$ 68,900,000**	**$ 143,300,000**	**$ 37,300,000**	**$ 59,100,000**	**$ 132,800,000**

[1]Based on no changes to existing water treatment plant.

[2]Excludes all replacement costs at required intervals.

Table 10. FDEP Potable Quality Water Offset and Recharge Fraction Values – Modified

Reuse Activity	Potable Quality Water Offset (percent)	Recharge Fraction (percent)	Justification
Golf Course Irrigation	75	10	Efficient landscape irrigation
Residential Irrigation	40	45	Rounded averages of efficient and inefficient residential irrigation
Other Public Access Areas	60	30	Rounded averages of efficient and inefficient residential irrigation
Groundwater Recharge and Indirect Potable Reuse	0	90	High desireability - rapid infiltration basins
Agricultural Irrigation	60	35	Rounded averages of efficient and inefficient residential irrigation
Industrial Uses, Toilet Flushing, and Fire Protection	100	0	High desireability - cooling towers, toilet flushing and fire protection
*Groundwater Recharge and Indirect Potable Reuse**	*100*	*100*	*High desireability - aquifer injection wells*

**This category added to represent aquifer injection.*

Table 11. Aquifer Withdrawal Water Offset Cost Comparison of Alternative Water Supply Sources Options (Bloetscher, et al, 2011a)

Components for 6.0 MGD System	1. Biscayne Aquifer Injection of Reclaimed Water with Lime Softening Potable Water Treatment[1]	2. Residential Irrigation Reuse System	3. Commercial Irrigation Reuse System	4. Floridan Potable Water Supply[2]	5. Floridan Aquifer Injection of Reclaimed Water with Reverse Osmosis Potable Water Treatment[2]
Present Worth Comparison	$ 68,900,000	$ 143,300,000	$ 37,300,000	$ 59,100,000	$ 132,800,000
Potable Quality Water Offset	1.00	0.40	0.75	1.00	1.00
Actual Full CUP Credit Cost	$ 68,900,000	$ 358,300,000	$ 49,800,000	$ 59,100,000	$ 132,800,000
Actual Full CUP Credit/MGD	$ 11,500,000	$ 59,800,000	$ 8,300,000	$ 9,900,000	$ 22,200,000

[1]Based on no changes to existing water treatment plant. [2] Offset value for Floridan potable water supply added for comparison.

Table 12. Recharge Fraction Cost Comparison of Alternative Water Supply Sources Options

Components for 6.0 MGD System	1. Biscayne Aquifer Injection of Reclaimed Water with Lime Softening Potable Water Treatment[1]	2. Residential Irrigation Reuse System	3. Commercial Irrigation Reuse System	4. Floridan Potable Water Supply	5. Floridan Aquifer Injection of Reclaimed Water with Reverse Osmosis Potable Water Treatment[2]
Present Worth Comparison	$ 68,900,000	$ 59,100,000	$ 143,300,000	$ 37,300,000	$ 132,800,000
Recharge Fraction	1.00	0.45	0.10	0.00	0.00
Actual Full CUP Credit Cost	$ 68,900,000	$ 131,400,000	$1,433,000,000	N/A	N/A
Actual Full CUP Credit/MGD	$ 11,500,000	$ 21,900,000	$ 238,900,000	N/A	N/A

[1]Based on no changes to existing water treatment plant. [2] Recharge value for Floridan potable water supply is not applicable.

Continued from page 36

viewed from an environmental benefit perspective. The options of Biscayne Aquifer recharge, commercial irrigation, and Floridan water supply are reasonably close in cost range when viewed from a potable water offset perspective. However, when viewed as a recharge fraction, it is clear that Biscayne Aquifer recharge is the least costly option. If the regulatory framework were in place to support recharge credit to the Floridan, this option would most likely prevail due to the lower annual operation and maintenance cost.

Table 13 provides an environmental impact based on carbon dioxide production. As expected, electricity demands on RO systems greatly outweigh pumping costs for irrigation reuse. Similar to Table 12, when recharge fraction is considered, the equivalent carbon impact rises commensurately (See Figure 13).

Conclusions

The City of Pembroke Pines has undertaken an extensive and thorough investigation of alternative water supply options, with specific pilot testing of aquifer recharge membranes. The City tested reverse osmosis membranes to determine its ability to remove constituents, especially phosphorous and nitrogen compounds, as well as unregulated emerging substances. The membranes performed under all circumstances and removal requirements were met or exceeded.

In addition, the City compared costs of potential alternative water supply solutions. Indirect potable reuse in southeast Florida was found to be much more cost-effective than initially expected, when consideration is given to actual environmental benefit.

The analysis also shows that the cost for reverse osmosis to accomplish aquifer injection may be far more competitive when compared with land application reuse systems than utilities may realize. However, significant water supply issues are raised, which indicate that further study and increased regulatory guidance is necessary before moving forward. The following areas are identified:

- All options for AWS systems presented are technically feasible. However, the financial impacts to residents should be considered as these capital costs translate to rate increases on the order of 28-51 percent, dependent on the option chosen.
- Regulatory guidance is needed in the area of CUP allocation. Currently, the water management district has no permit mechanism to credit the City for making the investments in indirect potable reuse. This has stalled the project. Until the water use permit issues are resolved legislatively, it is unlikely such projects will develop further.
- More regulatory guidance is needed for emerging substance removal. At this time, there is a lack of scientific consensus on the toxicity and possible adverse effects of these substances at such low concentrations.

References

- Bloetscher, F., Stambaugh, D., Hart, J., Cooper, J., Kennedy, K., Burack, L.S., Ruffini, A. P., Cicala, A., and Cimenello, S. 2011, Pembroke Pines Explores Aquifer Recharge As An Alternative Water Supply, Florida Section AWWA Conference Proceedings, Orlando, FL Nov. 27-30, 2011, St. Cloud, FL.
- Bloetscher , F., Stambaugh, D., Hart, J., Cooper, J., Kennedy, K., Burack, L.S., Ruffini, A. P., Cicala, A., and Cimenello, S. 2011a, Evaluating Membrane Options for Aquifer Recharge in Southeast Florida, IDA Journal, v2:4, pp 46-57.

Table 13. Carbon Footprint Comparison of Alternative Water Supply Sources Options for Pembroke Pines (Bloetscher, et al, 2011a)

Carbon Footprint for 6.0 MGD of Finished Product Water (tons CO_2/year)	1. Biscayne Aquifer Injection of Reclaimed Water with Lime Softening Potable Water Treatment[1]	2. Residential Irrigation Reuse System	3. Commercial Irrigation Reuse System	4. Floridan Potable Water Supply	5. Floridan Aquifer Injection of Reclaimed Water with Reverse Osmosis Potable Water Treatment
Base system	200	60	120	160	290
Equivalent recharge	200	133	1200	N/A	N/A

[1]Based on no changes to existing water treatment plant.