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COMPARING COSTS, WATER SUPPLY BENEFITS AND CONTAMINANT REMOVAL OF AQUIFER RECHARGE WITH WASTEWATER

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ABSTRACT

The City of Pembroke Pines, FL investigated the use of reverse osmosis membranes, coupled with ultraviolet light disinfection and advanced oxidation to treat water to standards whereby they could be used for aquifer recharge. The City had three goals for the project. The first was to evaluate whether the water quality requirements of Broward County for injection into the G-1 Biscayne aquifer could be met. The second was assuming goal 1 could be met, would a series of emerging contaminants also be removed to a minimum of three logs. Because the concentration were so low, determining real

removal percentages is difficult. Finally the City investigated whether the project costs were competitive with other forms of reuse or other water supplies. The proposed process was both competitive price-wise and met the water quality requirements, The combination of RO/UV/AOP was effective at obtaining a 3 log removal of ESOCs, but the RO and UP/AOP Processes alone were not capable of removing all substances on their own.

Key Terms: endocrine disruption, pathogens, public health, water resources management, ground water management, planning, sustainability, water supply

INTRODUCTION

Through various studies, it has been determined that the Lower East Coast of Florida does not have the water resources to provide for future population growth and to sustain natural systems. Due to this shortcoming of water resources available, a regional effort to implement water reuse programs to attenuate the increasing water demand is currently underway. A part of the program is to create alternative water sources to meet the projected water supply deficit. Considering the increasing restrictions on the Everglades system for drinkable water, utilities are looking into targeted groundwater recharge as an alternative water supply. Targeted recharge means injecting water within the capture zones of water supply wells as an indirect potable recharge program.

The state of the art technology in water reuse programs includes reverse osmosis as the most attractive since the water quality can almost always be achieved using it (Rautenbach, 1996). Membrane treatment processes can remove particulate and dissolved contaminants, including pathogenic microorganisms, salts, hardness, and organic micro-pollutants (EDCs/PPCPs). They also have the major advantage of running intermittently, without operators, and being compatible with existing water treatment trains (Gwon, 2003).

The standard-bearer for aquifer recharge projects is Water Factory 21 in Orange County, CA. Water Factory 21 has been operating for over 20 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 1992, 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 (Sloss, et al 1996). Since that time, five utilities in southeast Florida have investigated the process, the most recent being Pembroke Pines.

The City of Pembroke Pines WWTP, shown in an aerial photograph in Figure 1 (photograph also includes the pilot test equipment), is located at 13955 Pembroke Road, Pembroke Pines. The original WWTP was a 1.33 MGD package treatment unit (WWTU#1) installed in 1984 to service the Century Village housing development. After seven expansions, the plant now has a treatment capacity for 9.5 MGD and two deep injection wells rated at 9.52 MGD and 1,527 MGD respectively (City of Pembroke Pines, 2010). The City has been interested in some form of reuse program, but lacks sufficient large customers for a successful "purple pipe program."



Figure 1. City of Pembroke Pines WWTP

In addition the City needs more raw water supplies, so as apart of an ongoing regional effort to identify feasible alternative water supplies, the City of Pembroke Pines, its consultant Calvin, Giordano and Associates (CGA), and Florida Atlantic University (hereinafter refer to as the "Project Team"), evaluated an indirect potable reuse program that would inject highly treated reclaimed water into the surficial aquifer for retrieval downstream in their wells as an alternative water supply solution, compared costs to other options, and evaluated the removal pf phosphorous and ESOCs.

The Project Team evaluated the combination of microfiltration, reverse osmosis membranes and ultraviolet light/advanced oxidation as a treatment process. There were a

number of issues of concern: phosphorous, which has a regulatory limit of 0.01 mg/L in Broward County, metals, ESOCs. For the latter, the concern was the potential for endocrine disrupting compounds, pharmaceuticals and personal care products (EDCs/PPCPs), to contaminate the Biscayne aquifer as a result of injection with treated wastewater effluent.

The pre-treatment phase of the study included evaluating the performance of three different filtration technologies: Ballasted chemical precipitation, membrane filtration and media (sand) filtration. These processes formed the pre-treatment necessary for the second phase of the study, which included treatment via reverse osmosis and disinfection by UV and hydrogen peroxide (see Figure 2). A comprehensive analysis of substances found in the wastewater treatment plant was performed by CGA with the purpose of evaluating the plant's readiness to manage micro-pollutants present in feedwater. These preliminary results were used to specify compounds to be used to perform three spike tests, executed by FAU, on commonly found substances at the plant.

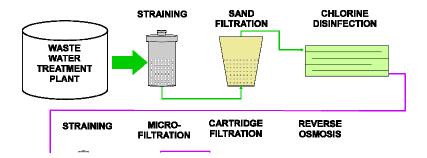




Figure 3 - Osmonics RO Skid 2:1 Configuration

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 for the project are summarized in Table 1.

	Feed
Constituent	(mg/L)
NH4	13.9
Κ	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

Table 1 - Feed Water Parameters for RO System

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

Operating parameters are outlined in Table 2. The RO pilot performance was monitored on a daily basis, recording: feed, permeate and concentrate flow rate. The recycle stream was not used. Water quality characteristics for specific conductivity, pH, ORP, temperature and dissolved oxygen were collected daily as well. Two positive displacement meters were installed on the permeate and concentrate pipes to measure flow. Meter accuracy was confirmed before the pilot started. It was determined that the positive displacement meters provided an accurate flow measurement and no calibration factor was required. Over 3 million gallons was treated during the test process.

Three membranes were tested (see Table 3). All three (3) 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. Numerous tests were taken during the process (explained in more detail in Bloetscher et al (2011). The pilot study demonstrated that RO is an effective tool to meet the regulatory requirements needed for aquifer recharge in Broward County. The remaining questions were whether the ESOCs were adequately removed, and whether the costs were competitive with other water supply options.

Parameter	DOW Filmtec	Hydranautics	Koch
Model Number	BW30-4040	ESPA2-LD-4040	TFC-4040-HR
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%	15%	15%
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%	99.6%	99.55%

Table 2. Summary of Membrane Operating Parameters (Source Bloetscher et al2011)

Notes

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

Parameter	DOW BW30-4040	Hydranautics ESPA2 4040HR	Koch TFC-4040HR
Rejection (%)	98	97.6	97.5
Recovery (%)	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 (%))	17	21	0
Crossflow Velocity (ft/d)	19.3	21.1	20

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

REMOVING ESOCs

During the pilot test, the City reviewed potential for removal of ESOCs. ESOCs are a group of chemicals, mostly man-made, which are released into the environment though normal daily activities, and interact with normal human and animal metabolic processes. Some interactions are detrimental, some toxic, and some are lethal. Some are common products, some are exotic compounds released during hazardous spills. Many compounds have long half-lives, on the order of decades. Once they are in the environment, they persist for years. These compounds need be present in only tiny amounts to have an effect.

ESOC's affect human physiology in several ways: via the hormone system (endocrine disrupting compounds, or EDC's), the immune system, or other metabolic pathways. Some substances affect via multiple pathways. ESOC's are mostly common, everyday household products, like pharmaceuticals, shampoos, detergents, sunscreens, pesticides and industrial chemicals. They enter the public waste stream through household sinks and drains. Not all are liquids, some are dusts, and comprise the major portion of household dust, like poly-brominated flame retardants (PBDE). PBDE's are in every seat cushion, drapery, and plastic item found in households. Normal usage creates the dust. Some enter the system through common house up keep, like pesticides and herbicides. There are so many avenues these chemicals enter the environment that they can't all be covered in this report. However, almost all of them will end up at the waste water treatment facility, and will need to be treated before the water will be suitable for reuse. Their impacts are discussed more fully in Bloetscher and Plummer, 2010. Typical human hormonal concentrations are on the order of 1 part in one billion.

Table 4 was developed in order to evaluate and compare the effectiveness of different treatment process when removing micro-pollutants, with reverse osmosis being of particular interest, based on literature review. What this shows is that few ESOCs are removed completely in the secondary aeration process: there is a need for membranes and UV/AOP to increase removal above three logs. However, none of the field tests to date provide a true measure of percent removal because the concentrations are too close to the detection limits to provide a viable removal percentage so most of the pilot studies do not report the actual removal efficiency of RO membranes because the permeate is usually at non-detect levels. They circumvent this issue by reporting values between the laboratory method detection limit and the practical quantitation limit.

In order to create an inventory of micro-pollutants present in the Pembroke Pines WWTP, eight (8) tests were performed in a period of four (4) months to determine the presence of emerging substances of concern (ESOCs). Each test evaluated the presence of: pharmaceuticals, antibacterials, steroids, hormones, surfactants, emulsifiers, plastic stabilizers, proteins, herbicides, organic compound, industrial solvents, flame retardants, and PCBs. As with prior studies, the concentration were too low to determine whether the three log goal was being met, so a spike test was constructed.

Analyte	CAS Number	Biologi cal Reactor	Secondary Sedimentation Activated Sludge	Chlorine Tank	MF	RO	UV- AOP	UV	AOP Ozone/ H ₂ O ₂	Nano- filtration
PHARMACEUTICALS										
Acetaminophen	103-90-2			>99 (5) 45 (6) 100(16) >80 (2)		>95 (4)	>80 (2)	37 (16) 20-50 (2)		
Carbamazepine	298-46-4			20 (5) <20 (2)		>99.9 (17) >99.9 (17)* >99.6 (19)	nd (7) 16->88 (16) >80 (2)	0 (16) <20 (2)		65 (8) 88-96 (9)
Ibuprofen	15687-27-1	22 (3) 75 (1)	70 (1) 75 (3)	23 (16) 38 (16) <20 (2)		>98 (4) >90 (7) 95-100 (12) 98 (17) >98.9 (17)* >95 (19)	nd (7) 73-94 (16)	8 (16) <20 (2)	55-90 (16) 50 (18) 88 (21)	82 (8) 98 (9) 99 (12) 90-100 (13)
ANTIBACTERIALS										
Triclosan	3380-34-5			100 (16) >80 (2)		95 (4) >90 (7) >99.8 (19)	nd (7) >80 (2)	65 (16) 50-80 (2)	82 (21)	
STEROIDS/ HORMONES										
Estrone	53-16-7	33 (15)		100 (16) >80 (2)	0-60 (10)	>96 (19) [>85 (7)	nd (7) >80 (45)	30 (16) <20 (2)		85-100 (11)
17b-estradiol	50-28-2	8 (15) 47 (1)		100 (16) >80 (2)		>95 (19) >80 (7)	>80 (45)	30 (16) <20 (2)		(Continued)

Table 4. Removal Efficiency of Different Water Treatment Processes

Table 4 (Continued)

Analyte	CAS Number	Biologi cal Reactor	Secondary Sedimentation Activated Sludge	Chlorine Tank	MF	RO	UV- AOP	UV	AOP Ozone/ H ₂ O ₂	Nano- filtration
17a-ethinylestradiol	57-63-6	26 (15)	>80 (2)	100 (16)		>95 (19) >80 (7)	>80 (2)	30 (16) <20 (2)		
Estriol	50-27-1		>80 (2)	100 (16)		95 (19) >80 (7)	>80 (2)	30 (16) <20 (2)		
PROTEIN DEGRADATION										
N-Nitrosodimethylamine (NDMA)	62-75-9					59-72 (14)	80 (20)	20 (20)		10 (14)
FLAME RETARDANTS (Chlorinated Phosphates) Tris (2-chloroethyl) phosphate (TCEP)	115-96-8		<20 (2)	2.1 (5) 0 (16)		95 (4) >97 (17) 99.2 (17)*	68 (7) 10-16 (16) <20 (2)	0 (16) <20 (2)	4 (16) 15 (21)	
1,4-Dioxane	123-91-1									

* Double Pass

Note: The values presented are in percentage. The literature reference is reported in parentheses relates as follows (see Reference section for details): (1) Carballa et al, 2005; (2) Snyder, et al, 2007a; (3) Hansen, et al, 1998 (4) Kim et al, 2007; (5) Stackelberg et al, 2007; (6) bender and MacCrehan, 2006; (7) Snyder, et al 2007; (8) Heijman, et al, 2007; (9) Verliefde, 2008)' (10) Chang, et al, 2002; (11) Nghiem, et al, 2004; (12) Xu, et al, 2005; (13) Park and Cho, 2005; (14) Miyashita, 2007; (15) Ternes, et al, 1999; (16) aga, 2008; (17) Kummerer, 2004; (18) Zweiner and Frimmel, 2000; (19) Water Quality, Opflow 2008; (20) Ishida, et al, 2008; (21) LeBrun and Robinson, 2009

The spike test was carried under the direction of FAU to evaluate the effectiveness of reverse osmosis (RO) membranes and ultraviolet and advanced oxidation process (UV/AOP) to remove ESOCs. The spike test chemicals were chosen based on results from a comprehensive inventory of compounds found entering the Pembroke Pines plant, and the effectiveness of the plant at removing these. Note that the chosen compounds are not effectively removed by the current contact stabilization process, which is why the RO/UV/AOP processes needed further evaluation. By spiking substances one thousand times their laboratory reporting limit, enough concentration was provided to fully study the actual removal rate of both RO and AOP treatment and determine if three log removal was achieved.

All ESOC measurements were performed using EPA Methods. A complete listing of the Methods, Reporting Limit (RL), and Method Detection Limit (MDL) for each tested chemical is located Table 5.

Pharmaceuticals	Method	RL (µg/L)	MDL (µg/L)
Acetaminophen	EPA 1694	0.05	0.025
Carbamazepine	EPA 1694	0.01	0.0012
Ibuprofen	EPA 1694	0.025	0.0063

Table 5 - ESOC	Test Methods
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Anti-Bacterials	Method	RL (µg/L)	MDL (µg/L)
Triclosan	EPA 1694	0.05	0.0061
Steroids/Hormones	Method	RL (µg/L)	MDL (µg/L)
Estrone	EPA 1698	0.01	0.0011

Protein Degradation/Plastic	Method	RL	MDL
Stabilizer (Nitrosomines)		(µg/L)	(µg/L)
n-Dimethylnitrosamine (NDMA)	Ion Trap	0.002	0.00074

Table 6 presents the maximum, average, and minimum concentrations of substances of interest (those belonging to groups analyzed in the spike test) for the eight (8) tests performed. These were tested at the influent, before Phase I (SP-1), after Phase I (SP-2), after RO membranes (SP-3). Table 7 summarizes these results for the membranes only.

Compound		Influer	nt			SP-	1			SP-2	2		SP-3			
	High Value	Average	Low Value	Count	High Value	Average	Low Value	Count	High Value	Average	Low Value	Count	High Value	Average	Low Value	
PHARMACEUTICALS																
Acetaminophen	150000	90,813	8500	8	180	127	100	3	180	180	180	1	0	0	0	
Azithromycin	1700	938	130	8	350	247	170	6	380	233	140	6	0	0	0	
Caffeine	94000	47,800	5900	8	2600	838	220	4	1400	450	160	5	0	0	0	
Carbamazepine	420	217	32	8	370	204	24	7	370	207	26	8	0	0	0	
Cotinine	2500	930	43	8	1800	426	15	5	130	100	71	4	0	0	0	
Diltiazem	540	322	35	8	290	205	29	8	230	144	15	8	0.86	0.67	0.47	
Fluoxetine	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
Gemfibrozil	3800	2,576	280	8	600	480	310	6	470	418	360	6	0	0	0	
Ibuprofen	18000	12,413	1500	8	1300	678	210	6	1200	605	230	6	0	0	0	
Iopromide	4700	1,385	140	4	510	229	81	3	620	227	71	4	0	0	0	
Lincomycin	15	6	1.2	5	10	6	1.7	5	19	11	3.8	2	0	0	0	
Naproxen	19000	12,813	1700	8	3100	1,580	500	6	1800	1,193	500	6	0	0	0	
Sulfamethoxazole	3300	2,140	330	8	900	595	76	8	830	538	71	8	0	0	0	
Trimethoprim	920	566	91	8	320	236	40	7	340	243	170	6	0	0	0	
Tylosin	54	26	12	3	42	28	12	2	26	19	12	2	0	0	0	
ANTIBACTERIALS																
Triclocarban	1200	928	110	8	290	178	39	7	280	233	160	6	6.6	5	3.3	
Triclosan	3600	1,506	86	8	150	98	69	6	120	110	100	2	110	110	110	ļ
															Cont	ti

 Table 6. ESOCs Summary of Removal for All Eight (8) Tests

Table 3 Continued		Influent SP-1					-1			SP-2		SP-3					
Compound	High Value	Average	Low Value	Count	High Value	Average	Low Value	Count	High Value	Average	Low Value	Count	High Value	Average	Low Value	Count	
STEROIDS/HORMONES	5																
17α-Estradiol	10	9.6	8.9	3	0	0	0	0	0	0	0	0	0	0	0	0	
17α-Ethinyl Estradiol	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
17β-Estradiol (E2)	23	17.8	14	5	0	0	0	0	0	0	0	0	0	0	0	0	
Equilenin	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
Estriol (E3)	210	113.3	56	7	0	0	0	0	0	0	0	0	0	0	0	0	
Estrone (E1)	41	35.6	27	7	22	18.5	15	2	0	0	0	0	2.6	2.6	2.6	1	
Progesterone	17	14.3	11	3	0	0	0	0	0	0	0	0	0	0	0	0	
Testosterone	96	70.7	40	7	0	0	0	0	0	0	0	0	0	0	0	0	
PROTEIN DEGRADATI	ON																
NDMA	29	19.33	7.3	7	9	5.43	2.6	8	130	30.1	6.5	8	8.3	3.8	2	8	
NDPA	4.4	4.40	4.4	1	0	0	0	0	0	0	0	0	0.54	0.54	0.54	1	
FLAME RETARDANTS																	
ТСРР	1200	827	78	7	1600	963	120	8	1500	939	89	8	33	33	33	1	
TCEP	990	483	200	4	1400	598	190	5	1200	508.333	220	6	190	112	34	2	
TDCPP	610	610	610	1	800	800	800	1	1100	1100	1100	1	0	0	0	0	

Notes All units are in ng/l

Table 7 – FAU Spike Test Removal Percentages, by Process Unit

		Percent Removal					
		Post RO			Post UV		
Spike T	est #1	#2	#3	#1	#2	#3	
Pharmaceuticals							
Acetaminophen	91.30%	96.88%	97.27%	99.92%	98.32%	99.95%	
Carbamazepine	85.00%	99.97%	99.91%	99.93%	99.98%	99.97%	
Ibuprofen	85.37%	100.00%	99.92%	100.00%	100.00%	99.98%	
Antibacterials							
Triclosan	27.94%	97.50%	99.98%	100.00%	100.00%	100.00%	
Steroids/Hormones							
Estrone	67.70%	98.84%	99.99%	99.87%	100.00%	100.00%	
Protein Degradation							
N-Nitrosodimethylamine (NDMA)	62.77%	48.29%	39.01%	99.96%	99.90%	100.00%	
Flame Retardants (Chlorinated Phosphat	es)						
Tris(2-chloroethyl)phosphate (TCEP)	73.97%	99.77%	99.80%	99.89%	100.00%	99.83%	
Other							
1,4-D (Dioxane)	97.84%	94.28%	96.86%	99.89%	94.17%	97.80%	
Avera	ige 73.99%	91.94%	91.59%	99.93%	99.05%	99.69%	

Green indicates 3 log target is achieved

A three log reduction was obtained for all chemicals except TCEP and 1,4-Dioxane which had a combined percent removal equivalent to 99.83 and 97.80 percent respectively. As a result, realizing that the concentrations used in the spiked test were many times the typical concentrations found at WWTPs, it is safe to assume that an RO/UV/AOP is a very effective treatment option for a conventional WWTP.

COST COMPARISON OF ALTERNATIVES

Based on the success of the RO/UV/AOP system, the City compared five options for water supply:

- Biscayne Aquifer Injection of Reclaimed Water, assuming recovery in the City's wellfield and treatment with Lime Softening
- Creating a Residential Irrigation Reuse System
- Creating a Commercial/Large User Irrigation Reuse System (golf courses and parks)
- Use of the brackish Floridan Aquifer as a potable water supply

• Use of the brackish Floridan Aquifer Injection of Reclaimed Water with RO potable water System since the Floridan has been determined to be unsustainable in the long-term

As can be seen in Table 8, a review of the initial capital investment leads to the commercial irrigation reuse alternative having the least capital cost, with the majority of cost 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 pre- and post-treatment on the wastewater side. This also is somewhat subjective as about 24% of the Floridan costs are tied to concentrate disposal wells, which, under other circumstances, may be shared with the WWTP. 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 Floridan). 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 (purple piping) system throughout the City. This analysis confirms the utility perspective that the construction costs for residential reuse are much higher than costs for other options again due to the necessary operational costs of RO multi-barrier system including membrane filtration (MF) and post treatment with UVAOP (Bloetscher et al , 2011a). Both of these processes carry a significant electricity burden and neither is required for Floridan 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 provide a measurement of implementation. They are:

- 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 ground water.

Due to a variety of reasons including reclaimed water availability, evapotranspiration and, in Southeast Florida, tidal influences on local groundwater by canal systems, the replenishment credit is always less than one for these methods of reuse. 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 9 translates the present values of each option into the actual CUP credit cost and cost per MGD using the offset value. Table 10 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 the aquifer is not sustainable.

Table 8 – Cost Comparison of AWS Options for Pembroke Pines (Bloetscher, et al, 2011a) Error! Not a valid link.

Table 9 – Aquifer Withdrawal Water Offset Cost Comparison of AWS Options Error! Not a valid link. Table 10– Recharge Fraction Cost Comparison of AWS Options Error! Not a valid link.

Finally, Table 11 provides an environmental impact based on carbon dioxide production. As expected, electricity demands on RO systems greatly outweigh pumping costs for irrigation reuse (Bloetscher et al, 2011a). Similar to Table 10, when recharge fraction is considered, the equivalent carbon impact rises commensurately.

Table 11 – Carbon Footprint Comparison of AWS Options for Pembroke PinesError! Not a valid link.

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 their 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.

The actual costs of these AWS systems are greatly impacted when 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 there were the regulatory framework in-place to support recharge credit to the Floridan, this option would most likely prevail due to the lower annual operation and maintenance costs.

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:

- 1. 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% dependent on the option chosen. Given the current economic climate, more thought should be given as to the economic feasibility of these methods of reuse.
- 2. Local nutrient removal criteria mandates that RO is a part of the process train. Given the operation and maintenance requirements of RO and the subsequent carbon impact, further research is needed in pursuit of alternative treatment technologies which achieve these limits.
- 3. Local nutrient removal criteria does not distinguish between the Biscayne (a class G-I aquifer) and the Floridan (a class G-II aquifer). Both are considered an Underground Source of Drinking Water (USDW) by 40 CFR 144.3. Further research is needed as to possible alternative treatment levels or processes as well as opportunities for regulatory relief.
- 4. Regulatory guidance is needed in the area of CUP allocation. Currently, utilities are not motivated to make capital investments beyond their minimum AWS requirements. A system of CUP credits and uses would provide motivation.

5. More research and regulatory guidance is needed for the Floridan aquifer. Although currently identified as an AWS, consideration should be given to a CUP credit system which may motivate Floridan injection of reclaimed water. More research is also needed on the sustainability of the Floridan.

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