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POTABLE REUSE PILOTS & DEMONSTRATIONS: A REVIEW OF FLOW, TREATMENT, & COSTS

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EXECUTIVE SUMMARY

As a part of its initial efforts to develop an Advanced Water Treatment Demonstration Program, Hillsborough County Public Utilities conducted a broad review of 33 potable reuse pilots and demonstrations in the United States, to observe what differentiates a potable reuse "demonstration" and to glean lessons learned from the approaches utilized by other utilities. The review considered more than 30 years of major potable reuse pilots and demonstrations (1985 to 2018). Facilities ranged in capacity from 1 GPM to 8 MGD.

Key findings from the County's study include:

- Most potable reuse "demonstration" plant capacities had greater than or equal to about 0.1 MGD (~70 GPM), smaller plants tended to be called "pilot" plants. The paper includes a bar chart summarizing the flows of the pilot/demonstration programs.
- The flow of 0.1 MGD (~70 GPM) is a significant threshold value for applying the label of a "demonstration" to RO/NF based treatment trains, since 70 GPM is the approximate flow produced by a full-scale (8" diameter element) two-stage RO/NF membrane system. However, among 26 RO/NF tests, 19 (73%) used 4" diameter membranes; three (3) (12%) used 2.5" diameter membranes; and four (4) (15%) used 8" diameter membranes. Use of smaller diameter RO/NF membranes is usually preferred to reduce program costs, reduce system footprint, and simplify operations.
- Some of the non-RO test systems had a "Large" (≥0.1 MGD) capacity; however, this may not be a requirement for non-RO processes to demonstrate full-scale equivalency.
- Several potable reuse test systems used a mixture of equipment sizes typically large units followed by smaller units), instead of a single size for all equipment in the treatment train.
- Other test schemes included multiple similar parallel treatment units or phased testing of various treatment trains.
- A summary table is provided for the projects profiled, including the following information: program sponsor, program name, state, type (IPR/DPR) (Pilot/Demonstration), operational period, capacity, treatment trains tested, and program cost.
- Potable reuse program costs were correlated to plant capacity, providing a useful model for other utilities to obtain a quick order of magnitude estimate of initial program costs based on program capacity. The model is Cost ($M)=16.98*$Cap^{0.678}$ (R^2=0.81). Where capacity is in MGD and cost is in 2018 dollars.

INTRODUCTION

Significance of Demonstration Plant Capacity

The Hillsborough County Public Utilities Department intends to build an advanced water treatment demonstration facility; however, Florida's regulations do not provide a straightforward minimum flow capacity for a facility to be classified as a full-scale demonstration. In fact, neither California nor Texas regulations provide specific guidance on the minimum capacity for a full-scale demonstration. This paper looks at over 30 potable reuse tests observing each system's flow, treatment processes, and cost.

Florida has been a hot spot for testing of potable reuse, with more than a dozen Florida utilities (Table 1) having conducted pilots or demonstrations. While many of these projects focused on indirect potable reuse, utilities are increasingly viewing direct potable reuse (DPR) as a potentially viable alternative water supply. Florida utilities actively evaluating DPR include Hillsborough County, City of Daytona Beach, City of Altamonte Springs, and Jacksonville Electric Authority (JEA). Previous pilot studies focusing on IPR applications may have limited applicability for the more stringent requirements of DPR, since DPR facilities do not have the margin for process upsets that a large environmental buffer provides to IPR facilities. Therefore, a priority for DPR testing programs is to accumulate an extensive body of monitoring data that can be used as a basis of discussion with regulators for setting performance and treatment redundancy requirements for a future full-scale system.

The following factors should be considered when selecting the capacity of a demonstration plant.

- Produce water of equivalent quality to full-scale facilities
- Support development of full-scale design criteria and operational set points
- Support testing of multiple technologies to enable a price competitive selection of full-scale equipment and consumables
- Provide access for tours by regulators, stakeholders, and the public
- Available site footprint

Demonstration Plant Capacities

Survey of Potable Reuse Test Programs

While the terms "pilot" test and "demonstration" test are commonly confused, full-scale equivalency appears to be the primary factor distinguishing demonstration programs from pilot programs. In general, potable reuse pilots tend to have smaller capacities, incur lower costs, and run for shorter durations, whereas potable reuse demonstrations tend to have larger capacities, incur higher costs, and run for longer durations. Pilot plants are more appropriate for lower-cost validation of alternative, innovative treatment trains, or narrowing down treatment alternatives for a follow-up demonstration. Demonstration plants are more appropriate for refinement of validated treated trains, operational training/response, space and visual impact for public tours, observing O&M costs, testing instrumentation & control, and providing flows in support of downstream testing (e.g. recharge wells, wetlands).

Absent regulatory guidance on capacity, the next best approach is to review the precedent from actual potable reuse test systems. Figure 1 shows the capacity of 28 potable reuse test systems (13 "demonstrations" and 15 "pilots") across the United States from the past 30 years on a

logarithmic scale in millions of gallons per day (MGD). Table 1 summarizes the details of several recent notable test programs for potable reuse. Table 2 provides a graphical summary of the treatment trains tested by location at pilot or demonstration scale. A review of potable reuse test system capacities suggests that 0.1 MGD is a capacity where other utilities have decided to use the term "demonstration". Neither Florida, California, nor Texas have regulations mandating a required capacity for a "full-scale" demonstration plant. One way to look for the difference in capacity for demonstration plants and pilot plants is to review the size of current and historical potable reuse test systems. While this is not an exhaustive list of every single potable reuse test system in the US, it is a large enough sample to be representative of industry views on demonstration capacities. More details about each of these test systems are provided in Table 1 including state, operational dates, treatment trains tested, and program costs.

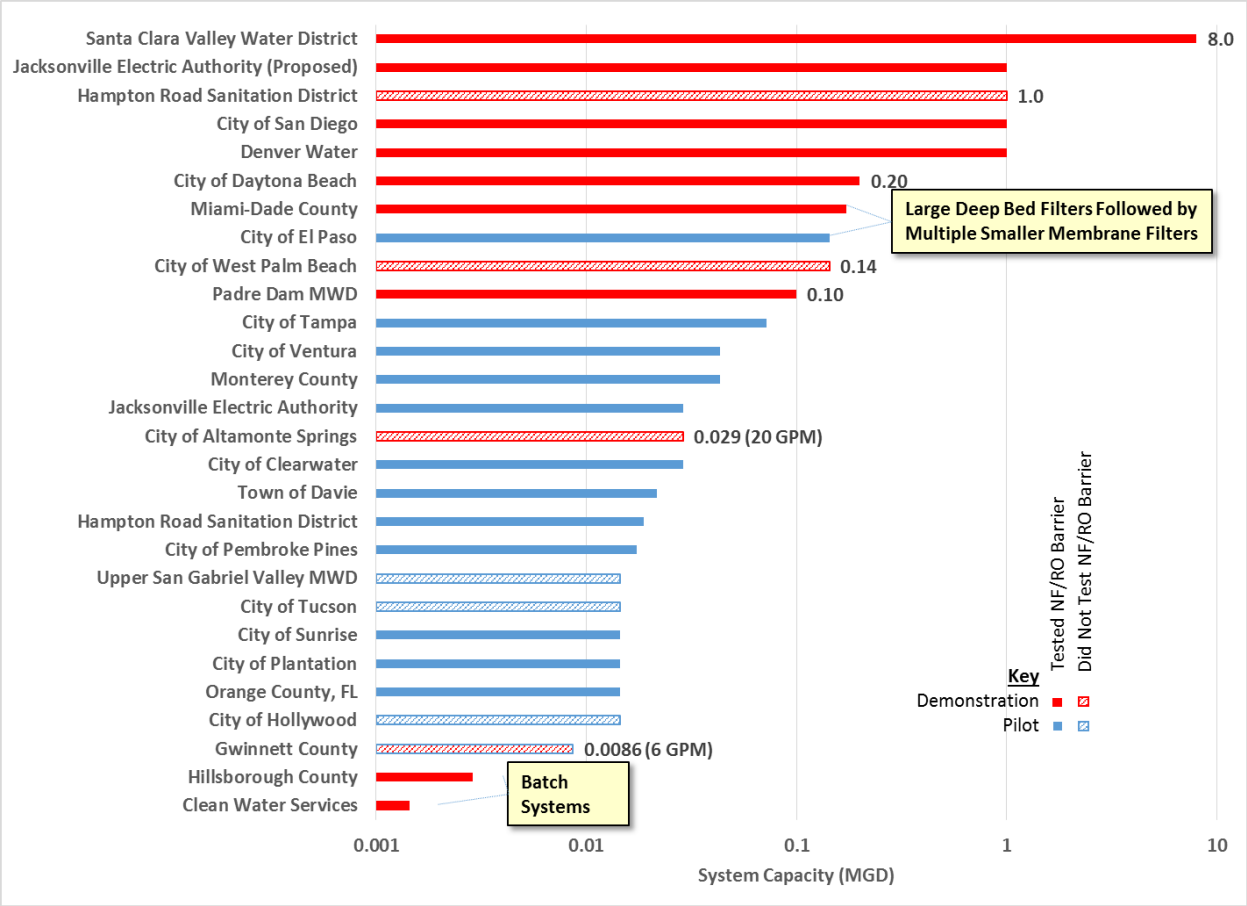

Figure 1 Capacities of Several Potable Reuse Pilot & Demonstration System in the United States

Table 1 Notable Potable Reuse Pilot and Demonstration Programs in the United States by Year Started

Sponsor	Program Name	State	Type	Operational Period	Capacity (each train)	Treatment Trains Tested	Pilot/Demo Program Cost ($M)	Notes
Denver Water	Potable Reuse Demonstration Project	CO	DPR Demo	1985-1989, 5 Years Alternatives Testing 1990-1991 2 Years Demo Testing	1 MGD/ 0.082 MGD (57 GPM)	Preferred train tested during two-year period, two parts in sequence with different capacity First Part (1 MGD):Secondary effluent to lime, recarb, filtration, to second part Second Part (0.082 MGD): From first part to UV, GAC, RO (4"), air stripping, O_3, chloramination	$10M (~1990)	"Ten year" project received funding from USEPA (20%). $4 million whole animal health effects testing program, with no negative health effects "The Demonstration of Direct Potable Water Reuse: Lauer, 2015. "The Denver Project Technical Report (1979-1993)" WateReuse. https://watereuse.org/watereuse-research/7920/
City of Tampa	Water Resource Recovery Project	FL	IPR Pilot	Jan. 1987- Jun 1989 (30 months)	50 GPM (0.072 MGD)	Four (4) Parallel Alternatives 1. Preaeration, lime, recarbonation, filtration, and disinfection 2. (*)Preaeration, lime, recarbonation, filtration, **GAC**, & disinfection 3. Preaeration, lime, recarbonation, filtration, **RO (4")**, and disinfection 4. Preaeration, lime, recarbonation, filtration, **UF**, & disinfection	N/A	Tampa Water Resource Recovery Project "Supplemental Treatment Pilot Plant". Disinfection process was chlorine until 6/88 and ozone after 7/88". (*)Treatment train (with ozone disinfection) selected for follow on toxicological studies.
City of West Palm Beach	Advanced Wastewater Treatment/ Constructed Wetlands Demonstration Project	FL	IPR Demo	Jul. 1996- Jun. 1997 (12 months)	100 GPM (0.15 MGD)	AWT Treatment (Actiflo (Ferric Sulfate Coagulation)>Deep Bed Denitrifying Filters (Methanol)>Cl_2 (HLD). Discharging to Two (2) Parallel Constructed Wetland Cells	N/A	After demonstration, phosphorus removal was moved to after DBFs to leave phosphorus in water to support denitrifiers.
Orange County	Advanced Reclaimed Water Treatment Pilot Study	FL	IPR/DPR Pilot	Mar. 2004- May 2005 & Jul. 2005- Apr. 2006 (21 months)	~10 GPM (est.)	UF+NF (4")+UVAOP+Cl_2	N/A	12 months at South WRF BNR Tertiary Treatment w/sand filtration 9 months at East WRF Advanced Secondary w/cloth filtration Observed varying microconstituent removal with loose NF, rejections varying primarily by molecular weight
City of Sunrise	Advanced Wastewater Treatment and Reuse Pilot Testing Program	FL	IPR Pilot	Apr. 2007- Oct. 2007 (7 months))	10 GPM	Three (3) Parallel Alternatives 1. BNR+MBR+**RO (4")**, (Bench-scale items: disinfection/oxidation (UV/O_3)) 2. BNR+MBR (Bench-scale items: disinfection/oxidation (UV/O_3)) 3. BNR+MBR (Bench-scale items: chemical phosphorus removal (alum and filtration), disinfection/oxidation (UV/O_3))	N/A	Parallel testing of two RO units Much testing limited to bench-scale MWH 2008. "City of Sunrise, Florida, Southwest WWTF AWT and Reuse Pilot Testing Program, Final Report." https://www.sfwmd.gov/sites/default/files/documents/reuse_pilot_swwwtf.pdf
City of Plantation	Advanced Wastewater Treatment Pilot Project	FL	IPR Pilot	Sep. 2007- Mar. 2008 (7 months)	10 GPM	Three (3) Alternatives 1. Primary effluent, MBR, including BNR with methanol & alum, RO (4"), & UV disinfection 2. Secondary nitrified effluent, deep bed denitrifying filter (with methanol), UF (with alum), RO (4"), UV disinfection 3. Secondary nitrified effluent, deep bed denitrifying filter (with methanol), UF (with alum), RO (4"), UV disinfection.	$0.3M (2007)	Alt 1: 2.0 months Alt 2: 2.5 months Alt 3: 0.5 month Hazen 2008. "City of Plantation, Final Report, Advanced Wastewater Treatment Pilot Project." https://www.sfwmd.gov/sites/default/files/documents/reuse_pilot_awt.pdf

Table 1 Notable Potable Reuse Pilot and Demonstration Programs in the United States by Year Started (Continued)

Sponsor	Program Name	State	Type	Operational Period	Capacity (each train)	Treatment Trains Tested	Pilot/Demo Program Cost ($M)	Notes
Miami-Dade County	Coastal Wetlands Rehydration Demonstration Pilot Project	FL	IPR Pilot	Feb. 2009-Jul. 2009 (5 months)	120 GPM (Total)	HLD with deep bed sand filtration to Cl_2, MF, RO (4"), IX, UVAOP	$1.7M (2009)	Deep bed sand filtration included in pilot since upgrades to South District WRF were incomplete IX for nitrogen removal Several vendors tested for each component : MF (5), RO (5), UVAOP (2), IX resin (2).
Town of Davie	Advanced Wastewater Treatment for Aquifer Recharge and Indirect Potable Reuse Pilot Study	FL	IPR Pilot	Jul. 2010-Jan. 2011 (7 months)	15 GPM	UF+RO (4")+UV (UV disinfection at pilot scale, UVAOP at bench-scale only)	N/A	AECOM 2011. "Town of Davie, Advanced Wastewater Treatment for Aquifer Recharge and Indirect Potable Reuse Pilot Study." http://sefluc.org/images/downloads/Meetings_and_Events_Attachments/aecom_davie_final_pilot_report_2011_sept.pdf
City of Pembroke Pines	Aquifer Recharge Pilot Plant	FL	IPR Pilot	Nov. 2010-Jan. 2011 (3 months)	12 GPM	MF+RO (4")+UVAOP+ remineralization (bench-scale)	N/A	N/A
City of San Diego	Pure Water San Diego Advanced Water Purification Facility Demonstration	CA	IPR Demo	Aug. 2011-Jul. 2012 (12 months)	1 MGD	MF/UF+RO (8")+UVAOP	$6.6M[1] (2010)	https://www.sandiego.gov/water/purewater/purewatersd/reports
City of Hollywood	Effluent Recharge Treatment Pilot Study	FL	IPR Pilot	Jan. 2013-Nov. 2013 (11 months)	10 GPM	Deep bed filters, IX (for TOC/NH_4), O_3, BAC, UV (NDMA destruction)	$3.0M (2013)	Other trains were also tested. Hazen 2014. "City of Hollywood, Florida, Effluent Recharge Treatment Pilot Study: Final Report." http://www.hollywoodfl.org/DocumentCenter/View/4065
Western Reserve Land Conservancy (Moreland Hills, OH) Tangent Company	Tangent Watercycle™	OH	Onsite DPR Demo to Installation	2013-2016	250 GPD (EST.)	*Preliminary Purification*: Primary Treatment and Equalization, Secondary Treatment (BNR) (including acetic acid and sodium bicarbonate addition), tertiary filtration *Advanced Purification*: Ultrafiltration, reverse osmosis (4"), granular activated carbon, UV advanced oxidation, magnesium oxide, sodium hydroxide, calcium hypochlorite, granular activated carbon (recirculating loop)	N/A	Commercial Pilot by the Tangent Company who is marketing systems for onsite direct potable reuse 4/2013-7/2014: Initial pilot, water sent to drain field 08/2014-11/2015: Drinking and Cooking Restricted 12/2015-5/2016: Unrestricted use OH. S.B. 179 added "recycled" water as supply for private water systems (04/2014).
City of Clearwater	Groundwater Replenishment	FL	IPR Pilot	Jul. 2013-Jun 2014 (12 months)	20 GPM	Ultrafiltration, reverse osmosis (4"), UV advanced oxidation, membrane degasification, direct lime injection, chemical quenching	$2.7M (2013)	Innovative testing of post-treatment technologies for mitigating impacts in the aquifer Pilot Funded with Matching Funds from SWFWMD
Upper San Gabriel Valley Municipal Water District	-	CA	IPR Pilot	Aug. 2013-Jul. 2014 (12 months)	~10 GPM (est.)	Title 22 effluent, Ozone, biologically active carbon, soil aquifer treatment	$0.3M[2] (2013)	Filter Columns Simulating Soil Aquifer Treatment of Chlorinated or Ozonated Reclaimed Water. Ozonated water more effectively treated for CECs by SAT.

[1] http://dockets.sandiego.gov/sirepub/cache/2/ly5prp0jqxicc2lunqnycwu5/221637082720170632062 41.PDF
[2] http://www.mwdh2o.com/FAF%20PDFs/6_RW_USGVMWD%20Final%20Report.pdf (Page 17)

Table 1 Notable Potable Reuse Pilot and Demonstration Programs in the United States by Year Started (Continued)

Sponsor	Program Name	State	Type	Operational Period	Capacity (each train)	Treatment Trains Tested	Pilot/Demo Program Cost ($M)	Notes
Monterey County (Monterey Peninsula Water Management District & Monterey Regional Water Pollution Control Agency)	Pure Water Monterey	CA	IPR Pilot	Oct. 2013-Jul. 2014 (10 months)	30 GPM	Ozone, microfiltration, reverse osmosis (4”), UV advanced oxidation (bench-testing only)	N/A	Treating secondary effluent Preozonation improved MF run times by a factor of 4 to 8 by reducing membrane fouling, allowing for a higher MF design flux. http://purewatermonterey.org/reports-docs/engineering-report/
Santa Clara Valley Water District	Silicon Valley Advanced Water Purification Center	CA	IPR Demo	Mar. 2014-Ongoing	8 MGD	Microfiltration, reverse osmosis (8”), UV disinfection	$68M (2014)	The purified water produced by the SVAWPC is not currently used for potable (i.e., drinking) purposes, but instead is blended with tertiary-treated recycled water and used for a variety of non-potable purposes such as irrigation, cooling towers, and industrial applications.
City of Tucson	Potable Reuse Pilot	AZ	IPR Pilot	Oct. 2014-Apr. 2015 (6 months)	10 GPM	Soil aquifer treatment, sidestream nanofiltration (2.5”), ozone, biologically activated carbon	N/A	Treating secondary effluent Substitutes soil aquifer treatment for MF/UF Sidestream NF for lower cost salinity removal NF has lower feed pressure, higher recovery, concentrate more usable for irrigation
Padre Dam Municipal Water District	Advanced Water Purification East County	CA	IPR Demo	Apr. 2015-Feb. 2016 (11 months)	0.1 MGD	Part 1 (0.1 MGD, 70 GPM):Free chlorine contact, membrane filtration, RO (4”) Part 2 (10 GPM): UVAOP	$5M[3] (2015)	“Padre Dam Advanced Water Purification Center” “Advanced Water Purification Demonstration Project” Treated secondary effluent. Evaluating high RO recovery, 92%-95% through conventional RO and closed circuit desalination (CCD) RO.
City of El Paso	Advanced Water Purification Facility Pilot Test	TX	DPR Pilot	Jul. 2015-Apr. 2016 (9 months)	100 GPM Denitrifying filters 12 GPM per RO train	Secondary effluent from the Bustamante WRF Phase I: **Denitrifying filters** +MF/UF + NF/RO (4”) + UVAOP + GAC (H_2O_2 quenching)+ Cl_2 Phase II: MF/UF + NF/RO (4”) + UVAOP + GAC (H_2O_2 quenching)+Cl_2 Phase III: **Ozone** + MF/UF + NF/RO (4”) + UVAOP + GAC (H_2O_2 quenching)+Cl_2	$4M (2015)	DPR Direct to Distribution System Planned for Full-Scale Implementation Two parallel membrane filtration units (microfiltration and ultrafiltration) Three parallel RO units with 12 gpm production capacity each
City of San Buenaventura (Ventura)	Ventura Water Pure	CA	DPR Demo	Jul. 2015-Apr. 2016 (9 months)	30 GPM	Tertiary effluent from the Ventura WRF Pasteurization, ultrafiltration, reverse osmosis (4”), UV advanced oxidation	N/A	Pasteurization showed promise to reduce UF biofouling Brief demonstration of an electrode based UV advanced oxidation process (no peroxide) in addition to conventional UV advanced oxidation with peroxide
Clean Water Services	NEWater Brew	OR	DPR Demo	Oct. 2015	1 GPM Batch	Constructed Wetland System Receiving Raw Wastewater Ultrafiltration, reverse osmosis (4”), UV advanced oxidation, granular activated carbon	N/A	Water from the Forest Grove WRF was purified and used for a beer brewing contest with approval from the Oregon Department of Environmental Quality.

[3] http://www.padredam.org/DocumentCenter/View/707

Table 1 Notable Potable Reuse Pilot and Demonstration Programs in the United States by Year Started(Continued)

Sponsor	Program Name	State	Type	Operational Period	Capacity (each train)	Treatment Trains Tested	Pilot/Demo Program Cost ($M)	Notes
Gwinnett County	Direct Potable Reuse Demonstration	GA	DPR Demo	Mar. 2016-Feb. 2017 (12 months)	6 GPM	Effluent from the F. Wayne Hill WRC Ozone, ferric coagulation, biologically active carbon, chlorine disinfection	$1.0M[4] (2016)	Baseline: 100% Lake Lanier Water (2 mos.) DPR Blending: 10%, 50%, 100% FWH effluent (6 mos.) Biofiltration Optimization: Test P and H_2O_2 addn. (2 mos.) Robustness: Performance in lake turnover (2 mos.)
Hillsborough County	Direct Potable Reuse Demonstration	FL	DPR Demo	Jul. 2016	2 GPM Batch	Denitrified tertiary effluent from the Falkenburg Water Reclamation Facility Ultrafiltration, reverse osmosis (4”), UV advanced oxidation	~$0.2M (est.) (2016)	First DPR Pilot in Florida Cleared by FDEP to Produce Water for Human Consumption Multiple Processes Operated in Batch Mode UF 6 GPM, RO 2 GPM, UVAOP 8 GPM. Produced water for the 2016 WateReuse Symposium
Hampton Roads Sanitation District	Sustainable Water Initiative for Tomorrow (SWIFT)	VA	IPR Pilot	Jul. 2016-May 2017 (11 months)	4 GPM Carbon Train 13 GPM Membrane Train	Denitrified secondary effluent from the York River Treatment Plant Carbon Based: Alum + Ozone (Peroxide) + BAC/GAC Membrane Based: MF+RO (4”)+UVAOP	$0.5M[5] (2015)	Carbon train was selected for a follow on demonstration study.
Hampton Roads Sanitation District	Sustainable Water Initiative for Tomorrow (SWIFT)	VA	IPR Demo	2017-2019 (24 months)	1 MGD	Nansemond Treatment Plan Secondary effluent to Alum+ O_3 (peroxide) + BAF+ GAC + UV+ Cl_2 + Stabilization + Test Recharge Well	$27M Capital (2017)	“Sustainable Water Phase 3 – Demonstration Facility” 27,000 SF facility
City of Altamonte Springs	pureALTA	FL	DPR Demo	2016-2017 (12 months)	20 GPM	Ozone/biologically active filtration, chloramination, ultrafiltration, granular activated carbon, UV advanced oxidation	$1.0M[6] (2016)	Fifty percent of pilot costs provided by the St. Johns River Water Management District (SJRWMD) under its Rural Economic Development Initiative (REDI) Community & Innovative Cost-Share Program
Jacksonville Electric Authority (JEA)	Water Purification Treatment (WPT) Evaluation and Pilot Testing	FL	Pilot	(Under construction) 2017-2018 (12 months)	20 GPM each (0.029 MGD)	Microfiltration, reverse osmosis (4”), UV advanced oxidation Ozone/biologically active filtration, UV disinfection	$2M (est.) (2017)	Phase 1 Pilot
	-		Demo	(Proposed)	1 MGD	TBD from pilot results	$8M (est.) (2017)	Phase 2 Demonstration
Arizona (Multiple Entities)	Arizona Pure Water Brew	AZ	DPR Demo	2017	4 GPM	UF+RO (4”)(+UV advanced oxidation, GAC, Free Chlorine	N/A	-
San Francisco Public Utilities Commission (SFPUC)	PureWaterSF Decentralized Purified Water Research Project	CA	Pilot	2017 (8 months)	1 GPM	Microfiltration, reverse osmosis (2.5”), UV hypochlorite advanced oxidation	$0.63M (2017)	“Building-Scale Treatment for Direct Potable Water Reuse & Intelligent Control for Real Time Performance Monitoring” Building Level Potable Reuse

[4] https://www.gwinnettcounty.com/static/upload/bac/52/20150804/ap_2015.08.04.Work.Session.Agenda.Package.pdf
[5] http://www.hrsd.com/pdf/Commission%20Minutes/2015/08-25-15_Final_Commission_Minutes.pdf (Page 155 of 229)
[6] http://files.altamonte.org/PW/AFIRST/Presentation/2015-06-19A-FIRST%20FSA%20Final.pdf (Page 35)

Table 1 Notable Potable Reuse Pilot and Demonstration Programs in the United States by Year Started(Continued)

Sponsor	Program Name	State	Type	Operational Period	Capacity (each train)	Treatment Trains Tested	Pilot/Demo Program Cost ($M)	Notes
City of Daytona Beach	Direct Potable Reuse Demonstration Test System	FL	DPR Demo	Under Construction2018-2020 (24 months)	0.2 MGD (139 GPM)	Ultrafiltration, reverse osmosis (8”), UV advanced oxidation	$3.5M (2017)	Demonstration Facility Under Construction Side by side testing of UF (2) and RO (2). Received $1M funds from the SJRWMD
Texas A&M University AgriLife Extension	Direct Potable Reuse Research & Demonstration System	TX	DPR Demo	(Proposed) 2018 (12 months)	0.34 GPM	Activated carbon, ozonation, chlorination, RO (2.5”), UV disinfection	$N/A (Bidding)	Sourced from raw domestic wastewater or secondary effluent from an existing MBR, with a BOD and TSS<10 mg/L, TN<30 mg/L, and TP<10 mg/L.[7] To be installed at University’s onsite wastewater training center at its RELLIS Campus in Bryan, TX.
Metropolitan Water District of Southern California	Regional Recycled Water Advanced Purification Center Demonstration Facility	CA	IPR Demo	Begins Late 2018 (12 months)	0.5 MGD (397 GPM)	“Regional Recycled Water Advanced Purification Center” Secondary effluent from the JWPCP to Membrane bioreactor, reverse osmosis (8”), UV advanced oxidation, stabilization	$17M[8] (Const.) (2018)	Includes membrane bioreactor. Water quality goals for nitrogen. Partnership between Metropolitan Water District of Southern California and Sanitation Districts of Los Angeles County. Groundwater recharge Proposed Full-Scale Facility would produce up to 150 MGD. Estimated to Cost $2.7B to build, $129 million annually to operate, producing water at a cost of $4.91/kgal[8].

[7] Water Desalination Report. 2017. “University Seeks DPR Demo Plant.” Vol. 53. Num. 31.
[8] http://www.mwdh2o.com/PDF_About_Your_Water/Regional_Recyled_Water_Supply_Program.pdf

Plants Using RO/NF Membrane Treatment

Most potable reuse demonstration plant capacities are greater than or equal to about 0.1 MGD (~70 GPM). The largest potable reuse demonstration facility (8 MGD) is run by the Santa Clara Valley Water District (SCVWD) and is known as the Silicon Valley Advanced Water Purification Center (SVAWPC), which uses the advanced treated water for non-potable purposes. The flow of 0.1 MGD (~70 GPM) is a significant threshold value for demonstration of RO/NF based treatment trains, since 70 GPM is the approximate flow produced by a full-scale (8" diameter element) two-stage RO/NF membrane system. Both Miami-Dade County and City of El Paso had pilot systems with multiple parallel 4" diameter RO/NF skids; however, both systems had large deep bed denitrifying filters at the front of the train, which led to the system capacities being above 0.1 MGD.

Nevertheless, among all 26 of the potable reuse tests conducted using RO/NF membranes, the majority of systems, 19 (73%) used 4" diameter membranes; three (3) (12%) used 2.5" diameter membranes; and four (4) (15%) used 8" diameter membranes. Use of smaller diameter RO/NF membranes is usually preferred to reduce program costs, reduce system footprint, and simplify operations. Since the water quality performance of 4" diameter membranes is well established as comparable to 8" membranes[9], many utilities choose to use 4" membranes and invest the cost savings into enhanced water quality sampling, online instrumentation/monitoring, and other program priorities.

Plants Using Carbon-Based Treatment

"Large" (≥0.1 MGD) demonstration systems are not limited to those with RO/NF membrane treatment. Hampton Roads Sanitation District's (HRSD) SWIFT (Sustainable Water Initiative for Tomorrow) demonstration system (1.0 MGD) is a non-membrane treatment train, with alum coagulation, ozone, biologically active filtration (BAF), granular activated carbon (GAC), UV disinfection, stabilization, and a test recharge well. HRSD selected non-membrane treatment for its demonstration plant, after piloting parallel membrane and carbon-based treatment trains. The City of West Palm Beach's demonstration program (0.14 MGD/100 GPM) (included high-rate ferric coagulation, deep bed denitrifying filters, and chlorination before discharge to two parallel constructed wetland cells. Below 0.1 MGD, the use of the word "demonstration" may be less-linked to full-scale equivalence of equipment, but rather, more representative of a desire to distinguish "direct" potable reuse pilot systems (i.e. City of Altamonte Springs (20 GPM), Gwinnett County DPR (6 GPM), Hillsborough County batch system, and Clean Water Services batch system) from the multitude of indirect potable reuse pilot studies that have been performed. Note, both Altamonte Springs and Gwinnett County are non-RO based test systems based on ozone and biologically active carbon, which can achieve full-scale equivalency at these lower flows.

Plants Using Multiple Equipment Capacities and Multiple Phases

Several potable reuse test systems used a mixture of equipment sizes (typically large units followed by smaller units), instead of a single size for all equipment in the treatment train. Denver Water's Direct Potable Water Reuse demonstration (1990-1991) consisted of a 1 MGD

[9] Mulford, L. A., et al. 1999. "NF performance at full and pilot scale." American Water Works Association. Journal 91.6 (1999): 64. https://www.awwa.org/publications/journal-awwa/abstract/articleid/14063.aspx

lime clarification, recarbonation and filtration train, coupled with a smaller 57 GPM (0.082 MGD) UV, GAC, RO, air stripping, ozone, and chloramination train. Padre Dam Municipal Water District's demonstration facility consisted of a 0.1 MGD (70 GPM) free chlorine, membrane filtration, and RO train followed by a 10 GPM UV advanced oxidation process (UVAOP). Other test schemes included multiple similar parallel treatment units (e.g. Miami-Dade, City of Daytona Beach, City of Hollywood, City of Sunrise, City of Tampa, or phased testing of various treatment trains (City of El Paso, City of Plantation, Gwinnett County).

Pilot/Demonstration Program Costs

Program costs were available for several potable reuse test programs, as detailed in Table 1. Program costs (in 2018 dollars[10]) are plotted against pilot/demonstration capacity in Figure 2. Both cost and capacity ranged over several orders of magnitude, therefore it was necessary to plot the data on a log-log scale for better visibility.

Multiple regression analyses were carried out to identify the significance of plant capacity and test duration on potable reuse test program cost. Simple linear regression yielded a high coefficient of determination (R^2), but was rejected since it tended to overestimate costs for smaller capacity systems. A power model (Figure 2) provided a better estimate of cost over the range of pilot/demonstration capacities. The exponent of the power model (0.678), is consistent with other water treatment models, where the exponent for cost with respect to flow commonly ranges between 0.65-0.75. While actual program costs varied significantly at any given capacity, this model can still provide helpful perspective for preliminary planning of demonstration plant capacities.

Assuming a demonstration facility capacity somewhere in the range of 0.1 to 1.0 MGD, associated demonstration program costs may be expected to range from approximately $2M to $27M dollars. However, at any given capacity, the actual program costs can be expected to vary as much as three-fold[11] depending on program specifics.

[10] Using a value of 10807 for the Engineering News Record Construction Cost Index (ENR CCI) projected via linear regression to June 2018.

[11] Near 0.1 MGD, program costs varied about three-fold ranging from a lower cost system (Miami-Dade, $2.1M) to a higher cost system Padre Dam MWD ($5.7M). The Miami-Dade system had a larger denitrification filter followed by several smaller capacity pilot systems. Near 1.0 MGD, program costs also varied about three-fold ranging from a lower cost system (City of San Diego, $8.1 M) to a higher cost system (Hampton Roads Sanitation District, $27.0M). The HRSD system was designed with a more expensive, permanent building designed for showcasing the project to the public, whereas the San Diego system utilized a lower cost shed covering the demonstration system.

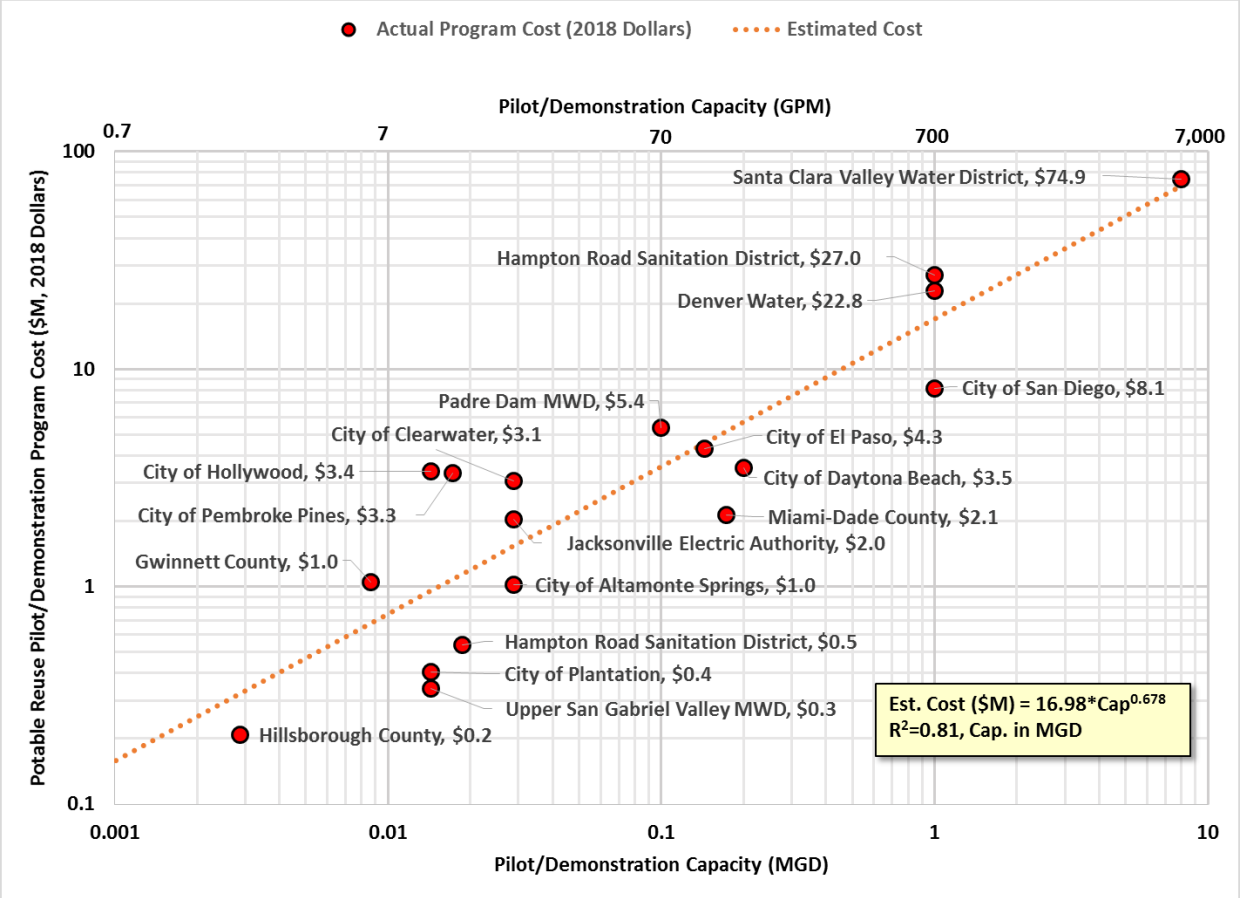

Figure 2. Cost ($M) vs Capacity (MGD) of Several Potable Reuse Pilot/Demonstration Programs

Advanced Water Treatment Demonstration Program

Graphical Summary of Potable Reuse Treatment Trains Tested at Pilot, Demonstration, and Full-Scale

Hillsborough County Florida | TETRA TECH | Hazen | ch2m

Index	Scale	Utility	Facility	State	WW	AWT	AWT	AWT	AWT	AWT	AWT	AWT	AWT	Destination
1	D/P	City of Tampa	Water Resource Recovery Project	FL	Secondary or Tertiary Treatment	Air Stripping	Lime & Recarbonation	Filtration	Granular Activated Carbon	Ozone				
2	D/P	City of Tampa	Water Resource Recovery Project	FL	Secondary or Tertiary Treatment	Air Stripping	Lime & Recarbonation	Filtration		Ozone				
3	D/P	City of Tampa	Water Resource Recovery Project	FL	Secondary or Tertiary Treatment	Air Stripping	Lime & Recarbonation	Filtration	Reverse Osmosis	Ozone				
4	D/P	City of Tampa	Water Resource Recovery Project	FL	Secondary or Tertiary Treatment	Air Stripping	Lime & Recarbonation	Filtration	Ultrafiltration	Ozone				
5	D/P	Denver Water	Potable Reuse Demonstration Project	CO	Secondary Treatment	Lime & Recarbonation	Filtration	UV Disinfection	Granular Activated Carbon	Reverse Osmosis	Air Stripping	Ozone	Chloramination	Distribution System
6	D/P	City of Sunrise	AWT and Reuse Pilot Testing Program	FL	Secondary Treatment	Membrane Bioreactor		UV Disinfection	Ozone					-
7	D/P	City of Sunrise	AWT and Reuse Pilot Testing Program	FL	Secondary Treatment	Membrane Bioreactor	Alum	UV Disinfection	Ozone					-
8	D/P	Jacksonville Electric Authority (JEA)	Water Purification Treatment (WPT) Evaluation and Pilot Testing	FL	Secondary or Tertiary Treatment			Ozone	Biological Activated Carbon	UV Disinfection				
9	D/P	City of Hollywood	Effluent Recharge Treatment Pilot Study	FL	Secondary or Tertiary Treatment	Deep Bed Sand Filtration	Dual Ion Exchange (TOC & NH_4)	Ozone	Biological Activated Carbon	UV Disinfection				Injection Wells
10	D/P	Upper San Gabriel Valley Municipal Water District	Upper San Gabriel Valley Municipal Water District	CA	Secondary or Tertiary Treatment			Ozone	Biological Activated Carbon					Injection Wells for Soil Aquifer Treatment
11	D/P	City of Tucson	Potable Reuse Pilot	AZ	Secondary or Tertiary Treatment	Injection Wells for Soil Aquifer Treatment	Nanofiltration (Sidestream)	Ozone	Biological Activated Carbon					
12	D/P	Gwinnett County	F. Wayne Hill Water Resources Campus	GA	Tertiary Treatment			Ozone	Biological Activated Carbon	Ozone	Conventional Treatment	Biological Activated Carbon	Chlorine	Distribution System
13	D/P	City of Altamonte Springs	pureALTA	FL	Secondary or Tertiary Treatment			Ozone	Biological Activated Carbon	Ultrafiltration	Granular Activated Carbon	UV/H_2O_2		
14	D/P	Hampton Road Sanitation District	Sustainable Water Initiative for Tomorrow (Pilot)	VA	Secondary or Tertiary Treatment	Alum		Ozone	Biological Activated Carbon					
15	D/P	Hampton Road Sanitation District	Sustainable Water Initiative for Tomorrow (Demo)	VA	Secondary or Tertiary Treatment	Alum		Ozone	Biological Activated Carbon	Granular Activated Carbon	UV Disinfection	Chlorine	Stabilization	Injection Well
16	D/P	City of West Palm Beach	AWT Constructed Wetlands Demonstration Project	FL	Secondary or Tertiary Treatment	Conventional Treatment	Deep Bed Denitrifying Filters					Chlorine		Constructed Wetlands
17	D/P	City of Sunrise	AWT and Reuse Pilot Testing Program	FL	Secondary Treatment			Membrane Bioreactor	Reverse Osmosis	UV Disinfection	Ozone			-
18	D/P	City of Plantation	AWT Pilot Project	FL	Primary Effluent		Alum & Methanol	Membrane Bioreactor	Reverse Osmosis	UV Disinfection				Surface Water Augmentation
19	D/P	City of Plantation	AWT Pilot Project	FL	Secondary Nitrified Effluent	Deep Bed Denitrifying Filters	Alum	Ultrafiltration	Reverse Osmosis	UV Disinfection				Surface Water Augmentation
20	D/P	City of Plantation	AWT Pilot Project	FL	Secondary Nitrified Effluent	Deep Bed Denitrifying Filters	Alum	Ultrafiltration	Reverse Osmosis	UV Disinfection				Surface Water Augmentation
21	D/P	Santa Clara Valley Water District	Silicon Valley Advanced Water Purification Center	CA	Secondary or Tertiary Treatment			Microfiltration	Reverse Osmosis	UV Disinfection				
22	D/P	San Francisco Public Utilities Commission (SFPUC)	PureWater SF Decentralized Purified Water Research Project	CA	Secondary or Tertiary Treatment (Varied)			Microfiltration	Reverse Osmosis	UV/HOCl				Building Level Use
23	D/P	Hampton Road Sanitation District	Sustainable Water Initiative for Tomorrow (Pilot)	VA	Secondary or Tertiary Treatment			Microfiltration	Reverse Osmosis	UV/H_2O_2				Injection Wells
24	D/P	City of San Diego	Pure Water San Diego Advanced Water Purification Facility Demonstration	CA	Secondary or Tertiary Treatment			Microfiltration/ Ultrafiltration	Reverse Osmosis	UV/H_2O_2				Surface Water Augmentation
25	D/P	Town of Davie	AWT for Aquifer Recharge	FL	Secondary or Tertiary Treatment			Ultrafiltration	Reverse Osmosis	UV/H_2O_2				Injection Wells
26	D/P	Jacksonville Electric Authority (JEA)	Water Purification Treatment (WPT) Evaluation and Pilot Testing	FL	Secondary or Tertiary Treatment			Microfiltration	Reverse Osmosis	UV/H_2O_2				
27	D/P	City of Pembroke Pines	Aquifer Recharge Pilot Plant	FL	Secondary or Tertiary Treatment			Microfiltration	Reverse Osmosis	UV/H_2O_2		Lime Stabilization		Injection Wells
28	D/P	Orange County	Advanced Reclaimed Water Treatment Pilot Study	FL	Secondary or Tertiary Treatment			Ultrafiltration	Nanofiltration	UV/H_2O_2			Chlorine	-
29	D/P	Hillsborough County	Direct Potable Reuse Demonstration	FL	Tertiary Treatment			Ultrafiltration	Reverse Osmosis	UV/H_2O_2			Chlorine	
30	D/P	Padre Dam Municipal Water District	Advanced Water Purification East County	CA	Secondary or Tertiary Treatment	Chlorine		Microfiltration/ Ultrafiltration	Reverse Osmosis	UV/H_2O_2				
31	D/P	Monterey County (Monterey Peninsula Water Management District & Monterey Regional Water Pollution Control Agency)	Pure Water Monterey	CA	Secondary or Tertiary Treatment		Ozone	Microfiltration	Reverse Osmosis	UV/H_2O_2				-
32	D/P	El Paso Water Utilities	Advanced Water Purification Facilitiy Pilot Test	TX	Secondary or Tertiary Treatment		Ozone	Microfiltration/ Ultrafiltration	Reverse Osmosis	UV/H_2O_2	Granular Activated Carbon		Chlorine	
33	D/P	Clean Water Services	NEWater Brew	OR	Primary Effluent	Constructed Wetlands		Ultrafiltration	Reverse Osmosis	UV/H_2O_2	Granular Activated Carbon			
34	D/P	El Paso Water Utilities	Advanced Water Purification Facilitiy Pilot Test	TX	Secondary or Tertiary Treatment			Microfiltration/ Ultrafiltration	Reverse Osmosis	UV/H_2O_2	Granular Activated Carbon		Chlorine	
35	D/P	Arizona (Multiple Entities)	Arizona Pure Water Brew	AZ	Secondary or Tertiary Treatment (Varied)			Ultrafiltration	Reverse Osmosis	UV/H_2O_2	Granular Activated Carbon		Chlorine	
36	D/P	El Paso Water Utilities	Advanced Water Purification Facilitiy Pilot Test	TX	Secondary or Tertiary Treatment	Deep Bed Denitrifying Filters		Microfiltration/ Ultrafiltration	Nanofiltration/ Reverse Osmosis	UV/H_2O_2	Granular Activated Carbon		Chlorine	
37	D/P	City of San Buenaventura (Ventura)	Ventura Water Pure	CA	Tertiary Treatment	Pasteurization		Ultrafiltration	Reverse Osmosis	UV/H_2O_2				
38	D/P	Miami-Dade County	Coastal Wetlands Rehydration Demonstration Project	FL	Secondary Treatment	Deep Bed Sand Filtration	Chlorine	Microfiltration	Reverse Osmosis	Ion Exchange (NH_4)	UV/H_2O_2			Constructed Wetlands
39	D/P	City of Clearwater	Groundwater Replenishment	FL	Tertiary Treatment	Ultrafiltration	Reverse Osmosis	UV/H_2O_2	Membrane Contactors (DO)	Carbon Dioxide & Lime Stabilization	Sodium Bisulfite	Sodium Bisulfide	Caustic Soda	Injection Wells
40	D/P	City of Daytona Beach	Direct Potable Reuse Demonstration Test System	FL	Tertiary Treatment	Ultrafiltration	Reverse Osmosis	UV/H_2O_2	Ozone/H_2O_2	Lime & Recarbonation	Filtration		Chlorine	Distribution System
41	D/P	Western Reserve Land Conservancy (Moreland Hills, OH) Tangent Company	Tangent Watercyle™	OH	Tertiary Treatment (After Septic Tank)	Ultrafiltration	Reverse Osmosis	Granular Activated Carbon	UV/H_2O_2	Magnesium Oxide	Caustic Soda	Calcium Hypochlorite	Granular Activated Carbon (Loop)	Potable Building Use
42	D/P	Texas A&M University AgriLife Extension	Direct Potable Reuse Research & Demonstration System	TX	Secondary or Tertiary Treatment	Granular Activated Carbon	Ozone	Chlorine	Reverse Osmosis	UV Disinfection				Research