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Carollo/ADC Set Low Energy Record for Seawater Desalination

By Thomas F. Seacord, P.E.
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The high cost of desalination has historically hindered interest in seawater as a possible fresh water supply. As cost has been a limitation to realizing large-scale seawater desalination, engineers, scientists, and manufacturers have worked over the last two decades to improve efficiency (Figure 1).

As a member of the Affordable Desalination Collaboration (ADC), Carollo Engineers has demonstrated that, by using a combination of proven technologies, seawater reverse osmosis (SWRO) can be used to produce water at an affordable cost compared to other supply alternatives. In March 2006, ADC's demonstration-scale SWRO plant completed over 6 months of testing at the U.S. Navy's Seawater Desalination Test Facility in Port Hueneme, CA. Three membranes were tested at varying flux and recovery rates to estimate the most affordable operating point, which was estimated by calculating the net present value for each tested condition, accounting for both capital and operating costs. The results of this study have drawn attention from all over the world and demonstrate that Carollo is on the cutting edge of practical, reliable, and affordable desalination.

Key Findings

Three membranes were tested at three different flux rates and three different recoveries. Carollo evaluated each of these conditions using a cost model that

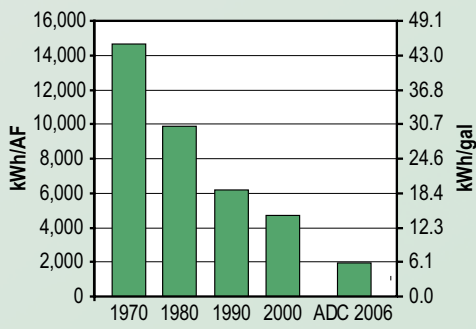


Figure 1. History of power consumption required for seawater desalination.

Process Design with Emphasis on Energy

The ADC's demonstration-scale SWRO plant was designed to produce between 48,100 and 75,600 gallons per day of permeate using a combination of state-of-the-art, off-the-shelf technologies that minimize power consumption. The process uses an open intake, media filters, and a cartridge filter for pretreatment. Key elements that differentiate the ADC's demonstration plant and minimize energy consumption include:

- A high-efficiency positive displacement pump.
- A high-efficiency isobaric energy recovery device.
- Energy-efficient SWRO membranes.

incorporated the pilot tests' power data and scaled up operating and capital costs for a 50-mgd treatment plant scenario. For the purposes of this cost analysis, it was assumed that the SWRO plant would be co-located with a power plant. Therefore, costs do not include a new intake or outfall, but do include the costs associated with connecting to the power plant's existing infrastructure.

Findings included the following:

- The ADC's SWRO process design demonstrated a 38 to 40% reduction over the industry experts' perception of power required for SWRO process designs. Specific power consumption

ranged from 6.81 to 8.90 kWh/kgal at the most affordable operating point (9 gfd, 50% recovery).

- 5.98 kWh/kgal, a record low energy consumption for SWRO, was demonstrated at a flux of 6 gfd and 42.5% recovery using a low-energy SWRO membrane; however, the lower flux and recovery raised capital costs, which made this option less affordable.
- While reduced membrane life and higher cleaning frequencies were assumed in Carollo's cost model, contrary to industry expectations, high recovery and high flux resulted in the most affordable operating condition (Figure 2). This demonstrates that bond payment can play a significant factor in annual costs and affordability.

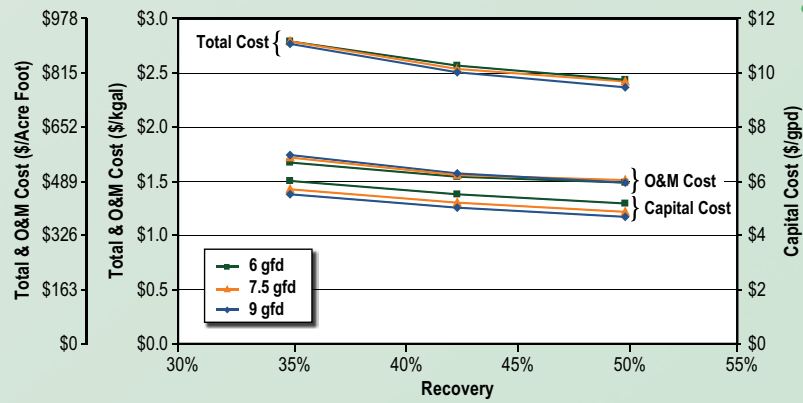


Figure 2. Carollo's cost model demonstrates that operating costs must be weighed with capital cost to identify the most affordable condition.

Based upon Carollo's cost model, the cost for seawater desalination is competitive with other new water supply options, with costs ranging from \$2.37 to \$2.80/kgal (\$772 to \$913/AF).

Validation Testing of an Electrodeless Microwave UV System Adds a New Option for Water Disinfection

The Ultraviolet Disinfection Guidelines for Drinking Water and Water Reuse (NWRI/AwwaRF 2003) were published “to provide a common basis for the evaluation and implementation of UV disinfection technologies.” In California, the Department of Health Services (CaDHS) requires that all UV disinfection systems installed for unrestricted reuse applications must undergo validation testing as per these guidelines prior to installation.

Key members of Carollo’s wastewater research group have been instrumental in conducting such independent third-party validation tests on the majority of the UV disinfection units that are currently used in water reuse applications, including systems for Trojan Technologies, Wedeco UV

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Technologies, Calgon Carbon, and Aquionics. Carollo has also recently finished validation testing a new type of UV disinfection device — the electrodeless microwave UV system (manufactured by Quay Technologies Ltd.). A picture of the validated system is shown in Figure 1. The validation report will be submitted to CaDHS to garner conditional acceptance of electrodeless UV as a technology that can be used in the production of recycled water for unrestricted reuse.

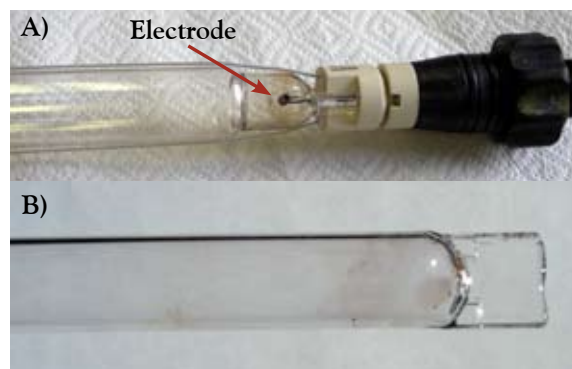


Figure 2. View of A) traditional low-pressure high-output lamp with an electrode and B) an electrodeless low-pressure high-output lamp used in a microwave UV system.

into the quartz lamp sleeves containing the gas filling (see Figure 1). It is the microwave energy that excites the gas filling of the lamps and not a direct electron flow via electrodes that results in the UV discharge. Although the mode of excitation is different, the spectral output of the electrodeless UV lamps is similar to that of a low-pressure or low-pressure high-output electroded lamp. Since electrode malfunction is the major mechanism of lamp failure in UV systems, eliminating the electrodes from the UV lamp eliminates the primary lamp deterioration process and can result in a lamp life approximately 3 times that of electroded lamps.

References

Cekic, M.; Ruckman, M. (2004) Physics of Electrodeless UV Lamps and Applications of UV Radiation. *The Physics of Ionized Gases: 22nd Summer School and International Symposium*, CP740.

Treatment Technology Report For Recycled Water (2005) State of California Division of Drinking Water and Environmental Management.

Ultraviolet Disinfection Guidelines for Drinking Water and Water Reuse (2003) 2nd Edition, National Water Research Institute and the American Water Works Association Research Foundation.

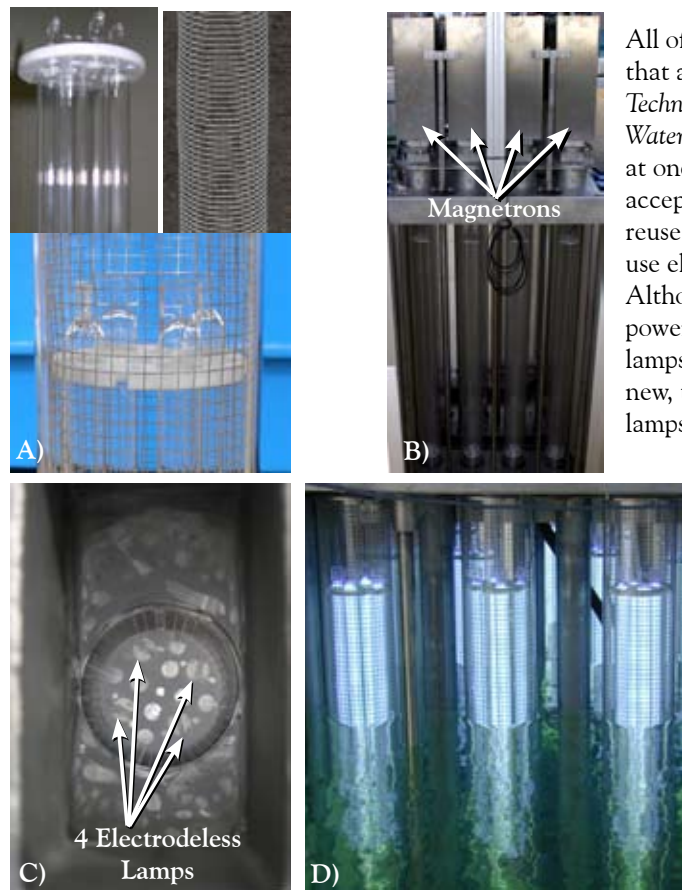


Figure 1. A) Quartz sleeve of the microwave UV system with the wave guide and 4-lamp bundle inside, B) rack in channel with magnetrons, C) top view of lamps in each quartz sleeve, and D) partially submerged microwave UV electrodeless lamps (low water level for display purposes only).

All of the UV disinfection systems that are listed in the *Treatment Technology Report for Recycled Water* (2005) that have now, or at one time received, conditional acceptance for unrestricted water reuse applications in California use electroded mercury UV lamps. Although the use of microwave-powered electrodeless mercury UV lamps in water reuse applications is new, the technology is not. These lamps were conceptualized over 40 years ago for industrial processing applications (Cekic 2004). Figure 2 presents examples of these two types of lamps.

Microwave-powered electrodeless UV lamps differ from the electroded lamps in that there is “no direct electron flow from the external driving circuitry through the discharge plasma” (Cekic 2004). Instead of using electrodes, microwave energy is generated by magnetrons and directed through wave guides

High-Recovery Membrane System Design to Meet LT2ESWTR Requirements

Obtaining Regulatory Approval for New High-Recovery Design and Operational Strategy through Pilot Testing

By Patrick Carlson (pcarlson@carollo.com), Vincent Roquebert, P.E., and Dan Hugaboom, P.E.

The Eastern Municipal Water District (EMWD) recently completed construction of their new 10-mgd (expandable to 40 mgd) Hemet (CA) Water Filtration Plant (HWFP). The core of the facility's filtration and disinfection process is a ZeeWeed 500d ultrafiltration membrane system utilizing a new innovative design developed by Carollo Engineers and Zenon Environmental. The design allows the facility to operate at 98% recovery while providing 4.0-log removal of *Cryptosporidium* to exceed requirements of the new Long Term 2 Enhanced Surface Water Treatment Rule (LT2ESWTR).

Implementation of this high-recovery design will save up to 117 million gallons of water per year.

Problem

The new HWFP relies on an existing sewer with a 150-gpm capacity for residuals discharge. This, coupled with the desire to efficiently use the water source, required the plant be designed to operate at 98% recovery. EMWD's design goals also included obtaining 4.0-log removal credit of *Cryptosporidium*, verifiable by a membrane integrity test (MIT), to conform to the then draft LT2ESWTR regulations.

As shown in Figure 1, increasing the recovery of the membrane system from 95 to 98% increases the maximum theoretical Volumetric Concentration Factor (VCF) from 20 to 50. VCF is the ratio of the concentration of particles on the feed side of the membrane to particles in the raw water. An elevated VCF is

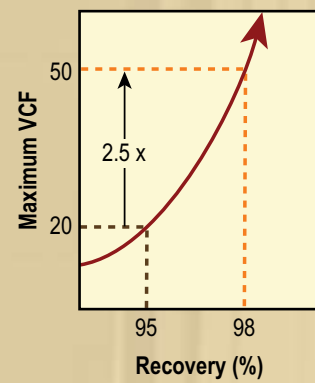


Figure 1. Small increases in recovery can sharply increase the maximum VCF in the membrane tank.

undesirable as it can reduce the calculated MIT sensitivity and consequently reduce the log removal credit awarded to the system.

Solution

To minimize the membrane feed water VCF while maintaining 98% recovery, a modified tank design and operational strategy were developed collaboratively by Carollo and Zenon based upon guidelines from the 2003 draft USEPA Membrane Filtration Guidance Manual (MFGM).

After evaluating several tank designs and operating scenarios, a two-zone membrane tank design with a periodic drain of Zone 2 was selected over a common single-zone tank design with a continuous concentrate bleed. The benefit to the two-zone design

relates to the VCF levels for the fourth membrane cassette, as shown in Figure 2.

In a standard single-zone tank, particles backpulsed from an upstream cassette feed into each successive downstream cassette and ultimately discharge through a continuous bleed at the end of the tank. When operating at 98% recovery, the maximum VCF of the fourth cassette is 50.

The new two-zone tank design developed for the HWFP has two significant modifications for reducing VCF. First, the tank is split with a wall that divides the fourth cassette into an independent zone. Second, rather than using a continuous bleed, Zone 2 is drained periodically to maintain a 98% overall system recovery.

The first three cassettes in the two-zone tank design operate at the same VCF values as the single-zone design. However, the fourth cassette operates at a variable maximum VCF ranging from 7 (the value from the third cassette) to 50 (based on recovery). The value of the VCF depends upon the time elapsed since the previous tank drain, reaching its maximum value (50) immediately prior to a Zone 2 tank drain. By accounting for this variability, the average maximum VCF is reduced to ~28,

which increases the overall MIT *Cryptosporidium* sensitivity to >4.0-log.

Regulatory Approval

Although the two-zone tank design approach was acceptable according to the draft MFGM, the design had not been used by Zenon, and had not been approved by the California Department of Health Services (CaDHS), the agency regulating the new plant. Therefore, it was necessary to work with the CaDHS throughout the design process to obtain regulatory approval for construction. To support the approval process, a pilot study was also conducted.

Pilot Testing

Carollo and Zenon performed the 6-month pilot study to demonstrate stable operation of the membranes (defined as >30 day cleaning intervals) for both Zones 1 and 2 operating conditions. Pilot data were also used to validate the theoretical calculations for the maximum membrane tank VCF for the Zone 2 operating conditions.

Figure 3 presents the results of VCF sampling of the membrane tank during

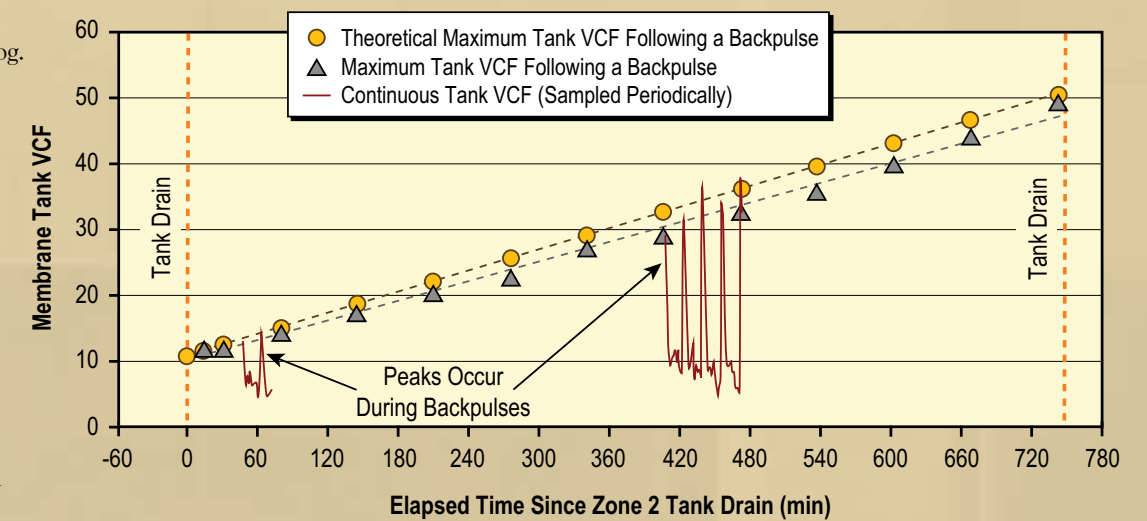


Figure 3. Results of VCF sampling of the pilot's membrane tank during simulated Zone 2 conditions show theoretical and maximum tank VCF values agree well.

simulated Zone 2 conditions. As shown, the theoretical and measured maximum VCF values matched closely. Once the system reached 98% recovery and a tank drain was performed, the difference between the theoretical and measured VCF was only 1.3 (2.6%), with the theoretical value slightly over-predicting the VCF.

The pilot testing also showed that the VCF decreased significantly between each regular backpulse (as shown by the solid red line

in Figure 3). This observation supports the theory presented within the MFGM that particles are trapped on the membrane surface between backpulses, resulting in a reduced membrane tank VCF, further increasing the calculated sensitivity of the MIT.

Based upon the pilot results, full-scale VCF sampling is scheduled as part of the plant start-up protocol. Pending the full-scale results, time- and position-weighted VCF averaging will be used in accordance with the MFGM to determine the full-scale average membrane tank VCF over a given tank drain interval.

Significance

By using the new regulatory guidelines presented in the MFGM, Carollo and Zenon developed an innovative design solution for EMWD that allows the system to operate at 98% recovery (not including a future waste water recovery system) while maintaining 4.0-log *Cryptosporidium* removal credit. Pending VCF sampling of the full-scale membrane system, the CaDHS is expected to grant the plant 4.0-log *Cryptosporidium* removal credit in accordance with the LT2ESWTR.

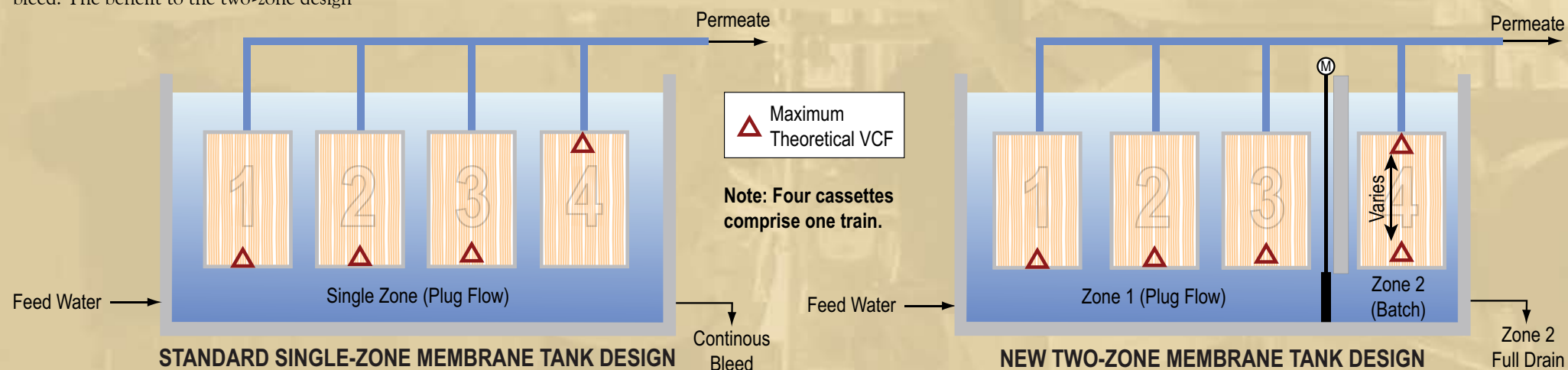


Figure 2. The new two-zone membrane tank design dramatically decreases the VCF conditions for the fourth cassette, exceeding LT2ESWTR requirements at 98% recovery.

Carollo Investigates Membrane Performance through U.S. BOR's Desalination and Water Purification R&D Program

Many of the available raw water sources in arid areas require desalting for potable use, and reverse osmosis (RO) is rapidly emerging as the preferred desalination process. However, two significant challenges often stymie its use in these regions: significant water loss from the process as "concentrate," and the need to safely dispose of this high-salinity wastewater.

Carollo was awarded funding through the U.S. Bureau of Reclamation's (BOR's) Desalination and Water Purification Research and Development Program (DWRP) to investigate the performance of RO membranes and anti-scalants for desalting two water sources in the City of Phoenix's service area. This \$500,000 project was co-funded by BOR and the City of Phoenix Water Services Department.

Clearly, the ability to operate successfully at high water recovery levels (typically 80-85% or higher) results in the production of more potable water and, more significantly, less concentrate. The volume of concentrate produced by RO treatment is determined by the water recovery rate at which the process operates (percent of feed water recovered as potable product water). The recovery, in turn, is determined by the chemistry of the source water. Dendrimer anti-scalants can be applied at higher concentrations than their counterparts and, therefore,

theoretically can be used to achieve higher water recovery levels. This project evaluated the use of a dendrimer-based anti-scalant to desalt surface water from the Salt River Project's canals, and groundwater from a well on the pilot plant site to elevate the maximum stable water recovery level at which RO could operate on two brackish water sources.

Surface Water Results

Typical raw water characteristics for the canal water included:

- TDS - 750 mg/L.
- Turbidity - 3 to 10 NTU.
- Silica - 16 mg/L.

Water quality modeling undertaken by the anti-scalant manufacturer indicated that a recovery of 92% might be achievable with this water. Appropriate anti-scalant dosages were thus established.

Pilot-scale ultrafiltration (UF) was installed to provide pretreatment of the RO feed water. Even with significant variation in the raw water turbidity, the polyethersulfone UF

membrane (Polymem™) was able to achieve consistently low feed water turbidity (median of 0.08 NTU) to the RO unit. Silt Density Index (SDI) measurements were always below 2.

In order to achieve a high-recovery rate, a three-stage RO pilot plant was used. Under the pretreatment conditions mentioned above, a short period of stable operation at 85% recovery was established before recovery was

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The ability of dendrimer anti-scalants to improve membrane performance was investigated for both groundwater and surface water.

increased to 90%. The recovery was held at 90% for three consecutive runs, with chemical cleaning after each run. Unfortunately, operation at 90% recovery showed gradually decreasing Normalized Permeate Flow, increasing Net Driving

Pressure in the second and third membrane stages, and a slow decline in Normalized Salt Rejection, especially in the third stage, indicating long-term irreversible scaling.

Conventional chemical cleaning using both high- and low-pH commercial products could not fully restore membrane performance, although the short duration of the cleaning process may have

impacted cleaning efficiency. The final test run did achieve 92% recovery, but heavy rains during this period had diluted the raw water source and invalidated the test.

Groundwater Results

Typical raw water characteristics of the groundwater included:

- TDS - 1,520 mg/L.
- Turbidity - 0.1 NTU.
- Silica - 25 mg/L.

The groundwater was anticipated to be more difficult to treat as the TDS concentration was almost twice that of the surface water and the silica concentration was over 50% higher. However, the groundwater did have low turbidity, so UF pretreatment was not needed.

Water quality modeling by the anti-scalant manufacturer indicated that a recovery of 92-94% might be attainable with this water. Once again, an appropriate anti-scalant dosing regimen was established.

Extensive membrane cleaning at the end of surface water testing did recover the membrane performance sufficiently to allow them to be used to test the groundwater with the exception of one new



Both Salt River Project canal water and a groundwater were tested at the pilot study site.

element installed in the first stage and a modification made to the second and third stages to improve hydraulics.

Testing began at 80% recovery and was increased to 85% after ~10 days of stable operation. Stable operation continued at 85% recovery for about 3 weeks. Recovery was then increased to 90%. For the first 35-day run, the membrane performance was relatively stable, apart from a slight decline in permeate flow from the third stage during the last week of operation. During the second and third runs, the membrane performance declined, particularly in the second and third stages, which also showed decreases in salt rejection.

Membrane Autopsy

During autopsy analysis, scale was detected on the surface of a membrane element taken from the third stage of the RO plant that membrane cleaning was not able to remove. This confirmed that the declining membrane performance observed during the groundwater testing was due to scaling. Analysis of the scale showed the presence of high concentrations of silica, calcium, iron, and aluminum. It is hypothesized that the silica scale was from the groundwater, and was exacerbated by the presence of a higher iron concentration than in the surface water. At 90% recovery, the silica concentration would be about twice its precipitation threshold. While the dendrimer anti-scalant was there to prevent such precipitation, the presence of iron and aluminum (which contribute to silica polymerization into colloids that can foul membranes) could have limited its effectiveness. This project indicates the value of pilot testing to establish the actual membrane performance as compared to model predictions.

Project Status

All testing has been concluded. A draft project report is currently in review.

Carollo Team Wins AwwaRF Project 3121: Methods to Assess GWUDI and Bank Filtration Performance

The Surface Water Treatment Rule (SWTR) designation of "groundwater under

the direct influence of surface water" (GWUDI) requires that the groundwater source be treated as a surface water. The GWUDI assessment follows State-specific guidelines — typically a three-step decision-making approach consisting of: 1) A general assessment of well placement, condition and water quality; 2) An assessment of the hydrogeological setting; and 3) A Microscopic Particulate Analysis (MPA) resulting in a risk ranking.

The primary tool to determine GWUDI status is the MPA protocol, which has been used for the last decade to identify which groundwater supplies needed further protection against pathogen intrusion. In recent years, however, several limitations to this method have become apparent.

The GWUDI designation is directed at reducing the risk of microbial contamination for groundwater supplies subject to potential contamination from surface water. In recent years, the GWUDI/MPA protocol has been criticized for being largely empirical, and not based on the evolving science of particle filtration and pathogen transport. For example, the MPA method, as currently defined, focuses primarily on larger particles that are more likely to be removed from the infiltrating surface water by physical filtration. It is less likely to identify risks posed by smaller particles. The goal of AwwaRF Project 3121 is to develop a revised GWUDI protocol that overcomes current method limitations, focusing on the following core needs:

- Expanding the MPA surrogate suite to include smaller-sized indicators.
- Re-evaluation of suitable MPA indicator surrogates and detection methods.
- Integration of *Cryptosporidium* and viruses into the MPA protocol.
- Re-evaluation of suitable conservative tracers for GWUDI assessment.
- Development of a scientific basis for MPA as a risk assessment tool.

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Riverbank filtration (RBF) systems provide a unique opportunity to assess GWUDI

status, as these systems are specifically designed to induce flow from nearby surface waters. The Carollo Research Team working on this project includes Dr. Tanja Rauch-Williams of Carollo, Dr. Morteza Abbaszadegan of Arizona State University, Dr. William Johnson of the University of Utah, participating utilities, national and international experts, and state and national U.S. regulators. The team's winning approach to improve the current GWUDI protocol involves:

- Testing a revised suite of MPA target indicators for integration of *Cryptosporidium*.
- Integrating suitable SW derived indicators for virus transport.
- Expanding analytical methods beyond microscopy for indicators in the critical smaller size range, including molecular biological detection.
- Establishing a QA/QC Plan as part of the GWUDI/MPA protocol.

The MPA method, as currently defined, focuses primarily on larger particles that are more likely to be removed from the infiltrating surface water by physical filtration. It is less likely to identify risks posed by smaller particles.

The project team will work with several utilities in the U.S. currently practicing bank filtration to test the revised GWUDI protocol, once developed. The 2-year project starts in August 2006 with a total budget of \$530,000.

The optimized GWUDI protocol will not only benefit utilities operating existing RBF systems, but also future RBF sites by providing assurance on the real risk associated with site-specific well settings and the subsequent level of treatment required to protect public health.



A dendrimer anti-scalant was added to the feedwater of the pilot-scale RO membranes to evaluate the improvement in system recovery.

Carollo Adds New Research Group Members



Tanja Rauch-Williams, Ph.D.

Dr. Tanja Rauch-Williams received a M.S. in Environmental Engineering from the Technical University of Berlin and a Ph.D. in

Environmental Science and Engineering from the Colorado School of Mines. Her doctoral research focused on the biological removal of effluent-derived organic carbon and organic trace pollutants in engineered soil systems, such as soil-aquifer treatment, direct injection, and bank filtration.

Tanja has authored and co-authored over 20 conference proceedings and peer-reviewed papers in the field of natural treatment systems, organic carbon removal and the environmental fate of emerging organic trace pollutants. Since joining Carollo's Denver office, Tanja has had the opportunity to support various clients in the optimization of secondary treatment process performance. She is currently leading Carollo's research efforts in an AwwaRF-funded bank filtration project aimed at revising the present protocol for GWUDI (Groundwater Under the Direct Influence of Surface Water) determinations (see page 7).



Mark Heath

Mr. Mark Heath received his B.S. in Industrial Engineering and M.S. in Environmental Engineering from the University of Illinois at Urbana-Champaign.

He has 17 years of experience as an environmental engineer and has authored or co-authored over 25 peer-reviewed and conference papers.

Prior to joining Carollo, Mark was an independent consultant specializing in research into *Giardia*, *Cryptosporidium*, and MS2 inactivation in drinking water and was involved with the early research into UV inactivation of *Giardia* and *Cryptosporidium*. He has performed numerous bench-, pilot- and full-scale disinfection studies on water and wastewater, using ozone, chlorine, chloramines, chlorine dioxide, and UV.

Since joining Carollo's Portland office in March, Mark has begun developing a UV optics bench for evaluating UV sensors and is currently testing a new small-scale UV reactor system for evaluating lamp aging and fouling of quartz sleeves. He leads all UV reactor validations at Carollo's Portland UV Validation Facility.

Carollo Wins Phase II of AwwaRF Project 3030

Carollo has recently awarded Phase II of AwwaRF Project 3030, *Desalination*

Product Water Recovery and Concentrate Volume Minimization. The overall objective of this project is to advance desalination for the treatment of impaired waters through maximization of the recovery and minimization of concentrate volume.

Phase I of the project is essentially complete, and focused on the technical assessment of several promising and emerging technologies for recovery enhancement. Additionally, the

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conceptual development of an innovative configuration for recovery enhancement was performed and completed by the Principal Investigator at Carollo, Dr. Sandeep

Sethi, and Co-Investigators at the Colorado School of Mines, Dr. Jörg Drewes and Dr. Pei Xu.

Phase II, recently approved by AwwaRF, will focus on the evaluation of the innovative configuration through bench-testing and detailed analysis. In addition, the proposed configuration will be compared with up to three other emerging and innovative desalination configurations being tested in the municipal water industry.

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- Walnut Creek, California
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- Denver (Lakewood), Colorado
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- Miami, Florida
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