Reuse and Desalination Technologies to Improve the Sustainability of Drinking Water Supplies

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1. Introduction

Sustainability, in its most fundamental definition, is the ability to meet current and future needs without causing unacceptable consequences. Sustainability has become a framework for water supply strategic planning in a manner similar to the watershed concept in the late 1980s and early 1990s. Like the watershed approach, sustainability is a very broad-based construct that provides a holistic context to water supply planning. From a water utility perspective, the key focus of sustainability is to ensure the long-term availability of safe and affordable drinking water for consumers, with recognition that other water uses (e.g., agricultural, recreational) and other priorities (e.g., ecology and environment, general economic prosperity and welfare) must also be sustained. Water supply management strategies such as conservation and demand management have a role in the sustainability of drinking water supplies, but new technologies for water reuse and desalination are becoming increasingly important.

Water reuse and desalination research coordinated and funded by the Awwa Research Foundation (AwwaRF) has developed both practical management strategies and proven technological advances that can aid utilities in making the most of their source water resources. Water quality, energy consumption, and waste management drive AwwaRF's reuse and desalination research. This paper describes AwwaRF's research program involving water reuse and desalination to improve the sustainability of drinking water supplies.

2. Water Reuse, Recycling and Reclamation

2.1 Brief Overview

Water reuse refers to the use of treated municipal wastewater as a source of supply for nonpotable uses (nonpotable reuse) or as a supplement to a drinking water supply through blending with raw water sources (indirect potable reuse). Nonpotable and indirect potable reuse applications can supplement a water utility's source water resources by using advanced processes to treat municipal and industrial wastewater, stormwater, and agricultural drainage to create high-quality water for a variety of uses. Water reuse is also referred to as water recycling and water reclamation.

Nonpotable reuse applications may include landscape and agricultural irrigation, industrial use, vehicle washing, toilet flushing, and air conditioning. Reclaimed water produced for nonpotable uses is not intended for drinking or other household uses. Indirect potable reuse applications may involve purposely discharging reclaimed water into either groundwater or surface water

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that ultimately supplies a public drinking water system. The quality of recycled water, and the ability to meet required water quality objectives via natural and advanced treatment technologies drives research in this area. AwwaRF has funded several projects in partnership with other organizations to advance the science of water reuse strategies and technologies.

2.2 Sustainable Underground Storage and Soil Aquifer Treatment

Treatment scenarios need not be technologically complex for reclaimed water quality requirements. One of the key emerging approaches to help ensure sustainability is underground storage – water deliberately recharged into an aquifer and later extracted for use. While relatively simple in concept, the actual practice presents a number of challenges, both technical and institutional. The term sustainable underground storage (SUS) refers to underground storage projects in which these technical and institutional challenges are overcome, resulting in the long-term viability and success of the projects. AwwaRF has partnered with domestic and international organizations to advance the science of SUS, including many projects on aquifer storage and recovery and a large, comprehensive phased study on soil aquifer treatment.

Soil aquifer treatment (SAT) is a treatment and storage system that allows for augmentation of potable water supplies with recycled water (indirect potable reuse). It includes three components; 1) infiltration through a biologically active interface less than three feet in depth, 2) percolation through a vadose zone, 10 to 100 feet deep, and 3) storage and/or transport in an underlying aquifer (0.5 to 10 years duration), prior to withdrawal via wells. AwwaRF has completed a phased research plan investigating SAT.

- *Soil Treatability Pilot Studies to Design and Model Soil Aquifer Treatment Systems* (1998) studies the treatment of wastewater effluent as it percolates through soil and evaluated means to maximize the treatment efficiency and capacity of SAT systems. The study included a systematic evaluation of the effects of soil type and effluent pretreatment on the efficacy of SAT.
- *Soil Aquifer Treatment for Sustainable Water Reuse* (Phase 1 published in 2001, Phase 2 published in 2006) evaluated the sustainability of SAT and elucidated SAT processes to improve the design of these systems. For indirect, potable reuse, the two SAT options are:
    - SAT with reclaimed water without membrane pretreatment, or
    - Groundwater recharge with reclaimed water treated by reverse osmosis (RO).

  The study found that effluent pretreatment did not affect final soil-aquifer treatment (SAT) product water with respect to organic carbon concentrations. Additionally, removal of organics occurs under saturated anoxic conditions, and a vadose zone is not necessary for an SAT system. If nitrogen removal is desired during SAT, nitrogen must be applied in a reduced form, and a vadose zone combined with soils that can exchange ammonium ions is required. It was also noted that the distribution of disinfection by-products produced during chlorination of SAT product water is affected by elevated bromide concentrations in reclaimed water.

2.3 Advanced Treatment Technologies

Advanced treatment technologies (e.g., membranes) can be used to produce water of necessary quality for nonpotable and indirect potable reuse. Two primary challenges for implementing and operating advanced treatment technologies, particularly membranes, regardless of application are 1) energy consumption and 2) concentrate (or waste) management. AwwaRF is carefully studying these issues for water reuse applications as described below, but also for desalination applications as described later in the summary.

The feasibility of nanofiltration (NF) and ultra-low-pressure reverse osmosis (ULPRO) membranes for rejecting total organic carbon, total nitrogen, and unregulated trace organic compounds under a range of experimental conditions at the laboratory-, pilot-, and full-scale to produce water suitable to augment drinking water supplies are currently being evaluated in the on-going study “Comparison of Nanofiltration and Reverse Osmosis in Terms of Water Quality and Performance for Treating Recycled Water” (Project #3012). This report should provide utilities with guidance on selecting membranes and predicting solute rejection during NF-ULPRO membrane treatment.

“Membrane Concentrate Treatment Strategies for Inland Water Reclamation Systems” (Project 3096) is developing methods to manage waste (or concentrate) streams from water reclamation systems (including agricultural drainage) so that the water may be recovered for potable or industrial purposes while the salts are converted into solid by-products. The research also aims to determine the optimum combination of membrane, thermal and solid-liquid separation processes for different concentrate solutions, and develop a computer model for optimizing unit processes for different water qualities.

2.4 Additional Information on Reuse Research

Industrial users are amongst a water utility’s largest consumers of high quality distributed water. *Water Quality Requirements for Reclaimed Water* (2004) identified industries that can use reclaimed water (excluding irrigation and groundwater recharge) and determined the water quality requirements for certain industrial uses. One key finding among industrial users is that *consistent* water quality is more important than actual water quality. General concerns about water quality that crossed industry lines include bacterial and residual organic issues, presence of ammonia, presence of nutrients, suspended solids, scale formation, staining, and sulfate corrosion.

Following is a select list of additional on-going research projects and published reports on water reuse, recycling, and reclamation by AwwaRF:

- “Design, Operation, and Maintenance Considerations for Sustainable Underground Storage Facilities” (Project 3034)
- “Water Quality Changes Associated With Aquifer Storage and Recovery” (Project 2974)

- *Framework for Developing Water Reuse Criteria With Reference to Drinking Water Supplies* (2005)
- *Characterizing Microbial Water Quality in Reclaimed Water Distribution Systems* (2005)

3. Desalination

3.1 Brief Overview

Desalting technology (reverse osmosis, nanofiltration, electrodialysis/electrodialysis reversal) is used in water treatment to provide new sources of potable water via the treatment of lower quality water resources. Over 230 desalination plants providing greater than 25,000 gpd of produced water were identified in a study by Mickley (2006) for the United States Bureau of Reclamation (Bureau). This represents a nearly 100% increase in implemented desalinating plants since Mickley performed the first study for the Bureau in 1992. Still challenging to all desalination plants are high energy costs and the lack of environmentally-sensitive and cost-effective concentrate treatment and disposal options. Inland facilities without access to large surface water bodies for concentrate discharge are especially burdened by lack of disposal options. Before desalination can be seen as a sustainable solution for drinking water supplies, these economic and environmental issues must be solved. Current AwwaRF desalination research focuses on the development of technologies to decrease energy consumption and provide for sustainable concentrate management options. More than a dozen studies are currently underway.

3.2 Advanced Treatment Technologies

In coordination with the Long Beach Water Department (California), the research resulting in the report *A Novel Approach to Seawater Desalination Using Dual-Staged Nanofiltration Process* (2006) proved that a dual-staged nanofiltration (known as NF^2) can desalt seawater to potable water levels with less energy than is theoretically needed for traditional single-pass seawater reverse osmosis. Additionally, the boron concentration in the permeate is below state regulations at certain pH levels. The permeate may however contain bromide ions that exert additional chlorine demand during contact-time requirements, and the brominated residuals thus formed will produce brominated DBPs and deplete disinfectant residual when desalinated water is blended with surface water. Thus, controlling the effects of bromination is essential for system implementation.

"Water Quality Implications of Large-Scale Application of Seawater Desalination" (Project 2841) aims to develop water quality and design information for desalination systems. The research is testing and monitoring membrane performance, analyzing finished water quality, and assessing operating costs as well as examining the impact of desalination on blended water quality and the disposal options for concentrate streams.

Projects 3030 "Desalination Product Water Recovery and Concentrate Volume Minimization" is developing a new membrane-based process to improve the recovery of high quality product water while reducing the concentrate volume. This is a phased study and the researchers have proven a concept at the bench-scale which is now being testing at the pilot level.

Enhanced Reverse Osmosis Systems: Intermediate Treatment to Improve Recovery #4061 will design and develop two inter-stage treatment systems to increase recovery in reverse osmosis plants and thus reduce disposal costs, in particular for inland facilities. The research will also compare recovery using advanced oxidation of anti-scaling compounds with that of electrodialysis.

3.3 Concentrate Treatment and Disposal

AwwaRF is giving concentrate management considerable emphasis in its research program. Currently in the United States there are four primary concentrate disposal options, 1) wastewater (or sewer) discharge, 2) surface water discharge, 3) subsurface injection, and 4) land application. Nearly 72% of desalting plants in the U.S. discharge to surface waters (Mickley, 2006). In the inland and arid regions of the U.S. where available new water supply is minimal and where desalting may provide a sustainable solution, surface water disposal is not available. AwwaRF has partnered with several organizations in the U.S. to fund numerous projects to advance the science of this challenging area, including:

- *Beneficial and Non-Traditional Uses of Concentrate* (2006)
- “Zero Liquid Discharge and Concentrate Volume Minimization for Inland Desalination” (Project 3010) – a technology based project where a new process has been developed and tested at the bench- and pilot-scales.
- “Regional Solutions for Concentrate Disposal” (Project 4071)
- “Membrane Plant Impacts on Wastewater Treatment” (Project 4072)
- “Zero Liquid Discharge for Water Utility Applications” (Project 4073) – a survey-based informational project about ZLD within and outside the water industry.

3.4 Additional Information on Desalination Research

The implementation of desalination technology is being critically and comprehensively evaluated in Project 4006 (“Critical Assessment of Implementing Desalination Technology”). The researchers will survey domestic and international desalination plants to obtain and report real implementation experiences including siting, permitting, capital and operating costs, water quality considerations, etc. One final project of note, “Desalination Facility Design and Operation for Maximum Energy Efficiency” (Project 4038) will compile and analyze data from operating brackish (ground and surface), seawater, and wastewater membrane desalination facilities to result in recommendations for the design and operation of desalination facilities to maximize energy efficiency and reduce energy use and costs. This partnership with the California Energy Commission will also investigate the relationships between plant location, design, operation and maintenance, and energy use and cost.

4. AwwaRF Website

Information is available for all projects funded by AwwaRF in the Project Center at www.awwarf.org.

References

Mickley, M. 2006. *Desalination and Water Purification Research and Development Program Report No. 123 (Second Edition) - Membrane Concentrate Disposal: Practices and Regulation*. U.S. Department of the Interior Bureau of Reclamation. Denver, Colorado.

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Who is AwwaRF?

- The Awwa Research Foundation (AwwaRF) is a member-supported, international, nonprofit organization that sponsors research to enable water utilities, public health agencies, and other professionals to provide safe and affordable drinking water to consumers.
- **Our Mission: Advancing the science of water to improve the quality of life**
  - Sponsoring research
  - Developing knowledge
  - Promoting collaboration

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What is a sustainable drinking water supply?

- **Sustainability** = meeting current and future needs without causing negative consequences
- **Triple Bottom Line** approach = balancing economic, environmental, and social needs
  - For a water utility…balancing the budget, meeting regulations, keeping customers safe and satisfied!! No small feat.

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Water Reuse, Recycling, and Reclamation

- Making use of treated municipal wastewater
  - Nonpotable uses include irrigation, industrial use, vehicle washing, toilet flushing, etc.
  - Indirect potable uses include groundwater recharge, surface water blending

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Sustainable Underground Storage

- Water deliberately recharged into an aquifer for later use
- Relatively simple in concept
- In practice, technical and institutional challenges
- Soil Aquifer Treatment may be a sustainable solution!

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Soil Aquifer Treatment (SAT)

- Indirect potable reuse…
  - Infiltration through a biologically active interface
  - Percolation through a shallow soil zone
  - Storage/transport into underlying aquifer
- In theory, recharged water is "clean" and ready for extraction

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SAT Research Projects

- *Soil Treatability Pilot Studies to Design and Model SAT Systems* (2006)
  - Evaluated effects of soil type and effluent pretreatment on efficacy of SAT
- *SAT for Sustainable Water Reuse* (2001, 2006)
  - For organic C, pretreatment had no effect
  - To be removed, N must be applied in reduced form
  - Bromide levels and DBPs

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Membrane Research

- AwwaRF first funded membrane treatment research in 1988
- ~50 projects funded at nearly $20 Million
- Topics:
  - reverse osmosis (RO)
  - nanofiltration (NF)
  - ultrafiltration (UF)
  - microfiltration (MF)
  - electrodialysis (ED)
  - reuse
  - integration
  - O&M, costs
  - fouling
  - contaminant removal
  - process optimization
  - **desalination**
  - **concentrate management**

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Focus of Membrane Technology Research

- Energy consumption
- Sustainable concentrate management solutions
  - 4 common practices each with limitations:
    - Surface water discharge
    - Wastewater (or sewer) discharge
    - Land application
    - Deep well injection
  - Beneficial reuse? Markets for salts?

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Membrane Research for Reuse

- Membrane Concentrate Treatment Strategies for Water Reclamation Systems (Project 3096)
  - $150K effort with Arizona State University and four water inland, arid water utilities
  - Developing a WQ model and bench-scale testing protocol
  - Report available in 2007

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Membrane Research for Reuse Continued

- Comparison of NF and RO in Terms of Water Quality and Performance for Treating Recycled Water (Project 3012)
  - ~$400K effort with Colorado School of Mines, WateReuse Foundation, and West Basin Municipal Water District
  - Guidance on membrane selection for water reuse purposes

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Desalination

- RO, NF, and ED/EDR
  - > 230 desalting plants producing >25,000 gpd each in the U.S.
- It's the same story….
  - High energy costs!
  - Lack of sustainable waste management solutions!

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Current Desalination Research

- WHO Guidance Manual for Desalination Facilities (Project 4049)
  - Address WQ specifications, monitoring, and operational requirements on a global basis
  - Global effort including U.S. contributors AwwaRF and USBR

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Current Desalination Research, Cont'd

- Water Quality Implications of Large-Scale Application of Seawater Desalination (Project 2841)
  - $800K effort involving McGuire Environmental Consultants and six water utilities
  - Develop WQ "road map" to plan, design, and implement seawater desal

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Current Desalination Research, Cont'd

- Desalination Product Water Recovery and Concentrate Volume Minimization (Project 3030)
  - $700K effort with Carollo Engineers, CO School of Mines, and 17 water utilities
  - Lit review, international survey, pilot select technologies

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Current Desalination Research, Cont'd

- Enhanced RO Systems: Intermediate Treatment to Improve Recovery (Project 4061)
  - $250K effort with the Univ of Texas – Austin, HDR, Carollo, B&V, and CDM
  - Developing two inter-stage treatment systems to increase recovery and reduce concentrate volume

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Current Desalination Research, Cont'd

- Desalination Facility Design and Operation for Maximum Energy Efficiency (Project 4038)
  - $300K effort with Carollo, CEC and 16 water utilities
  - Project title says it all…guidance, guidance, guidance

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Current Concentrate Management Research

- Zero Liquid Discharge and Volume Minimization for Inland Desalination (Project 3010)
  - $850K partnership with CEC, B&V and five water utilities
  - Develop ZLD technologies that are less energy-intensive for inland desalination
  - Began September 2004, Report available 2007

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Current Concentrate Management Research, Cont'd

- Concentrate Disposal for Inland Regions Partnership Program
  - $385K Joint Water Reuse & Desalination Task Force initiative; managed by WateReuse Foundation
  - Four studies:
    - ZLD and Volume Minimization for Water Utility Applications
    - Beneficial and Non-Traditional Uses of Concentrate
    - Impacts of Membrane Process Residuals on Wastewater Treatment
    - Investigation of Regional Solutions for Disposing Concentrate

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Available Reports

- *A Novel Approach to Seawater Desalination Using Dual-Staged NF Process* (2006)
  - $450K partnership with LBWD (EE&T and UN-Reno)
  - One year pilot at LBWD
  - Proven less energy intensive than traditional single-pass RO

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Available Reports Continued

- *Characterizing and Managing Salinity Loadings in Reclaimed Water Systems* (2006)
  - Partnership with IRWD, WateReuse Foundation,WateReuse Assoc, and 11 water utilities
  - Protocol for characterizing commercial, industrial, and residential salinity contributions to sewers and reclaimed systems
  - Guidelines for identifying economic impacts of salinity management practices

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Available Reports Continued

- *Nonthermal Technologies for Salinity Removal* (AwwaRF 1997, Order No. 90840)
  - Partnership with MWD, OCWD, and Lawrence Livermore Nat'l Lab
  - Evaluates RO w/ ultra-low pressure membranes to desalinate CO River water
  - Evaluates capacitive deionization w/ carbon aerogel electrodes at the bench-scale

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What's Next?

- Seawater and Brackish Water Research and Development Program Partnership
  - California Department of Water Resources grant
  - Research program designed by the Joint Water Reuse and Desalination Task Force through a research needs roadmapping process
    - Solicited and unsolicited projects to be funded beginning in 2007

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