Concentrate Management
Carollo Engineers is an environmental consulting firm with more than 1,050 employees in 44 offices throughout the United States. All of our work is performed in the areas of water and wastewater, resulting in a level of understanding of key project issues that few can match. Carollo strives to maintain the tradition of using sound and proven engineering principles while moving progressively forward to keep abreast of changing times and new technologies.

This Statement of Qualifications (SOQ) details some of Carollo's capabilities and experience in the field of desalination concentrate management.

CONTENTS

Issues and Differentiators
Key Achievements
Testing and Optimization Capabilities
Publications
Company Profile
Challenges Facing Water Supply
The water industry faces continued demand for freshwater due to increases in population, standard of living, industrialization, agricultural and environmental needs, as well as freshwater supply challenges due to salinity buildup. Because of this, several public water utilities have turned to alternative (or impaired) water sources to produce freshwater, besides considering and adopting other options, such as improved conservation efforts, and increased recycling and reuse.

Desalination Technologies Can Treat Alternative Water Sources
Desalination with reverse osmosis (RO), nanofiltration (NF), or electrodialysis reversal (EDR) has been successfully used to treat brackish waters for the past several decades, and some regions are even considering seawater desalination as part of their water resource portfolio.

Additionally, desalination technologies have demonstrated reduced costs and increased energy efficiencies over the past several years. Together, these trends support the increasing use of desalination for treating impaired waters.

Carollo provides a total approach to desalination via effective concentrate management that facilitates cost-effective, innovative, and sustainable solutions.

Concentrate Management is Critical to Desalination Implementation
Desalination processes separate water molecules from the feed stream, resulting in a “reject” or concentrate (aka brine) stream that is more concentrated than the feed water and requires appropriate handling. Carollo understands that a key aspect in the feasibility and efficient implementation of desalination technologies is the management (i.e., treatment and/or disposal) of the concentrate stream. The typical range of efficiency or “recovery” (defined as the ratio of product water to feed water volumes) for brackish water desalination plants depends on the source water characteristics and is typically 65 to 85 percent for brackish waters. Water that is not recovered as product or “permeate” is lost as concentrate. Thus, the concentrate ranges from 15 to 35 percent of the feed stream for brackish water RO, to as much as 40 to 70 percent of the feed stream for seawater RO.

Larger volumes of concentrate streams have conventionally been discharged through surface water outfalls or deep injection wells. Other conventional methods include sewer discharge, land disposal, evaporation ponds, and thermal evaporation. Carollo has experience with implementing these conventional methods in desalination projects. However, the significant challenges with accessibility, cost, and/or permitting associated with conventional methods can sometimes limit the additional use of alternative water sources, particularly in inland communities. Therefore, it is critical to develop and implement methods for treating and minimizing concentrate.
When Less is More

Additional treatment can minimize concentrate disposal, thereby expanding the volume of water available for potable use. Various technologies can be used to achieve concentrate minimization to zero-liquid-discharge (ZLD) or near-ZLD, such that no or negligible waste liquid is discharged from the site. The actual increase in recovery for a specific facility would depend on its specific raw water quality characteristics and the concentrate treatment technology selected.

Conventional thermal evaporation processes and evaporation ponds can be used for ZLD (or near-ZLD), but are typically characterized by high costs and/or energy use, and are not feasible for large concentrate flows. Over the past decade, Carollo has been involved in testing, developing, and implementing a range of solutions for concentrate management and minimization. In addition to approaches focusing on enhancing recovery/minimizing concentrate, other approaches and reuse technologies consider the extraction of useful solids from the concentrate stream, as by-products, for possible beneficial uses.

Leaders in Enhanced Management and Treatment of Concentrate

Carollo is a recognized leader in professional services for technology and treatability evaluations and desalination implementation. Within the last 10 years alone, we have completed the design and/or construction of over $1 billion worth of desalination plant infrastructure with over 300-mgd capacity in operation. Additionally, over the past 10 years, we have been involved in the completion

Carollo recognizes that the need for alternative sources and the potential application of desalination technologies means affordable and sustainable concentrate management will be needed. Consequently, Carollo has been at the forefront of testing, developing, and implementing a range of available and emerging technologies for concentrate management and minimization.

Carollo has extensive experience in all the elements pertinent to concentrate management:

- Process evaluations and water quality studies.
- Process modeling and cost estimation.
- Process selection and decision analysis.
- Bench/pilot-scale treatability testing.
- Demonstration and full-scale testing.
- Planning and design services.
- Permitting services.

Carollo offers multiple strengths in Concentrate Management:

- Experts in planning and implementation of membrane and concentrate management projects.
- Leaders in full-scale design and implementation of ZLD and concentrate minimization projects.
- Familiar with the state-of-the-science and technical advancements, such that the right considerations and technologies can be included in each specific project.
- Broad and extensive experience in concentrate management technology assessment and evaluations, and bench/pilot testing.
- Expertise in developing detailed full-scale capital and operational costs, understanding of the associated pre- and post-treatment requirements, and awareness of practical operational considerations and maintenance requirements.
- Understanding of the water quality and permitting considerations, as well as a thorough understanding of both local and national regulatory drivers.
dewvaporation, membrane distillation, and capacitive deionization, among others. Since this leading study, Carollo has been involved in several studies for national, regional, and local agencies for developing and evaluating alternatives for concentrate treatment and management. Carollo’s unique focus on water and wastewater, our national presence, and expertise in technology and concentrate management evaluations have made an impact on the national market for professional services.

The breadth of Carollo’s concentrate management experience is unmatched in the industry and includes a wide range of projects and collaborations. We have evaluated, field-tested, and then successfully designed and constructed full-scale concentrate management solutions that are in operation. These include a range of projects for national water agencies and for multiple clients in California, Florida, Arizona, and Utah, among other states. We have been invited by water management districts (e.g., South Florida Water Management District) and national agencies (e.g., U.S. National Academies) to assist them with concentrate management evaluations and discussions.

**Examples of Key Carollo Achievements**

Examples of key Carollo achievements in concentrate management include:

- **Establishing the State of Science:** In 2005, the Water Research Foundation selected Carollo for the first-of-its-kind detailed study of concentrate treatment. The broad goal of this national level project was to assess and advance the science of concentrate management. The study included technical assessments of 21 desalination technologies and configurations, with a focus on recovery maximization and concentrate minimization, development of guidance tools, as well as development and testing of an innovative treatment alternative. A range of conventional, advanced, and emerging technologies were evaluated, including conventional brackish and seawater desalination systems, dual-RO systems with chemical precipitators, dual-pass NF, brine concentrators, crystallizers, evaporation ponds, forward osmosis, seeded slurry, salt extraction, BIOBROx® process to treat EDR concentrate blended with wastewater.
• **Design of First Large Municipal Concentrate Treatment Facility in the U.S. Using Softening and Secondary RO:** For the Chino Basin Desalter Authority in California, Carollo successfully pilot tested and subsequently designed pelletized softening, filtration, and secondary RO, which will reduce primary RO concentrate volume by up to 70 percent and provide a net recovery of over 95 percent. This will result in 1.2 mgd of additional finished water to increase the net RO/IX capacity to 21.7 mgd and reduce the volume of concentrate from 1.8 to 0.6 mgd. This $46.7-million project will be operational by Fall 2015.

• **Design of First Municipal ZLD Facility in the U.S.:** The State of California Department of Corrections and Rehabilitation selected Carollo for the design of an RO treatment plant at the Deuel Vocational Institute. As there were no options for disposing off concentrate at the inland location of the facility, Carollo designed a ZLD concentrate disposal system including a vapor compression brine concentrator and a 4-acre evaporation pond. This resulted in the construction of the first municipal ZLD RO plant in the U.S. The 0.6-mgd RO plant required a 200-gpm ZLD system. The project cost was $26.5 million, and the plant was operational in February 2009.

• **Three-Stage High Recovery Membrane Systems:** The design of the 165-mgd NF facility for Miami Dade County in Florida involved pilot testing of innovative concepts, including three-stage NF configuration, to overcome the conventional barrier of 85-percent recovery and facilitate sustained treatment at recoveries up to 93-percent. The testing demonstrated that the unique approach of this project is practical, reliable, and cost-effective. The new treatment approach was designed providing enhanced water recovery and an additional 8 mgd of capacity. The approach further reduced the final concentrate volume by approximately 60 percent.

• **Evaluating and Developing Regional Solutions:** The South Florida Water Management District (SFWMD) retained Carollo to focus on Florida with the strategic goal of developing alternatives for enhancing desalination through concentrate treatment and minimization. Numerous utilities throughout the state shared RO data and operations information, participated in the project's technical review committee, and worked with Carollo to define state-of-the-art solutions to help shape Florida's future concentrate minimization strategies. Carollo performed preliminary evaluations of the cost and feasibility of concentrate treatment at 14 Florida RO facilities, in combination with demonstration field-testing at the North Miami Beach Water Treatment Plant.

• **Advancing Concentrate Management through Collaboration with National Agencies:** We have led concentrate management projects sponsored by national agencies, such as the Water Research Foundation (WRF), the WaterReuse Research Foundation (WRRF),
and the U.S. Bureau of Reclamation (USBR). Our expertise has been recognized by industry stakeholders and regulators. This relationship with regulators and industry stakeholders has benefited our clients through a better understanding of regulatory drivers and expedited permit reviews. Some additional examples of agency involvement and collaboration include:

- U.S. National Academies Committee on “Advancing Desalination Technology” and co-author of the associated report.
- USDOE Workshop on Scoping and Advancing Membrane Technologies in the U.S.
- NASA Workshop on Desalination Recovery Enhancement.
- Coauthor of 2012 ASCE publication “Concentrate Management Case Studies.”

Carollo actively collaborates with national agencies to advance desalination and concentrate management. For example, we served in the committee established by the U.S. National Academies for Advancing Desalination Technology.

To help develop regional solutions for advancing desalination and concentrate management, South Florida Water Management District (SFWMD) asked Carollo to perform concentrate minimization evaluations for RO plants in South Florida.
The projects on the following pages present highlights of Carollo’s key achievements in the desalination concentrate treatment. These examples illustrate our ability to:

- Develop and implement innovative solutions for concentrate management to enhance process recovery.
- Offer advanced solutions that are practical, affordable, and reliable.
- Integrate engineering and research to achieve practical solutions tailored to specific client needs.
- Provide the technical, regulatory, and institutional expertise to bring projects from planning through design and construction.

We would be happy to provide client references that can attest to the quality and responsiveness of Carollo’s services upon request.
CHINO BASIN DESALTER AUTHORITY, ONTARIO, CALIFORNIA
Chino Desalting Phase III

HIGHLIGHTS
Concentrate treatment system reduces concentrate volume by 70 percent.
$120-million project with multiple agency coordination.
Expansion from 10 to 20.5 mgd of RO and IX capacity.
Recovery of over 95 percent to meet capacity needs.
Obtained state and federal funding ($79 million) to cover 2/3 project cost.

The Chino Basin Desalter Authority (CDA), a multi-member agency comprised of eight utilities, operates the Chino I and II Desalters to treat high total dissolved solids (TDS) and nitrate contaminated groundwater. CDA retained Carollo to design a $12-million expansion of their RO/IX facilities, a task that included facilitated consensus-building workshops. Carollo successfully obtained significant state/federal funding ($53-million state/$26-million federal). Other key project elements included new water supply wells, raw water piping, and finished water pump stations and pipelines to provide regional deliveries. The construction phase of the Chino II RO/IX expansion from 10 to 20.5 mgd was completed in 2011.

After the RO/IX expansion project, the CDA reselected Carollo for a strategic follow-up project to minimize the RO concentrate. Expanded capacity was essential to achieve regional groundwater management goals, demanding an innovative and cost-effective approach to concentrate treatment and minimization given the limited capacity of the existing concentrate disposal system. Carollo successfully pilot tested and designed pelletized

softening, filtration, and secondary RO, which will reduce concentrate volume by up to 70 percent and provide a net recovery of over 95 percent. This results in 1.2 mgd of additional finished water to increase the net capacity to 21.7 mgd and reduce the volume of concentrate from 1.8 to 0.6 mgd. This $46.7-million project will be operational by Fall 2015.
WATER RESEARCH FOUNDATION, DENVER, COLORADO

Desalination Product Water Recovery and Concentrate Volume Minimization

HIGHLIGHTS
Technical assessment of 21 configurations and technologies to maximize recovery and minimize concentrate volume.
Developed and tested RO-Precipitation-EDR hybrid methodology for reduction in concentrate volume and disposal cost.
Innovative methodology resulted in recovery enhancement up to 95%.
Developed guidance matrix to aid in the selection of appropriate concentrate minimization technologies.

The Water Research Foundation selected Carollo to develop RO desalination technology configurations for maximization of system recovery and minimization of concentrate volume. The overall objective of this project was to advance the science of desalination. Phase I included technical assessments of 21 desalination technologies and configurations with a focus on recovery maximization and concentrate minimization, as well as development of an innovative treatment alternative and its bench/pilot testing (in Phase II), and development of guidance tools.

Technologies assessed included:
• Brackish and seawater RO
• Dual-pass NF
• EDR
• Four types of dual RO systems
• Thermal desalination processes
• Membrane distillation (MD)
• Forward osmosis (FO)
• Capacitive desalination
• Dewvaporation

• ZLD configurations, including: brine concentrators; crystallizers; evaporation ponds; salt recovery; and reuse and co-produced water recovery applications, among others.

The key criteria used in performing the technical assessments included specific production efficiency; product water quality; infrastructure considerations and constraints; energy usage; chemical usage; life cycle, capital, and operational costs, O&M considerations; and pre- and post-treatment requirements. The innovative treatment alternative developed in the project included a primary RO step followed by a concentrate treatment scheme comprising chemical precipitation, media or membrane filtration, and coupled stages for secondary electrodialysis (ED) and EDR, allowing recoveries up to about 95 percent.

Phase II of the project included concept refinement, design and operation of bench-scale testing, modeling, and cost estimation for the innovative RO/EDR treatment alternative. Phase II also included integration of results from three other ongoing tests of emerging technologies for recovery enhancement, comparison of technologies, and enhancement of guidance tools.
ALAMEDA COUNTY, LIVERMORE, CALIFORNIA
Mocho Groundwater Demineralization Plant

**HIGHLIGHTS**
- Comparative evaluation of treatment and concentrate disposal alternatives.
- Design and construction services for a demineralization process that removes 6,000 tons of salt annually.
- Production of 6.1 mgd of RO-treated water.
- $24-million facility in a residential area.

The Alameda County Flood Control and Water Conservation District (ACFWCD)/Zone 7 Water Agency serve as the overall water quality management agency for the Alameda Creek Watershed north of Niles in Northern California. Zone 7 has primary responsibility for management of the Livermore-Amador Valley surface water and groundwater resources. It has historically managed the main groundwater basin by maximizing surface water deliveries, recharging the basin with low TDS surface water, restricting groundwater pumping, and restricting wastewater disposal within the watershed.

The Mocho Groundwater Demineralization Plant is one element of Zone 7’s Salt Management Plan, which is intended to reverse the salt build-up in the main groundwater basin. Zone 7 hired Carollo to provide conceptual, design and construction-phase engineering services for a demineralization plant that will remove up to 6,000 tons/year of salt from the groundwater basin. Treated water will be provided back to the public as potable water.

During the conceptual design phase, Carollo evaluated:
- Three treatment alternatives: EDR, NF, and RO.
- Brine disposal options: connecting to an existing export pipeline, evaporation ponds, and deep wells.
- Wellhead treatment plant siting alternatives.

Carollo conducted these evaluations with a significant level of stakeholder involvement. Principal stakeholders included Zone 7 management, engineering, and operations staff; the City of Pleasanton; and water retailers within Zone 7’s service area.

The Mocho Groundwater Demineralization Plant produces 6.1 mgd of RO-treated water. The facility is located on a 1.5-acre parcel in a residential area. The project included 2,200 feet of 28-inch diameter HDPE well field piping with two jack-and-bore roadway crossings. Operational in 2009, the project cost was $24 million.
MIAMI-DADE COUNTY, MIAMI, FLORIDA
Nanofiltration (NF) Water Treatment Plant

HIGHLIGHTS

- Designed world’s largest nanofiltration facility (165 mgd).
- Sustained improvement in recovery by 8 percent (93-percent recovery).
- Lowered concentrate generation by more than 60 percent.
- Successfully completed extensive permitting and utility coordination requirements.

The groundwater at the Northwest Wellfield of Miami-Dade Water and Sewer Department (WASD) was expected to be reclassified as Groundwater Under the Direct Influence (GWUDI) of Surface Water. To cope with this challenge, WASD decided to proceed with a new treatment plant and hired Carollo for the design of a 165-mgd NF facility to be located on a new site in their Northwest Wellfield. The new treatment plant would be the largest NF facility in the world.

Carollo tailored the design to meet all treatment goals while retaining flexibility for future cost savings, limiting operator’s burden, and controlling capital and O&M costs. Carollo used 3D design capabilities to facilitate review meetings with WASD managers and regulators, while improving clarity of design drawings.

Pilot testing of innovative concepts, including three-stage NF configuration, to overcome the conventional barrier of 85-percent recovery and facilitate sustained treatment at recoveries up to 93-percent demonstrated that this unique approach is practical, reliable, and cost-effective. The new treatment approach enhanced water recovery, providing an additional 8 mgd of capacity. The approach further reduced the final concentrate volume by approximately 60 percent.

Other key project aspects included a LEED Silver administration/operations building, on-site high strength chlorine generation system, pretreatment filtration, post-treatment aeration, low-lift and high-service pumping facilities, and new deep concentrate injection wells for disposal.
As part of its Desalination and Water Purification Research and Development Program, the U.S. Bureau of Reclamation selected Carollo to conduct a demonstration-scale pilot study for treatment of two high TDS water supplies that could be used to meet the growing water demands for the City of Phoenix, Arizona. The objective of the project was to develop a 120-mgd water treatment plant that would treat either the Western Canal (surface water) or the local high TDS groundwater. The two main challenges in this project were:

- Designing a treatment plant that could be used for the treatment of both groundwater and surface water.
- Minimizing the production of concentrate from the RO process.

Carollo designed, procured, and operated a demonstration-scale RO pilot plant that mimicked a full-scale three-stage process and successfully treated both the groundwater and surface water. The treatment train for the surface water consisted of ultrafiltration (UF) and low-pressure RO processes in sequence, while the UF process was bypassed during the groundwater treatment. The pilot plant allowed testing recoveries ranging from 85 to 94 percent. Efficacy evaluation of scale inhibitors showed sustained recoveries of up to 90 percent without fouling, while a recovery beyond 92 percent resulted in irreversible fouling.

Based on the results of the study, the City of Phoenix’s Western Canal Water Treatment Plant has planned to draw both brackish groundwater and surface water from the Salt River Project’s Western Canal.

**HIGHLIGHTS**

- Demonstration testing of RO for concentrate volume reduction showed sustained recoveries up to 90 percent.
- Designed a low-pressure three-stage RO process for the treatment of both groundwater and surface water.
- When treating surface water, ultrafiltration provided pre-treatment to stabilize the feed water to the RO unit.
- The three-stage RO process allowed 85- to 94-percent recoveries.

A three-stage low-pressure RO pilot plant was used to evaluate desalting of Western Canal Water and Salt River Project brackish water.
CENTRAL ARIZONA WATER CONSERVATION DISTRICT, PHOENIX, ARIZONA
Brackish Groundwater Treatment and Brine Management Feasibility Study

HIGHLIGHTS
Concentrate management master planning for a 30,000-AFY facility.
Evaluated multiple contaminant minimization technologies and developed conceptual design for the top two options.
Stakeholders input was integrated in the decision-making process.
Evaluated RO, NF, and EDR for groundwater treatment.

The Central Arizona Water Conservation District (CAWCD) identified brackish groundwater in the Goodyear/Buckeye area of the Phoenix metropolitan valley as an ideal source to meet future demands due to the productivity of the Upper Alluvial Aquifer. CAWCD tasked with Carollo for a feasibility study of a 30,000-AFY project using the brackish water.

Carollo adopted a five-pronged decision-making process that allowed evaluation of potential brackish water treatment and brine management options that included:

- **Defining Project Parameters:** Determine which treatment technology is most efficient for the identified groundwater quality.
- **Identifying Viable Brine Management Options:** Determine which brine management options are feasible for a 30,000-AFY project in the Goodyear/Buckeye area.
- **Defining Decision-Making Climate:** Identify stakeholders and their values to help guide treatment and brine disposal selection.

Carollo identified viable treatment and brine management options using a stakeholder-informed, decision-making process.

The study evaluated RO, NF, and EDR as the potential brackish water treatment options and identified RO as the best primary treatment process. Brine management options evaluated included: reuse of brine as cooling water; volume minimization with chemical precipitation; staged irrigation; vibratory shear enhanced process; thermal technologies; and zero-discharge options (evaporation ponds and crystallizers). Based upon the screening performed, the following brine management options were identified as the most viable, reliable, and cost-effective for this project. A conceptual design report was developed based on these options:

- **Preferential Conceptual Design:** Prepare conceptual level designs and cost estimates.
- **Grading and Ranking Options:** Evaluate and rank treatment and brine management options based upon stakeholder values.

- Reuse of brine as cooling water at the Palo Verde Nuclear Power Plant.
- Volume minimization with chemical precipitation, secondary RO, followed by thermal brine concentrators and finally evaporation ponds.
Following Carollo’s nationally acclaimed project for the Water Research Foundation that assessed 21 treatment technologies for concentrate minimization and recovery, the South Florida Water Management District (SFWMD) retained Carollo to focus on Florida with the strategic goal of developing alternatives for enhancing desalination through concentrate treatment and minimization. Numerous utilities throughout the state shared RO data and operations information, participated in the project’s technical review committee, and worked with Carollo to define state-of-the-art solutions to help shape Florida’s future concentrate minimization strategies.

Carollo performed preliminary evaluations of the cost and feasibility of concentrate treatment at 14 Florida RO facilities, in combination with demonstration field-testing at the North Miami Beach Water Treatment Plant. To achieve the project goals, the following key tasks were undertaken:

- Screening and modeling of 14 RO facilities to identify recovery-limiting salts and classify source waters

- Evaluation of promising concentrate treatment technologies and configurations.
  - Dual RO system with intermediate chemical precipitation.
  - Brine concentrator followed by brine crystallizer.
  - Brine concentrator followed by evaporation pond.
  - Salt recovery and extraction.
  - Site-specific capital and O&M costs and benefit development.

- Alternatives evaluations that considered technical, permitting, implementation, and other non-cost factors.

- Bench and pilot testing at North Miami Beach’s RO facility, which demonstrated that the combination of chemical softening, media filtration, and secondary RO would reduce concentrate volume by 50 percent, increasing overall recovery from 75 to 88 percent.

Carollo pilot tested concentrate treatment for desalination feasibility in costly/limited disposal areas.
WESTERN MUNICIPAL WATER DISTRICT, RIVERSIDE, CALIFORNIA

Arlington Desalter Expansion Evaluation

HIGHLIGHTS

Capacity expansion via concentrate treatment, and recovery by softening and secondary RO.
RO capacity expansion alternative analysis.
Concentrate treatment and recovery by softening and additional RO.

The Arlington Desalter has been in operation since 1989 treating impaired groundwater that is high in nitrate, TDS, and hardness. The desalter expansion has typically been limited by:

• Availability of groundwater.
• Bypass blending volume, which is limited by nitrate.
• Concentrate disposal volume.

Concentrate produced from the RO process is currently disposed to the Santa Ana Regional Interceptor (SARI) line. Disposal capacity is limited, expensive, and subject to escalating disposal costs at a rate that exceeds inflation.

Western Municipal Water District (WMWD) hired Carollo to evaluate ways to expand the Arlington Desalter from 6 to 10 mgd. Carollo developed following alternatives for the expansion:

• Ion-exchange treatment to reduce nitrate in the groundwater bypass: would allow 1-mgd more blending and 0.3 mgd additional daily concentrate flow.
• Biological treatment to reduce nitrate in the groundwater bypass: would allow 1 mgd more blending with no additional concentrate flow.
• Adding a fourth RO train to the existing RO treatment plant and installing bypass biological nitrate removal: would allow 4 mgd more capacity, but would require additional raw water and produce 0.8-mgd more concentrate.
• Expanding the existing RO trains, bypass nitrate removal, and concentrate softening followed by additional RO treatment: would allow 4 mgd more capacity, reduce concentrate flow, and require no additional groundwater.

The alternative with concentrate softening and biological nitrate removal followed by RO was identified as the best alternative.

Concentrate softening and biological treatment to reduce nitrate were demonstrated by pilot testing at the Arlington Desalter in Riverside, California.
The State of California Department of Corrections and Rehabilitation selected Carollo for the design of an RO treatment plant at the Deuel Vocational Institute, California. The groundwater at the site has high TDS and contains modest concentrations of iron and manganese. An RO treatment plant of 0.6-mgd capacity was designed. The design included ZLD brine (concentrate) disposal system and non-potable water distribution system improvements. A vapor compression brine concentrator and a 4-acre evaporation pond were included in the brine disposal system. Iron removal was not included in the RO design. However, the well and groundwater conveyance system were designed to prevent air from entering the system and subsequently oxidizing the iron and manganese. The design included sulfuric acid addition to ensure the presence of only soluble iron and manganese in the water.

The RO generates sufficient amount of potable water to ensure the wastewater effluent TDS concentrations below the regulated level. Key project elements included the following:

- 0.6-mgd RO treatment plant.
- 50-gpm ZLD system consisting of a brine concentrator and an evaporation pond.
- Non-potable distribution main for irrigation that consists of 1,000 feet of pipeline, a 750,000-gallon storage tank, and a pump station.

The project cost was $26.5 million, and the plant was operational in February 2009.
WATERUSE RESEARCH FOUNDATION, ALEXANDRIA, VIRGINIA

Investigation of Regional Solutions for Disposing of Concentrate

**HIGHLIGHTS**

Surveyed concentrate disposal and management strategies.

Developed a decision model to sort through regulatory, environmental, and public issues.

The model allows for the selection of site-specific optimal concentrate disposal and management strategy.

The objective of this Water Research Foundation study was to survey concentrate disposal and management practices and to develop a decision methodology for managers, regulators, and stakeholders to assess the viability of concentrate disposal options on a regional and local basis. Disposal and management of desalination process by-product water (i.e., concentrate) is a significant issue in desalting operations. A complex regulatory environment and questionable public acceptability make planning-level decisions uncertain. This level of uncertainty and potential impact to the safety, sustainability, and adequacy of our water supplies makes it very difficult to complete the planning process with a single option for concentrate disposal that is acceptable, and has clear cost implications and a reliable implementation timeline.

The approach used in this report combines a survey of the feasible concentrate disposal options and the associated laws and environmental concerns with a decision methodology that walks the user through the thought process of selecting among the technically feasible treatment options to:

- Understand the advantages, disadvantages, and limitations of the various concentrate management alternatives available.

- Determine which alternative(s) would be sound, defensible choice(s) for specific desalting needs.

This decision methodology can be used to integrate local and regional planning, growth forecasts, and water resources availability to develop a regional water supply portfolio, which may include desalination. Using this decision process, options for concentrate disposal can be further assessed for viability based upon environmental impacts (e.g., regional salinity balance and safety of other impacted water supplies), sustainability, costs, and regulatory and public acceptability.
JORDAN VALLEY WATER CONSERVANCY DISTRICT, WEST JORDAN, UTAH
Southwest Groundwater Treatment Plant

Carollo provided design and construction-phase services for a new 7-mgd groundwater RO water treatment plant.

HIGHLIGHTS
- Permitting of RO concentrate disposal via pipeline and outfall to the Great Salt Lake.
- State trust-funded project.
- Design, permitting, and construction services for wells, pipelines, and 7-mgd RO.
- The most significant groundwater cleanup project in the country in 2011.

Carollo was selected to provide engineering services for the design, permitting, and construction of a new 7-mgd RO treatment plant, associated groundwater well fields, raw water conveyance pipelines, and RO by-product disposal system. This $75-million project is funded by a state trust to remediate sulfate contaminated groundwater, which resulted from nearby mining activities. The District will own, operate, and provide potable water back to the public from this damaged groundwater resource.

Carollo's involvement in this project spans back to the Spring of 2000, when we were first hired to demonstrate the feasibility and cost benefits of RO technology. Upon successful completion of these activities, Carollo assisted the District with RO by-product disposal permitting, which ultimately resulted in the planned disposal system to the Great Salt Lake.

Carollo's services associated with the Southwest Groundwater Treatment Project consists of the following elements:

- 7-mgd RO treatment plant.
  - 3.5 mgd of sulfate-contaminated groundwater RO.
  - 2.3 mgd of shallow, riverbank filtration RO.
  - 1.2 mgd of shallow riverbank filtration bypass (UV treatment).
- Eight sulfate contaminated groundwater wells.
- Four shallow groundwater, riverbank filtration wells.
- 52,800 feet of sulfate-contaminated groundwater conveyance pipeline.
- 10,000 feet of shallow groundwater conveyance pipeline.
- 11,000 feet of finished water pipeline.
- RO by-product disposal system:
  - 137,000 feet of pipeline and pump station.
  - Outfall to the Great Salt Lake.

This project began in March 2012.
MAGNA WATER COMPANY, MAGNA, UTAH
Barton Wellfield Water Treatment Plant

**HIGHLIGHTS**

Innovative biological process to treat EDR concentrate blended with wastewater.

Fourth largest EDR plant in the U.S.

New site requiring full site development, permitting, and utility coordination.

Federal funding assistance ($12 million) covered more than half of the project costs.

Carollo evaluated alternatives for treating arsenic-, nitrate-, and perchlorate-laden residuals for a Water Research Foundation project. Following this, Carollo received a grant from the EPA’s Office of Research and Development for a pilot test to treat these residuals and TDS from groundwater using EDR technology. An innovative approach was developed to treat the EDR concentrate using wastewater as a carbon source and treating in a bioreactor to destroy perchlorate and reduce BOD and TSS. Carollo received a patent for this new process, known as Biodestruction of Blended Residual Oxidants (BIOBROx™).

Carollo provided engineering and funding assistance for the new 6-mgd (15.4 mgd with blending) EDR water treatment plant, and a new 2.7-mgd (ultimate 3.8 mgd) BIOBROx™ concentrate treatment facility at the existing wastewater treatment plant. Other features included pumping and storage facilities, new supply wells, chemical feed/storage systems, and site planning (permitting, easement acquisition, utility coordination, etc.). Carollo facilitated decision making among the multiple stakeholders that included the water district member agencies, regional wholesale water suppliers, and permitting and regulatory agencies.
The reversible configuration of RO improved performance of the RO system. The combined system of RO followed by EDR achieved an overall recovery of 92 percent. The final effluent contained 140 mg/L TDS with 90-percent removal of the influent TDS. Similarly, approximately 90 percent removal was achieved for all other contaminants of concern, including arsenic, selenium, uranium, iron, and manganese, with the exception of boron. All other water quality objectives were met. The study suggested that a treatment train consisting of primary RO followed by concentrate treatment with EDR was the most cost-effective process train for the treatment of the groundwater sources. Data collected during the pilot study will be useful for any future design of a full-scale ZLD.

In addition, the project established the CDPH permitting requirements for the treatment system, as well as the Regional Water Quality Control Board requirements for the disposal of any waste streams from the process, including brine (concentrate). After the completion of the Preliminary Design Report, Carollo worked with the District to design and construct a pilot-testing facility for the treatment of well water with the combined system of RO and EDR.
EASTERN MUNICIPAL WATER DISTRICT, PERRIS, CALIFORNIA
Desalination Recovery Enhancement and Concentrate Management Study

HIGHLIGHTS
Assessment of multiple concentrate minimization alternatives and pilot testing of two alternatives.
Process optimization lowered total hardness from 3,500 to 1,300 mg/L CaCO₃ and silica from 160 to 50 mg/L.
The softening plus RO configuration resulted in 93-percent recovery.
The softening plus EDR configuration resulted in 75- to 80-percent recovery.

The Eastern Municipal Water District, which serves a population of over 650,000 people, relies on groundwater to provide 20 to 30 percent of its potable water supply. The groundwater treated by the Menifee desalters, owned and operated by the District, contains approximately 2,500 mg/L TDS, 60 mg/L silica, 331 mg/L calcium, 430 mg/L sulfate, 0.3 mg/L iron, and 0.13 mg/L barium and has a high scaling potential. Due primarily to the high levels of silica, Menifee desalters currently achieve only about 70-percent recovery even with chemical pretreatments, such as acid or scale inhibitor addition. The concentrate generated in the process (30 percent of the feed) is discharged at relatively high costs. The District’s primary RO desalters produce brine containing about 6,000 mg/L TDS, which is transported to the Pacific Ocean through SARI pipeline. Concentrate disposal via the SARI pipeline is expensive and of limited capacity. Therefore, concentrate volume minimization is the only practical approach for producing supplemental potable water with reasonable costs.

The District hired Carollo for a turnkey pilot project aimed at reducing brine volume and increasing potable water recovery. Carollo identified softening followed by secondary RO and partial softening followed by EDR as the potential treatment processes for pilot testing. The concentrate softening process was optimized for the removal of calcium and silica, and was carried out in two phases. During Phase I, the addition of caustic soda lowered total hardness from 3,500 to 1,300 mg/L CaCO₃, while silica was lowered from 160 to 50 mg/L. Lime and soda ash were added for brine softening during Phase II.

The pilot study demonstrated technical feasibility of the process combinations (i.e., softening followed by RO and softening followed by EDR) for concentrate minimization and recovery maximization. While the combination of softening and RO achieved 93-percent overall recovery, the second configuration (i.e., softening followed by EDR) allowed 75 to 80-percent recovery. In addition, the performance data were used in part to evaluate a wide range of existing and emerging ZLD technologies for concentrate management. Preliminary cost estimates for various ZLD process combinations were also established.
Pilot Testing Capabilities

Carollo maintains a fleet of pilot equipment. These pilot plants are custom-designed by Carollo to screen membrane products to test concentrate treatment processes and pretreatment chemicals, to test concentrate treatment processes, and develop reliable long-term data that will accurately portray the water quality and costs of the full-scale concentrate treatment process. Pilot testing can be used both as part of the design process and to optimize the operation of existing systems.

The Carollo Research Group (CRG) consists of engineers, scientists, and environmental experts with various backgrounds. This group is a company-wide resource whose purpose is to evaluate water quality and treatability, perform pilot testing, develop design criteria, assess regulatory concerns, perform operations audits, and work with Carollo design engineers to tailor design solutions to be practical, yet incorporate reliable innovations that produce cost-effective solutions. The CRG has performed over 35 large-scale pilot studies from coast-to-coast in the last 5 years.

Carollo has a wide array of analytical capabilities and maintains a laboratory facility in Boise, ID, that provides cost-effective analytical and bench-scale testing services for our clients. This laboratory also provides space for the manufacturing, storage, and maintenance of testing equipment and pilot plants. The primary benefits of our in-house laboratory and testing facility include customized testing and the rapid turnaround of basic process evaluations and water quality analyses. Ultimately, these benefits contribute to the development of cost-effective and timely studies that few of our competitors can match.

Pilot-Testing Approach

Carollo’s standard approach to pilot testing minimizes the allocation of resources in the early phases of the project, providing the owner protection should concentrate treatment prove too costly. The flow diagram below illustrates the progression of a desalting or concentrate treatment project and a typical estimated allocation of resources from conceptual planning through construction and start-up of a full-scale facility. At each point in the planning and pilot-testing process, the owner may decide whether to continue the project based on the results of each phase, minimizing cost if the project is not meeting objectives.

### Proceed Upon Having the Facts — Project Approach

<table>
<thead>
<tr>
<th>Phase of Project</th>
<th>Percent of Cost</th>
<th>Relative Duration</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water Quality Testing and Preliminary Process Review</td>
<td>&lt;1%</td>
<td>Short</td>
</tr>
<tr>
<td>Preliminary Pilot Testing Membrane/Chemical/Concentrate Treatment Screening</td>
<td>~2%</td>
<td>Short</td>
</tr>
<tr>
<td>Demonstration-Scale Testing</td>
<td>~3%</td>
<td>Moderate</td>
</tr>
<tr>
<td>Preliminary Design</td>
<td>~2%</td>
<td>Short</td>
</tr>
<tr>
<td>Design</td>
<td>~10%</td>
<td>Moderate</td>
</tr>
<tr>
<td>Bidding</td>
<td>&lt;1%</td>
<td>Short</td>
</tr>
<tr>
<td>Construction</td>
<td>~80%</td>
<td>Long</td>
</tr>
<tr>
<td>Start-up</td>
<td>&lt;1%</td>
<td>Moderate</td>
</tr>
</tbody>
</table>
Before considering pilot tests for concentrate treatment, it is critical to have a thorough set of water quality data. The type of primary membrane process (i.e., RO, NF, or EDR) and the cost of primary treatment and concentrate treatment will be greatly dependent upon the water quality. The table below lists the primary water quality constituents that are critical for engineers to have before developing a pilot testing program based on the most affordable treatment concept. Seasonal variations in quality should be assessed for surface water sources.

<table>
<thead>
<tr>
<th>Cations</th>
<th>Anions</th>
<th>General</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ca</td>
<td>SO4</td>
<td>Alkalinity</td>
</tr>
<tr>
<td>Mg</td>
<td>Cl</td>
<td>pH</td>
</tr>
<tr>
<td>NH4</td>
<td>F</td>
<td>Temperature</td>
</tr>
<tr>
<td>Na</td>
<td>NO3</td>
<td>TDS</td>
</tr>
<tr>
<td>K</td>
<td></td>
<td>Conductivity</td>
</tr>
<tr>
<td>Ba</td>
<td></td>
<td>SDI</td>
</tr>
<tr>
<td>Sr</td>
<td></td>
<td>Turbidity</td>
</tr>
<tr>
<td>Fe</td>
<td></td>
<td>H2S</td>
</tr>
<tr>
<td>Al</td>
<td></td>
<td>SiO2</td>
</tr>
<tr>
<td></td>
<td></td>
<td>TOC</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Color</td>
</tr>
</tbody>
</table>

### Carollo’s standard pilot testing approach

Carollo’s standard pilot testing approach protects the owner’s interests by minimizing upfront costs and risks.

Once the water quality is known, a preliminary assessment of the primary process (i.e., RO, NF, or EDR) and the concentrate treatment options can be made. Treatment by RO, NF, and EDR is well-understood and computer models can be used to approximate design criteria and costs before pilot testing. However, when developing new supplies, and/or implementing concentrate treatment, pilot testing must be performed to accurately portray finished water quality, concentrate water quality, post-treatment design criteria, and costs associated with chemical cleaning and membrane replacement.

If concentrate treatment is selected, Carollo’s standard pilot testing approach is to first develop and screen alternatives at the desktop level, then perform a pilot- or demonstration-scale test of the most promising alternative to develop the most accurate and reliable water quality and operations cost data. Some studies have involved a preliminary screening of chemicals or membranes using jar-testing or a bench-scale testing apparatus.

This approach minimizes the allocation of pilot testing resources in the beginning of the project, providing further protection to the owner should concentrate treatment prove not to be viable.

If secondary RO is selected for concentrate treatment, pilot testing requires specifically designed equipment that mimics the performance and operation of the full-scale process. Only equipment that is designed to have the same hydraulics as the full-scale system is capable of producing acceptable results. Carollo’s demonstration-scale pilot plant has been used in previous studies to provide long-term data on cleaning frequency, membrane life, verification of feed pressures, and energy costs that were previously estimated using models. This level of testing provides the owner and design engineer the most reliable information to ensure that the concentrate treatment system that is designed and installed can be operated cost effectively.

Pilot testing can also be used as a tool for operator training and public relations. Carollo has assisted owners in developing a pilot testing program that is geared toward operator training. Issues such as data collection and interpretation and daily operations can be addressed through this type of program. Pilot testing equipment can also be housed in a public location. This provides customers the opportunity to see the equipment and read about the process and its use in treatment to help water purveyors provide high-quality drinking water and/or maximize recovery via concentrate treatment.

Regardless of the desalting or concentrate treatment application, Carollo has the expertise and the project experience to help our clients successfully implement a pilot program as part of a full-scale RO, NF, or concentrate treatment project. The following sections describe our NF and RO pilot equipment.
Reverse Osmosis/Nanofiltration: Single-Element Pilot Plant

Carollo's single-element RO/NF pilot plant provides a fast, cost-effective way to screen membranes and pretreatment chemicals. For screening tests, where the results are not certain, the cost of the membranes and the rental fee for the two-stage demonstration-scale equipment is not justified. Cost-effective screening is accomplished with this pilot by using one membrane element, and simulated full-scale operational settings such as hydraulics and recovery.

Critical to the successful screening of membranes and pretreatment chemicals is an accurate simulation of the full-scale design conditions. Flux, recovery, and cross-flow velocities are important parameters in these evaluations and must represent full-scale conditions to provide an appropriate evaluation. The pilot plant is equipped with a programmable logic controller (PLC) system capable of controlling feed water pH, permeate water flow (i.e., flux), and recovery. Full-scale cross-flow conditions are created through concentrate stream recirculation, which provides adequate flow into and out of the membrane element. The system is also equipped with a data acquisition system that is accessible by remote telemetry.

A low-head feed water booster pump is provided, operating at approximately 5 gpm at 30 to 60 psi. As water flows through the pilot plant, pretreatment chemicals (i.e., acid and scale inhibitor) are added and the water is passed through cartridge filters. Cartridge-filtered water is mixed with recycled concentrate water and the pressure is boosted using a high-pressure RO feed pump. Flows and pressures are metered at all critical locations. The permeate flow rate is controlled by metering the flow and varying the speed of the high-pressure pump variable frequency drive (VFD). The recovery is controlled by metering the concentrate flow rate and adjusting it with a control valve. A sample tap panel is provided to gather water from all points throughout the process. Manual flow measurements can be taken to verify electronic meter calibration.

Carollo has used this pilot plant to screen membranes and to develop initial design criteria in Florida, Kansas, Missouri, South Carolina, and Utah. It is sufficiently flexible in design to be housed in filter galleries, maintenance sheds, and temporary storage trailers. An operations and maintenance (O&M) manual and a standard operating procedures (SOP) manual are available. Data spreadsheets are also available to generate report-quality graphics.

Reverse Osmosis/Nanofiltration: Demonstration-Scale Pilot Plant

Carollo's demonstration-scale RO/NF pilot plant is designed to simulate full-scale system operation and water quality. The demonstration plant is used to develop full-scale design criteria and operation
costs. Membrane replacement frequency, chemical cleaning frequency, and membrane life are also determined through demonstration-scale testing with this equipment. Additionally, this pilot can be used to verify the accuracy of RO models that predict feed pressure and permeate water quality.

The demonstration-scale pilot plant is configured in a 2:1 array, with seven 4-inch-diameter elements per pressure vessel. This configuration can be used to simulate the operating conditions for brackish water treatment and membrane softening applications at a product water recovery of up to 85 percent. The pilot system is equipped with a PLC system capable of controlling feed water pH, total permeate water flow, and permeate flow balance between stages. Flow balance can be controlled by either an inter-stage booster pump or by throttling permeate pressure in the first stage. The system is also equipped with a data acquisition system that logs pertinent data automatically and is accessible by remote telemetry.

Feed water is delivered through a low-head booster pump and then a cartridge filter. Pretreatment chemicals (i.e., acid and scale inhibitor) are then added. A static mixer blends the pretreatment chemicals and feeds the water to a high-pressure RO pump. High-pressure RO feed water passes through the RO membrane array while gauges and sensors monitor various parameters at critical locations. Flow is metered at the following process locations: first-stage permeate, system permeate, and concentrate. A sample tap panel is provided to gather water samples from all points throughout the process. Manual flow measurements can also be taken from every pressure vessel and at points where flow is metered electronically to verify meter calibration.

An O&M manual and a SOP manual are included with the unit. Spreadsheets are also available to generate report-quality graphics, and facilitate data analysis and interpretation.

Carollo's demonstration-scale RO/NF pilot plant mimics full-scale conditions and includes a state-of-the-art PLC and data acquisition system to minimize operator time and maximize data production.
# SELECT CONCENTRATE MANAGEMENT PUBLICATIONS - PEER-REVIEWED


SELECT CONCENTRATE MANAGEMENT PUBLICATIONS - OTHER-REVIEWED


WATER AND WASTEWATER EXPERTS

Carollo is an environmental engineering firm specializing in the planning, design, and construction management of water and wastewater facilities and infrastructure. For 86 years, Carollo’s reputation is based upon client service, a continual commitment to quality, and technical leadership.

Carollo is one of the largest firms in the United States dedicated solely to water-related engineering—it’s all we do. This targeted expertise allows us to focus on developing cost-effective, innovative, and reliable solutions to help our clients protect public health and overburdened water supplies. It also allows us to recruit the brightest minds in the water industry, train our staff on the issues impacting water, and lead the industry with innovative ideas tailored to the specific needs of our clients.

Carollo is currently ranked within Engineering News Record’s top 500 design firms...ENR’s annual Source Book ranks Carollo among the top 10 firms for water and wastewater treatment plant design.
In addition, Carollo’s Research Group, a dedicated team of scientists and engineers from across the country, has been responsible for discovering new treatment technologies, improving operations practices, and expanding the science of water use and reuse. Because of this, clients across the United States repeatedly look to Carollo to help them find the best solutions to their most complex challenges.

Our Services
Carollo provides a full range of planning, design and construction management services to meet the water and wastewater needs of municipalities, public agencies, private developers, and industrial firms. Our areas of expertise include the following:

- Alternative Project Delivery
- Business Solutions
- Construction Management
- Energy Technologies
- Infrastructure
- Integrated Planning
- Program Management
- Research and Development
- Sustainable Solutions
- Wastewater Treatment
- Water Reuse/Resources
- Water Treatment

Carollo’s staff numbers more than 1,050 employees, including more than 500 registered engineers. We are a full-service water and wastewater engineering company with the experience and qualified professionals to successfully manage projects of any size. Our staff includes civil, sanitary, electrical, environmental, mechanical, chemical, structural, instrumentation, and corrosion control engineers, as well as architects, planners, and specialists in other areas.

MANAGEMENT PHILOSOPHY
Carollo’s management philosophy and the success of our company are founded on simple precepts:

- **Seek out, hire, and hold onto the best people in the business.** Carollo aggressively recruits the top candidates from the leading engineering schools across the country. We train and mentor these engineers to become the next generation of leaders for Carollo and the industry. This long-term commitment to developing excellent engineers has resulted in a depth of talent unmatched by other consulting firms.

- **Specialize in the planning, design, and construction management of water and wastewater projects.** This is our business. Our success hinges solely upon our ability to provide responsive service to our municipal clients.

- **Commit our principals to an active role in every project.** This provides our clients with top management interest, clear accountability, responsiveness, and talent—and helps to ensure that the necessary staff and resources are committed to each assignment.

- **Focus on client service.** Carollo knows the value of listening to our clients and recognizes that successful projects result from the combined expertise of our staff and the client’s staff. This commitment to understanding client needs and valuing their input is one of the cornerstones of Carollo’s success.
FORMULA FOR SUCCESS
Much of our success as an industry leader is based on our ability to offer advanced solutions that are practical, affordable, and reliable. We strive to maximize the use of existing infrastructure whenever possible, promote environmental conservation, and make the best technologies available at a competitive cost.

Our firm takes pride in the large number of clients with whom we have maintained continuing working relationships. We have worked with some clients for more than 80 years—a clear indication of the quality of our work, our control of costs, and our ability to meet schedules. This dedication to quality has resulted in a long list of successful projects and satisfied clients.

Our client list includes the following:

- City of Phoenix, AZ
- East Bay Municipal Utility District, Oakland, CA
- City of Los Angeles, CA
- Metropolitan Water District of Southern California
- Sacramento Regional County Sanitation District, CA
- City of San Diego, CA
- City and County of San Francisco, CA
- City of San José, CA
- City of Sacramento, CA
- Miami-Dade County, FL
- Palm Beach County, FL
- South Florida Water Management District, FL
- Colorado Springs Utilities, CO
- Denver Water, CO
- Metro Wastewater Reclamation District, CO
- Kansas City, MO
- City of Omaha, NE
- Clark County Water Reclamation District, NV
- City of Las Vegas, NV
- Southern Nevada Water Authority, NV
- Clean Water Services, OR
- City of Portland, OR
- Oklahoma City, OK
- City of Austin, TX
- Dallas Water Utilities, TX
- North Texas Municipal Water District, TX
- Trinity River Authority, TX
- King County, WA
- Seattle Public Utilities, WA