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 is a specialty Statement of Qualifications (SOQ) for Carollo Engineers detailing some of our experience and expertise in the field of water treatment specific to this topic.

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DISTRIBUTION SYSTEM WATER QUALITY CHALLENGES

The significance of the distribution system as a potential source of contamination of potable water can be illustrated by the magnitude of piping currently in service. An estimated 880,000 miles (1.4 million km) of distribution piping are currently used in the U.S. to convey potable water to roughly 223 million people (USEPA Distribution System White Paper - New or Repaired Water Mains).

Regulatory officials are now recognizing the importance of addressing distribution system water quality. As such, future regulations may place a stronger emphasis on the distribution system than past regulations. In response to the impending regulations that pertain to distribution system water quality, many utilities have changed their treatment strategy including their use of primary, intermediate and final disinfectants. Because some of these regulations are conflicting, they create a significant burden on water suppliers. As an example, a change in disinfection practice may increase a utility’s ability to comply with one regulation, while introducing secondary impacts that may compromise its ability to comply with other regulations.

Summary of Distribution System Water Quality Issues

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Requirements for distribution system disinfectant residuals and microbial contaminants are regulated by the Surface Water Treatment Rule (SWTR), which was promulgated in June 1989. Among others, the SWTR outlines distribution system disinfection requirements to inactivate microbiological pathogens for systems using surface water sources. Under the rule, a measurable disinfectant residual must be maintained in at least 95 percent of the samples from the distribution system each month, for any two consecutive months. Samples with HPC levels less than 500 CFU/mL are considered to have a detectable disinfectant residual.

The distribution system microbial integrity is monitored via a microbial indicator, the coliform group. The Total Coliform Rule (TCR) promulgated in 1989 is associated with the SWTR and established a maximum contaminant level goal (MCLG) of zero coliform. The rule allows no more than 5 percent positive samples per month for systems that collect 40 or more samples per month. In systems that collect fewer than 40 samples, no more than one sample may be positive. The TCR requires that a minimum disinfectant residual of 0.2 mg/L for free chlorine or 0.5 mg/L for chloramines be present as the water enters the distribution system.

In terms of disinfection byproduct control, the Stage 1 Disinfectants/Disinfection By-Products Rule (D/DBPR) was promulgated in December of 1998. Maximum contaminant levels (MCLs) of THM4 and HAA5 were established for point of entry, average, and maximum residence time distribution system sites. The D/DBPR also includes MCLs for other DBPs such as chlorite and bromate, maximum disinfectant residual levels for chlorine, chloramines, and chlorine dioxide, treatment strategies for high total organic carbon (TOC)/low alkalinity waters to address precursors of DBPs, and best available technologies (BATs) to achieve the MCLs.

The Stage 2 D/DBPR published on December 15, 2005, builds on the Stage 1 D/DBPR. It addresses the health risks of DBPs in distribution systems that add a primary or residual disinfectant other than ultraviolet (UV) light or deliver water that has been treated with a primary or residual disinfectant other than UV. The Stage 2 D/DBPR modifies the method of calculating compliance DBP results by establishing locational running annual averages (LRAAs) instead of RAAs. Some of the key provisions of the Stage 2 D/DBPR include:

- An initial distribution system evaluation (IDSE) to identify compliance monitoring locations that represent high THM4 and HAA5 concentrations throughout the distribution system.
- An LRAA calculated for each monitoring location in the distribution system for THM4 and HAA5.
Consecutive systems.

Operational evaluation levels to document significant excursions of THM4 and HAA5.

The challenge thus lies in preserving the biological integrity of the distribution system by maintaining a minimum disinfectant residual, while maintaining halogenated DBP levels below the MCLs. To ensure the delivery of high quality potable water to customers’ tap, water utilities need to optimize their distribution system operation and maintenance practices in regards to disinfectant residuals, microorganisms, DBPs, metal release and uptake, color, taste and odor, etc.

DISTRIBUTION SYSTEM RESEARCH EFFORTS AND PRACTICAL SOLUTIONS

Historically, water suppliers were focusing on producing treated water that complies with all established federal and state regulations at the water treatment plant effluent. Little thought was given to the fate of water quality as water flows through miles and miles of distribution system pipes and tanks. More recently, a stronger focus was placed on the water quality in the distribution system and the infrastructure itself. This change in focus was partially driven by the availability of new information, aging infrastructure, and customer inquiries, namely health and safety concerns.

At Carollo, we are active on the regulatory, research, and practical levels of distribution system water quality issues. This is demonstrated by our staff’s commitment and active involvement in the following key activities:

- Distribution system projects at all levels, including research and industry.
- Development of guidance manuals, book chapters, journal publications, and other outreach documents.
- Presentations at local, regional, national, and international conferences, workshops and seminars.
- Participation in regulatory activities.

Select solutions to distribution system water quality issues are summarized in the table on the following page.
Understanding the factors affecting water quality in the distribution system is critical for the development of optimal treatment solutions and distribution system management techniques. Because of the variety and complexity of factors affecting distribution systems, conducting specialized studies at the bench or pilot scale can help isolate one factor at a time and better relate causes and effects. Carollo has completed a number of research projects that address these issues, including:

- A critical full-scale study for the Water Research Foundation investigating the formation and decay of decay of DBPs in distribution systems. Participating utilities included free chlorinated...
systems, chloraminated systems, and a chloraminated system that switch to free chlorine on a temporary basis. The project resulted in a decision tool to assist utilities in selecting compliance sites for the IDSE, as part of the Stage 2 D/DBPR. The USEPA used the study findings to finalize the Stage 2 D/DBPR. Study results have also been published in the AWWA manual: Water Quality in the Distribution System (2005).

- A Water Research Foundation bench-, pilot-, and full-scale study investigating the impact of water quality conditions in distribution systems on microorganism inactivation. Ultimately, the project provided information about the minimum disinfectant residual that can adequately maintain microbial quality of treated drinking water under typical distribution system operation. Study results will be used by regulators to revise the Total Coliform Rule (TCR) and determine the needs and specifics of a possible Distribution System Rule.

- A recent Water Research Foundation project that developed a comprehensive manual to guide identification of particulate matter in distribution systems. Aesthetic issues, such as particulate matter in water at the consumer’s tap and taste and odor, are perhaps the most important issues facing water utilities in terms of dealing with consumer confidence in the quality of their drinking water.

Carollo also maintains extensive and readily available bench- and pilot-scale equipment for use in treatment simulations, including secondary disinfection schemes. In addition, Carollo owns equipment to assess water quality changes in simulated distribution systems. The benefits of in-house equipment for testing include flexible and customized testing, and rapid turnaround of water quality analyses and data reduction. Ultimately, this contributes to the development of cost-effective solutions for our clients.

Practical Utility Experience

Carollo’s experience does not stop at the research level. We use lessons learned from our research projects to identify and develop practical solutions for the many challenges affecting full-scale distribution systems. Carollo has assisted several utilities during the conversion of their distribution systems from free chlorine to chloramine disinfection. Practical solutions include the development of nitrification action plans, development of monitoring plans, and the formulation of preventive action and active response plans. Other services include the optimization of utilities’ tank and reservoir management plans, which involve flushing, mixing, and turn-over. Key projects include:
Synthesizing relevant operational and practical information on the use of chloramines in drinking water treatment and developing revised operational chloramination guidelines. These guidelines will be published in an AWWA manual and used by treatment plant operators.

An important study of customer perception of tap water chlorinous flavors. The study found that consumers generally have a negative opinion of chlorinous tastes and odors in their drinking water and that the perception of this flavor leads to lower satisfaction with tap water, including health and safety concerns. The study concluded that consumer satisfaction can be increased by: 1) improving customer knowledge regarding tap water quality and the safety of chlorinated tap water, 2) reducing chlorinous flavors in finished water, and 3) educating consumers about drinking water treatment and distribution. Recommendations included modifying Consumer Confidence Reports/Annual Water Quality Reports by providing more user-friendly information, and focusing on safety and health issues.

In addition to evaluating key issues of concern and providing operational recommendations to utilities, Carollo has also designed various capital improvements that help our clients maintain excellent distribution system water quality. Examples include:

- Distribution system modifications that facilitate moving older water from low water demand areas to high water-demand areas.
- Pump station modifications to facilitate filling reservoirs more quickly for controlling water age.
- Remote chemical monitoring and additional facilities to address low disinfectant residual, and correct chlorine to ammonia ratios at remote portions of the distribution system.
- Various types of reservoir mixing strategies including internal and external check valve arrangements, separating inlets and outlets, and other types of mechanical mixers.
- Preliminary design for modifications to air valves and blowoff structures to prevent cross-connection and contamination in distribution systems.
- Assisting a research and development firm in the development and validation of an innovative mixing technology to improve mixing efficiency, reliability, and reduce power consumption in drinking water reservoirs.
Water Quality Modeling for Optimum Delivery to System Customers

One key piece of a properly managed distribution system is the availability of a well-calibrated hydraulic model. The hydraulic model is the first component in the preparation of a water quality model, which can be used to simulate water quality changes along the pipes and nodes. Carollo has expertise in developing, calibrating and implementing models, and has assisted several clients in modeling their distribution system, which can then be used to serve master planning needs.

Carollo uses hydraulic and water quality models to help its clients better understand how water flows throughout their distribution systems, and to identify any potential areas of concern. For example, we use simulated tracer studies to assess how groundwater and surface water sources blend in the distribution system, and determine the potential for water quality issues such as taste and odor and low chlorine residual that may result at the blending areas. We use similar techniques to assess daily and seasonal distribution system flow patterns to identify low flow or “dead zones” in distribution systems where water can age, and potentially lead to localized water quality problems such as nitrification. Using our model analyses, we can better identify potential upgrades to improve water flow in all areas of the system and determine optimal water quality monitoring sites, enabling purveyors to deliver the highest quality of water possible to their customers.

Carollo has a long successful history in water distribution system master planning. We have completed over 100 water system master plans in the last 15 years.
The project profiles on the following pages present highlights of Carollo’s key achievements in distribution system water quality. These examples illustrate our ability to:

- Implement innovative technologies to improve process design and performance.
- Integrate engineering and research to achieve practical solutions tailored to specific client needs.
- Involve project participants early in the process to “demystify” advanced technology and fully understand each other’s needs.
- Offer advanced solutions that are practical, affordable, and reliable.

Upon request, we would be happy to provide client references that can attest to the quality and responsiveness of Carollo’s services.
Carollo Engineers performed a distribution system water quality monitoring study and conceptual design for the City of Avondale. The City’s main objectives for this project were to develop strategies to:

- Collect real-time water quality data from the distribution system to improve operations.
- Identify areas of the distribution system with water quality challenges.
- Provide an early warning of potential contamination events (intentional or unintentional).

In order to achieve these objectives, the project consisted of the following main tasks:

- Summarize distribution system water quality considerations and regulatory requirements.
- Identify critical water quality parameters for monitoring.
- Research and evaluate technologies for monitoring distribution system water quality in real-time, including cost impacts.
- Convert the City’s network hydraulic model to an EPS model.
- Establish design criteria and develop a conceptual design for various configurations of remote water quality monitoring stations capable of real-time measurement of critical water quality parameters.
- Define strategies for identifying and prioritizing monitoring station locations.

The team researched and evaluated numerous real-time monitoring systems on the market. The evaluation focused on technologies that had been tested by the Environmental Technology Verification (ETV) process by the USEPA. Technologies were evaluated based on the number and type of water quality parameters that could be measured; accuracy of the analyzers; SCADA communication capabilities; and cost, among others.

Multiple conceptual designs were developed to address potential monitoring station configurations, including incorporating the station into an existing City-owned facility; an underground vault within the right-of-way; and a stand-alone above-grade facility. Preliminary cost estimates were developed for each configuration and a ranking system was developed to identify the configuration that best met the City’s goals.

A placement optimization tool, such as TEVA-SPOT, was recommended to optimize the location and number of monitoring stations throughout the City’s distribution system.
Distribution System Water Quality Monitoring Station Design and Construction Management

As part of a waterline extension project, Carollo Engineers prepared construction drawings and specifications for the first distribution system water quality monitoring station for the City of Avondale. The monitoring station is to help the City achieve the following goals:

- Collect real-time water quality data from the distribution system to improve operations.
- Identify areas of the distribution system with water quality challenges.
- Provide an early warning of potential contamination events (intentional or unintentional).

The station is designed to be configured in a remote underground vault within the right-of-way (determined during preliminary design). The buried vault provides an added measure of security against theft and vandalism, locates the monitoring equipment near the water main, and avoids the extra cost of purchasing land and developing a new site.

The design includes a real-time water quality monitoring system with provisions to communicate the data stream, as well as any alarms, to the City’s SCADA system. The monitoring system is capable of measuring multiple critical water quality parameters, analyzing the data to determine whether there is an anomaly, and automatically takes multiple samples for confirmation testing if contamination is detected. Non-hazardous sample waste is drained to a sump and then pumped to the sewer.

In addition to design services, the team provided bid support during the contractor selection process and construction management services.
In collaboration with the US Environmental Protection Agency (EPA) National Homeland Security Research Center (NHSRC), Carollo Engineers performed a Distribution System Water Quality Sensor Placement Optimization Study for the City of Avondale. The City is in the process of implementing a network of distribution system water quality monitoring stations (sensors) aimed at optimizing operations for water quality and detecting contamination events. The objectives of the study are to:

- Optimize sensor placement in the distribution system to minimize the public impact of a contamination event.
- Optimize the number of sensors to cost-effectively provide human health protection.

This project is a collaborative effort between Carollo, EPA NHSRC and the City of Avondale to apply a newly developed water security tool to a real-world distribution system. The tool is called Threat Ensemble Vulnerability Assessment-Sensor Placement Optimization Tool (TEVA-SPOT), Graphical User Interface (GUI) version. The EPA tool uses a hydraulic network model and optimization algorithms to simulate a wide range of contamination events, measure the resulting public health impact and recommend the number and location of sensors that maximizes human health protection.

Carollo was trained on TEVA-SPOT GUI by EPA staff and worked with the City to develop user-specified inputs for the model, including the design basis threat, performance measures, potential sensor locations and utility response measures, among others. Model results were periodically verified and reviewed by EPA staff to help ensure quality. Carollo provided feedback to EPA on potential improvements to the model.

Project deliverables included master plan maps of recommended sensor locations; graphs showing the relationship between the number of sensors and public health impacts; and potential costs for optimized sensors, among others.
Evaluation of the behavior of trihalomethanes and haloacetic acids in distribution systems.

Impact assessment of dynamic water quality conditions in distribution systems on the inactivation of suspended microorganisms.

Development of guidance tools critically needed by the water industry to manage disinfectant residuals.

Formation and Decay of Disinfection By-Products in Distribution Systems

Carollo recently conducted a Water Research Foundation project that dealt with key distribution system issues. The goal of the project, entitled “Formation and Decay of Disinfection By-products in Distribution Systems,” was to evaluate critical factors that affect THM and HAA behavior in distribution systems, to determine the fate and behavior of other critical DBPs (such as NDMA, bromate, haloacetonitriles), and to identify by-products of DBP degradation. This project provided important information for utilities to address the Stage 2 Disinfectants/Disinfection By-Products Rule.

Key features of this extensive one-year study investigating the formation and decay of DBPs in five full-scale distribution systems included:

- Evaluation of distribution systems that featured free chlorine final disinfection, chloramine final disinfection, and systems that periodically converted from chloramines to free chlorine disinfection.
- Inclusion of booster stations and reservoirs.
- Use of calibrated hydraulic models to select distribution system sites for the study.
- Selection of sites that showed signs of biological degradation of HAAs.
- Selection of sampling locations that represented various water ages (i.e., ranging from close to the treatment plant to dead-ends).
- Selection of sampling locations that considered pipe material and diameter, as well as pressure zones and possible presence of automatic flushers.

By applying the results of the study, Carollo developed practical decision and operational tools for determining distribution system sites to comply with the Stage 2 D/DBPR. These tools would be more user-friendly than the guidance manuals available thus far to help utilities select their monitoring sites for compliance.

This Water Research Foundation study provided vital information on the minimum disinfectant residual that can adequately maintain microbial drinking water quality under typical distribution system operation.
Qualitative Procedures for Identifying Particulate Matter in Distribution Waters and at the Customer’s Tap

A common and important customer complaint concerning drinking water is the presence of unknown particulate matter. Often, the nature and source of the particulate matter is not investigated, because utilities do not know the origin of the problem. There are a number of possible sources for the various types of particulate matter; some may originate in the source water, whereas others may come from utility-operated facilities or household plumbing. A key to dealing with this issue is the formulation of a step-by-step set of instructions to identify the particulate matter and demonstrate the findings to the consumer. This identification will also help determine the significance and origin of the matter.

The overall objective of this project was to develop a user-friendly manual of step-by-step procedures for identifying types of particles in distribution system and tap waters. Specific objectives included:

- Developing a decision tree framework to allow stepwise progress toward a positive identification and to determine the significance of the particulate matter.
- Demonstrating and refining the application of the decision tree framework and associated methods in on-site workshops by receiving immediate feedback from the participating utilities.
- Identifying, improving, and enhancing existing wet chemistry and advanced analytical techniques for the identification of particulate matter.
- Producing a comprehensive photo library (CD-ROM format) of example types of particulate matter found in North American distribution systems and tap waters.

Participating utilities in this project included the Columbia Water Treatment Plant (Missouri), Grand Strand Water and Sewer Authority (South Carolina), Crescenta Valley Water District (California), City of Cedar Rapids Water Department (Iowa), Duck River Utility Commission (Tennessee), and the City of Washington (Missouri).
CITY OF PASADENA, CALIFORNIA

Conversion of Chlorination Facilities to Chloramination Facilities at Sunset and Windsor Reservoirs

The City of Pasadena purchases chloraminated water from the Metropolitan Water District (MWD) of Southern California to supplement its own groundwater supplies which are disinfected using chlorine. Blending of the two sources creates problems, including a loss of disinfectant residual, nitrification, and taste and odor episodes.

In addition, Pasadena is concerned about its ability to meet the Stage 2 D/DBPR while using chlorine. Faced with these challenges, Pasadena retained Carollo to evaluate the situation, develop solutions, and prepare a predesign of the selected alternative.

Carollo evaluated the Pasadena’s chloramination approach by reviewing existing reservoir configurations and operations, water quality goals and regulations, and O&M requirements. Carollo developed alternatives for resolving operational problems resulting from blending chlorinated groundwater and chloraminated water supplied by MWD and prepared a complete predesign of the recommended changes. Carollo also held a series of workshops throughout the project to promote consensus decisions between Pasadena and Carollo.

Carollo worked with the City of Pasadena to develop alternatives for minimizing chlorinated/chloraminated blending issues in the distribution system.

HIGHLIGHTS

- Evaluation of Pasadena’s chloramination approach.
- Review of existing reservoir configurations and operations, water quality goals and regulations, and O&M requirements.
- Development of alternatives for resolving operational problems.
- Predesign of recommended changes.
The Castaic Lake Water Agency, which sells water to Santa Clarita Water Division and Newhall County Water Districts, recently switched their final disinfection from free chlorine to chloramines. This triggered Santa Clarita Water Division and Newhall County Water District, which were both on free chlorine disinfection in their system, to come up with an action plan to minimize issues of blending free chlorinated water with chloraminated water. As part of this effort, Carollo assisted Santa Clarita Water Division and Newhall County Water District with the following:

- Development of Nitrification Action Plans (NAP) and follow-up with California Department of Health Services (CDHS). The NAP included a monitoring and prevention protocol, and response actions to nitrification.
- Distribution system water quality data analysis before, during, and after the switch to chloramines.
- Recommendations and response plans to potential issues of concern.

Services provided to Newhall County Water District included the following:

- Finalizing the Annual Water Quality Report.
- Developing source water sampling schedule.
- Compiling general distribution system water quality data.
Carollo completed a study for the Mid-Peninsula Water District (MPWD) to evaluate converting from chlorine disinfection to chloramine disinfection. MPWD receives water from the San Francisco Public Utilities Commission (SFPUC), which converted to chloramine disinfection in the year 2003. Though chloramines are more stable than chlorine, the conversion posed significant water quality issues, including nitrification and bacterial growth in the water distribution system if the proper operational procedures were not planned and implemented.

Carollo prepared a computer model of MPWD’s water distribution system using H₂ONET® that not only helped to identify potential problem areas, but also helped evaluate remedial measures. Carollo evaluated both capital improvements and operational changes to identify those that would most cost effectively help the MPWD maintain high water quality throughout its distribution system following the SFPUC’s conversion to chloramine disinfection. Carollo presented the results of the study and the recommended improvements and operational changes in a report that included estimated costs and the recommended schedule for completion.
Carollo completed a study for the City of Mountain View to evaluate converting its distribution system from chlorine disinfection to chloramine disinfection. Mountain View receives its water from the City of San Francisco Public Utilities Commission, which converted from chlorine to chloramines in the year 2003. Though chloramines are more stable than chlorine, the conversion posed significant water quality issues, including nitrification and bacterial growth in the water distribution system if the proper operational procedures are not planned and implemented.

Carollo prepared a computer model of Mountain View’s water distribution system to help identify potential problem areas and evaluate remedial measures. Carollo evaluated both capital improvements such as pipe looping and reservoir mixing systems, and operational changes such as pump controls and operational schemes. Based on the results of the study, Carollo prepared a report that provided recommended improvements, costs, and an implementation schedule to help Mountain View maintain high water quality throughout its distribution system in the most economical fashion.
Advanced Water Treatment of Estuarine Water Supplies

Estuarine waters (fresh waters under tidal influence) are an important source of drinking water for millions of people. These waters pose a number of treatment challenges, including salt and bromide intrusions from seawater, as well as the presence of DBP precursors and anthropogenic chemicals from upstream discharges. Considering these challenges, successful treatment scenarios need to include a multiple-barrier approach.

The Water Research Foundation and the USEPA provided funding to the Contra Costa Water District, who then retained Carollo to study advanced water treatment of estuarine waters. The goal of this project is to fill knowledge gaps regarding treatment of estuarine supplies using existing and advanced technologies, as well as disinfectant combinations. The aim is to meet current and future regulations as well as drinking water utilities’ water quality treatment goals. Project objectives include:

- Investigating the additive and synergistic effects of multiple disinfectants/oxidants, including chlorine, chloramines, chlorine dioxide, ozone, and UV disinfection on disinfection efficacy and DBP formation.
- Investigating a selection of advanced technologies, namely coagulation, powdered activated carbon (PAC), granular activated carbon (GAC), MIEX® resin, and membranes, to remove dissolved organics, bromide, and taste and odor compounds prior to disinfection in estuarine waters.
- Investigating the impact of multiple disinfectants and the proposed advanced technologies on distribution system water quality, including disinfection by-product formation, nitrification, and microbial regrowth.
- Determining the threshold levels of source water quality and associated disinfection requirements; identifying whether optimization, retrofit, or installation of advanced technologies may be required, and recommending the treatment levels necessary to achieve regulatory horizon targets.
- Determining practical operational conditions and limitations of the technologies tested, and proposing alternatives and solutions to meet regulatory requirements.
- Providing a comparative cost analysis for the proposed solutions, including operating requirements.
This project involved a collaboration between Carollo, American Water and Economic and Engineering Service (EES) to update the original *Optimizing Chloramine Treatment Manual* (Water Research Foundation, 1993). Its goal was to synthesize all relevant research, operational and practical information on the use of chloramines in drinking water treatment, and develop new utility case studies into an updated best management practices manual that will have an operations and implementation focus. The project developed “practical chloramination guidelines for use in the utility operation toolbox,” focusing on four key objectives:

- Decision approach: helping the utility decide whether to use chloramines.
- Design guidelines for safe and reliable treatment facilities.
- Start-up and operations of chloramine treatment facilities.
- Community relations: approaches to gain input and support.

To meet these goals and objectives, the team developed a five-step approach:

- Assembling the latest information.
- Developing and conducting a chloramine survey.
- Identifying and conducting case studies.
- Preparing new chloramine guidelines.
- Empowering the user.

The team developed and conducted a survey of all relevant operational and practical information, problems encountered, and control practices related to the use of chloramines. This involved preparing an electronic survey to facilitate questionnaire distribution and data analysis. Responses from 69 utilities were received.

For the case studies, American Water led the development of effective strategies with respect to chemical feed system design, dose and application points, operator training, community education, and plant and distribution system monitoring programs.

EES led the development of several tools to transfer the information to the water industry, including a print and electronic manual, an interactive CD-ROM for the decision process on whether to switch to or optimize the chloramine process, approximately 20 detailed case studies, a design checklist, 15 to 20 example brochures related to community acceptance, and monitoring protocols, etc.
Consumer Perceptions of Tap Water, Bottled Water, and Filtration Devices

Recently, much attention has been given to the consumption and use of tap water alternatives (TWAs) such as bottled water and point of use/point of entry (POU/POE) devices. The water market has changed dramatically in recent years. Significant growth in public/private partnerships, intense marketing of bottled water and POU/POE devices, and the recent increase in media attention to drinking water issues have contributed to a shift in public attitudes toward tap water. Data collected in recent years reveal some interesting statistics, (as of 2002):

- Two million POU/POEs are purchased annually in the U.S. and Canada.
- Forty-one percent of Americans use POU/POEs, bottled water or both.
- Annual bottled water sales are $4 billion in the U.S.

Satisfaction levels for both tap water and TWA drinkers were greater than 50 percent for each water quality feature examined. Tap water drinkers consistently had a higher level of satisfaction compared to TWA drinkers. For example, 92 percent of tap water drinkers were satisfied with the “overall quality” of their tap water compared to 74 percent satisfied TWA drinkers. Tap water “taste” received the fewest satisfied respondents (52 percent from TWA drinkers). In fact, TWA drinkers were three times more likely to report an “offensive” flavor (e.g., musty/earthy, metallic, or chlorinous), compared to tap water drinkers.

Consumption of TWAs varied considerably across the U.S. As few as 20 percent (Midwest market) of the local population to as many as 87 percent (West Coast market) consumed either bottled or filtered water. Sixty-eight percent of filtered water drinkers were motivated by safety. Bottled water drinkers were motivated equally by safety (28 percent), taste (30 percent), and healthiness (28 percent).

On average, utilities overrated consumers’ satisfaction levels by 15 percent in areas of tap water quality and utility service. This gap between utility managers’ perceptions of consumers’ satisfaction level and actual consumer satisfaction levels may, in part, account for the consumption trend toward tap water alternatives.
Changes in Distribution System Water Quality on Disinfection Efficacy

The maintenance of a disinfectant residual in distribution systems has traditionally been used to protect microbial water quality. However, experiences reported by utilities have shown that microorganisms survive in the bulk water of distribution systems despite the continuing presence of disinfectants. Such occurrences place doubt on the ability of disinfectant residuals to ensure microbial protection, especially when facing challenges such as biological regrowth, treatment failure, and breaches in distribution system integrity.

The goal of this project was to address questions concerning the usefulness of maintaining a secondary disinfectant residual and the target level to be maintained. The project involved five phases:

- **Phase I** - Conducting a literature review on disinfection efficacy, surveying North American utilities to assess the primary questions presented above, and analyzing historical water quality data collected from selected utilities.

- **Phase II** - Conducting a mathematical analysis of published microbial inactivation kinetics and proposing theoretical required minimum disinfectant concentration.

- **Phase III** - Conducting secondary disinfectant challenge experiments to fill in gaps where published inactivation kinetics are inadequate.

- **Phase IV** - Examining secondary disinfectant analytical limitations and errors, mainly the potential disinfection efficacy of organic chloramines when measuring chloramine concentration.

- **Phase V** - Conducting bench-scale experiments using annular reactors and pilot-scale studies using pipe loops to determine the minimum disinfectant concentration required to sufficiently inactivate microorganisms, and correlating this concentration to various distribution system related factors.

Participating utilities included the East Bay Municipal Utility District (California), the Jordan Valley Water Conservancy District (Utah), the Halifax Regional Water Commission (Nova Scotia), the Regional Municipality of Waterloo (Ontario), Southern California Water Company (California), Seattle Public Utilities (Washington), Newport News Waterworks (Virginia).
The City of Glendale Water and Power Department retained Carollo to develop a hydraulic model of its water distribution system. Glendale’s distribution system is relatively complex, with three connections to the Metropolitan Water District of Southern California, 13 wells, two treatment plants, interconnections with two other agencies, 28 pump stations, and 27 storage facilities. These facilities are organized into 11 separate pressure zones that provide water service to approximately 35,000 connections.

The main objectives of this project include:

- Providing Glendale with a hydraulic model that will assist them in planning and optimizing the operation of their water distribution system.
- Meeting the Stage 2 DBPR and the IDSE requirements for a system specific study (SSS) in lieu of the standard monitoring program (SMP) option.

At the completion of this project, the calibrated hydraulic model will become a tool for addressing the proposed Stage 2 DBPR IDSE requirements for a well-calibrated distribution system model for the purpose of the SSS. This will be accomplished by accurately modeling pipelines (4 inches and larger), storage facilities, pumping stations, control valves, pressure zones, groundwater wells, supply sources, and interconnections.
The City of Anaheim retained Carollo to prepare a system-wide disinfection study to serve as a planning tool for the development of operational strategies and capital costs. Anaheim currently uses groundwater, which is chlorinated, supplemented by Metropolitan Water District of Southern California surface water, which is chloraminated. Furthermore, the topography of Anaheim’s western half is relatively flat and contains the majority of the supply wells, while Anaheim’s eastern half consists of hills and canyons and contains the majority of the City’s water storage facilities.

Carollo used a hydraulic water distribution system model, assembled with H₂ONET® and containing over 10,000 pipes, to run water quality simulations. The team used these simulations to trace water sources and relative blends of groundwater and surface water, to monitor water age, and to evaluate disinfection residuals. The project included identifying disinfection alternatives and recommending facility improvements.
Carollo conducted a study for the City of Palo Alto to evaluate and develop recommendations to improve Palo Alto’s water wells, reservoir storage, and distribution system. Major project tasks included:

- Developing emergency scenarios and providing model analysis.
- Calibrating and updating the distribution system model to current conditions, providing recommended system design and analysis criteria, and preparing a capital improvement program for the recommended improvements. Carollo converted the model from Waterworks to H₂ONET®.
- Performing an audit to quantify the amount of unaccounted for water.
- Evaluating storage needs to address requirements for daily operational demands and emergency scenarios, as well as operational or facility changes to improve utilization and water quality in the foothill areas’ reservoirs.
- Reviewing hydrogeologic data regarding the ground water sources and providing recommendations for well testing.
- Providing recommendations for improving the existing well system as a source of supply, as well as the suitability of the well field to serve as an emergency or standby supply.
- Investigating the potential impacts of the proposed chloramine conversion on the existing distribution system.

Carollo is continuing to help Palo Alto design and implement the improvement projects. Carollo designed, and is providing construction management services for improvements to five existing pumps stations, three existing wells, and four existing reservoirs. Carollo is also performing a siting analysis, including a public involvement campaign and Environmental Impact Report (EIR) for a new 2.5-million-gallon reservoir.
The California Men’s Colony (CMC) is a state prison facility near San Luis Obispo, California. CMC is responsible for providing potable water to CMC, Camp San Luis Obispo, the County of San Luis Obispo detention facility system, and Cuesta Community College. In all, CMC operates and maintains approximately 40 miles of distribution pipelines, five storage reservoirs, two booster pump stations, and three inactive wells. The water distribution system was hastily constructed by the Corps of Engineers at the advent of World War II when Camp San Luis Obispo was developed as a regional training facility by the army.

Carollo prepared a facilities plan, including hydraulic modeling, to identify capacity and pressure deficiencies, evaluate water quality problems, and recommend improvements. Design includes replacement of more than 21 miles (112,000 linear feet) of 6-inch to 18-inch diameter pipelines, improvements to two booster pump stations, storage tank modifications, new control valves, pressure-reducing valve stations, blowoff and air/vacuum relief facilities, hydrants, and reactivation of one key well. Construction methods include traditional open-cut, bore/jack crossings of State Highway 1, and horizontal directional drilling for creek crossings. The total estimated construction cost is $23 million.

Associated activities include aerial photogrammetry and topographic surveying, a geotechnical investigation, a Phase I Environmental Site Assessment, and coordination of an environmental impact report. The design accommodated numerous threatened or endangered species, and included an evaluation of the potential for encountering serpentine rock (with naturally occurring asbestos).
CITY OF YUMA, ARIZONA

Water Distribution System Master Plan Update

The City of Yuma is experiencing significant growth in both residential and industrial water demands. In response to this growth, Carollo updated Yuma’s water distribution master plan. This study included the following primary objectives:

- Building a new hydraulic model for the entire water system based on Yuma’s digital water atlas using H₂ONET® Version 3.
- Preparing a data collection protocol and assist Yuma in conducting a detailed fluoride tracer study, including THM measurements.
- Performing extended period simulations to evaluate chlorine residuals and THM formation, after using the results of the tracer study to perform a detailed calibration of the hydraulic model.
- Building a new demand generator to project future demands based on customer billing information, population projections, and land use data.
- Evaluating the existing system and developing recommended short-term improvements.
- Evaluating the future water service area and developing a long-range water system master plan that identifies future water system requirements.

The geographical distribution of the demands within Yuma is shifting significantly within the pressure zones. The study also included a detailed evaluation of alternatives involving the shifting of pressure zone boundaries to allow the best utilization of existing facilities.

In addition to calibration data collection, model development involved a detailed demand analysis. This analysis was based on customer billing records which are tied to parcels through GIS. The customer billing records were evaluated to determine average annual and seasonal demand patterns throughout the study area. The customer billing records for the existing system were then tied to individual model demand nodes by aggregating parcels through a polygon analysis.

Distribution system water quality (chlorine residual and disinfection by products) was evaluated using the H₂ONET® software. Carollo used a special field data collection program based on fluoride tracing for the water quality model calibration.

Carollo prepared a long-range master plan update, which included identifying required improvements, phasing of facilities, and preparation of a Capital Improvements Program.
Water Distribution System Master Plan Update and Chloramine Conversion Study

Carollo updated the water master plan for the City of Hayward. The intent of this project was to update the master plan to account for recent upgrades to the water distribution system, prepare for the buildout development plans, and evaluate various water supply and water quality issues such as a conversion from chlorine to chloramine disinfection.

This project began with updating the land use and water demand projections for the buildout year of 2020. Carollo worked with Hayward to obtain the latest information on proposed development plans that included various in-fill projects, as well as a very large residential and golf course community development. Using a combination of historical water demand data, data from neighboring agencies, and water use estimates from the land developers, Carollo updated Hayward’s water demand projections through buildout.

Carollo used the updated water use estimates and the information on recent system upgrades to update the hydraulic model of Hayward’s water distribution system. Carollo also used this information to evaluate the capacity of Hayward’s ten existing/proposed water pump stations and 13 existing reservoirs and to provide an initial assessment of where pump station and reservoir capacity upgrades were needed.

After calibration, Carollo used the computer model to evaluate the performance of the water distribution system and refine the pump station and reservoir capacity recommendations to better meet Hayward’s operational needs, such as time-of-use pumping.

Hayward purchases water from the San Francisco Public Utilities Commission. In preparation for SFPUC’s conversion from chlorine to chloramine disinfection, Carollo examined the potential impacts of the conversion on the distribution system. Carollo used Hayward’s updated distribution system model to identify potential problem areas, as well as operational schemes to reduce water age. The results of this effort included a revised operational plan focused on maintaining high distribution system water quality without impacting system operations, and a water quality monitoring and action plan focused on preventing nitrification episodes.

The water master plan update summarized the recommended improvements to address the identified deficiencies and addressed issues related to water supply, pump station and storage capacity, emergency preparedness, system capacity to meet fire flows, and water quality.
Preliminary Design for the Cross-Connection Prevention Program

The Metropolitan Water District of Southern California has implemented a cross-connection prevention program to protect its treated water supply system from potential contaminants, and to meet California Code requirements. The program includes corrections and modifications to potential cross-connection structures on the MWDSC treated water distribution systems in Southern California, including air release valves, air-release/air-vacuum valves, blowoffs, and air stacks.

Among the 1,360 potential cross-connection structures identified by MWDSC, Carollo worked with the MWDSC team and provided engineering services to prepare preliminary design drawings for 413 structures located across Southern California. Carollo prepared preliminary design plans and sections for the modifications/relocation of the air release valves, air-release/air-vacuum valves, and blowoffs in sizes varying from 1.0 to 12 inches in diameter.

At MWDSC’s request, Carollo prepared a preliminary construction cost estimate for 338 structures based on the preliminary design drawings and available field information. The cost estimate considered various site-specific factors and constraints to allow MWDSC to refine earlier planning-level estimates. A subsequent independent cost estimate prepared by a local contractor confirmed Carollo’s cost estimate.
South Valley Lateral, Air Release, and Air Vacuum Valve Modifications

The Southern Nevada Water Authority (SNWA) found that construction of the South Valley Lateral a 90-inch to 120-inch diameter water transmission pipeline included the installation of air valves in vaults with standard vent bonnets. This is a deviation from their Facility Engineering Guides, which require air valves in vaults to include hard pipes to vents above grade. This deviation in the installation was apparently caused by restricted headroom in the vaults. The original construction contracts were closed prior to the time of the review by SNWA.

Besides providing the normal air valve duties, the purpose of the hard piping is to minimize the possibility of cross-contamination from water that might collect in the vault over a period of time and eventually submerge the air valve. If the air valve was not hard piped, there is a chance that contaminated water could enter the potable water supply system.

Carollo was asked to review the existing air valve installations and comment on the plans for modifications that were prepared by the three original design firms. The plans for modifying the air release/air vacuum valves (AR&AVVs) were then included in a project for which Carollo was responsible for design and construction phase services.
Innovative Reservoir Mixing Technology Validation

Potable water reservoirs are typically kept greater than 70 percent full at all times to maintain a source of water for fighting fires and other water supply emergencies. Water stored in reservoirs tends to warm due to the heat from the sun and rises toward the top of the tank. The cool and warm waters tend not to mix—a condition known as thermal stratification. As a result, the water at the top of the tank tends to age with time, leading to low disinfectant residuals. In the case of chloraminated distribution systems, these reservoirs can become sources of nitrification.

To combat this issue, many water utilities are modifying their reservoirs to include water mixing capabilities. Potential solutions include separating the inlets and outlets, installing check valves, or adding mechanical mixers. Each of these systems has varying costs, benefits, implementation issues, and effectiveness.

Carollo is continually seeking ways to bring novel, creative, and improved solutions to our clients, especially when these improvements provide benefits at lower costs and reduced environmental impact. PAX Scientific, Inc. is an industrial design firm that has translated nature’s flow efficiencies into streamlined design geometries for equipment such as fans and pump impellers. Carollo and PAX have explored opportunities to use the PAX technology to benefit the water and wastewater treatment industry, and chose reservoir mixing as the first application to verify and validate its efficacy.

Carollo devised a series of tests that studied disruption of thermal stratification in drinking water reservoirs and conducted these tests in 1-million-gallon, 2.5-million-gallon, and 4.0-million-gallon ground-set, welded steel tanks. PAX installed its mixer at the bottom of each tank using a simple stainless steel tripod stand for support. A 110-volt outlet located in a pump station at each tank site supplied power. Carollo ran the reservoir mixing tests for six weeks, testing different power requirements, impeller rotation direction, and repeatability of the test results.

Test results indicated that the PAX-designed impeller provided reliable mixing at very low power requirements. In the 4.0-million-gallon reservoir for example, a temperature stratification of 4 degrees Celsius was reduced to 1 degree Celsius using between 100 and 150 watts power.
Carollo owns bench- and pilot-scale testing equipment that can be used to evaluate different distribution system conditions in parallel. This equipment can be used to examine treatment schemes and their effect on the distribution system, and includes pre-oxidation skids, rapid mixers, flocculation tanks, settling tanks, intermediate ozonation systems, filtration columns, UV disinfection systems, and membrane treatment systems. A detailed description of this testing equipment is summarized in Carollo’s specialty SOQ on Capabilities for Pilot- and Bench-Scale Testing.

The testing capabilities summarized below are strictly related to distribution system simulations through bench-scale testing and hydraulic modeling.

**Bench-Scale Treatment Capabilities**

**Simulated Distribution System Testing**

Simulated distribution system testing (SDS) testing can simulate water age in distribution systems in a simple manner. However, these simulations are conducted in amber glass bottles, and the effect of distribution system pipe materials and hydraulics are not assessed. In the SDS test, variables include final disinfection pH; incubation time (average or maximum residence time in the distribution system); incubation temperature; and disinfectant type (chlorine, chloramines); dose; and target residual. Conditions are selected to be as closely related as possible to actual distribution system conditions. If temperature is an issue, repeat seasonal sampling and testing are recommended. Before and after the incubation period, samples are collected and analyzed for the desired parameters (e.g., disinfectant residuals, DBPs, microorganisms, etc.). SDS results can then be compared to actual distribution system results.
Annular Reactors

Carollo maintains BioSurface Technologies annular reactors for conducting distribution system studies. These reactors have the unique capability of allowing separate control of the detention time and shear stress within the system. The reactors consist of a rotor turning inside a stationary outer cylinder. Hydraulic conditions within the reactor, such as shear stress and water velocity, depend on the rotational speed of the rotor. A rotational speed of 50 rpm is commonly used in drinking water studies, as it creates a shear stress of 0.25 N/m² at the outer wall, which corresponds to a flow of approximately 1 foot per second (0.3 meters per second) in a 4-inch-diameter (100 mm) smooth pipe. Four draft tubes inside the inner cylinder enhance liquid mixing.

The reactors allow the collection of both water samples and coupons from which biofilm growth and the extent of corrosion may be determined. Polycarbonate coupons are often used to evaluate biofilm growth without the presence of corrosion or corrosion by-products. Coupons manufactured from common pipe materials such as ductile iron may also be used. The influent flow rate determines the water residence time inside the reactor, simulating the residence time in the distribution system.

In most bench-scale experiments, the reactor is assumed to approximate a finite section of a distribution system. A common set up for drinking water experiments consists of pumping the test water into the annular reactor. Test waters may be augmented by adjusting water quality parameters such as pH or the level of background organic material, or seeded with specific consortia of microorganisms. Additional nutrients, disinfectants, corrosion inhibitors, or other constituents may also be pumped into the reactor depending on the specific experimental objectives.

Annular reactors may also be used in combination with batch incubation bottles to differentiate the effect of the pipe wall from the effect of water age. For batch incubation, a clean bottle is filled with reactor influent water. The bottle is kept under the same conditions of temperature and darkness as the reactors. After a period of time equivalent to the reactor residence time, water is sampled from the incubation bottle and from the reactor effluent. A comparison of the results allows the impact of biofilm growth and corrosion at the pipe wall to be distinguished from the effect of water age.

The reactors are readily transportable, and can be shipped along with other required equipment such as control unit, a feed water pump, and chemical dosing pumps.

Carollo has used the annular reactors to evaluate the effectiveness of scale inhibitors for preventing scale formation in a reverse osmosis
brine disposal pipeline. These reactors have also been used to evaluate biofilm formation and regrowth in distribution systems with varying levels of available biodegradable organic matter.

Hydraulic and Water Quality Models

Computer-aided hydraulic modeling is a powerful tool in all aspects of water distribution system planning, design, operation, and water quality analysis. Carollo uses a variety of state-of-the-art commercially available hydraulic modeling software including: H2ONET, H2OMAP Water, InfoWater, WaterCAD, WaterGEMS, EPANET, and others. Geographic information system (GIS) tools such as the ArcGIS Family, and Autodesk Map, are used to optimize the development and data management of hydraulic models.

The assembled hydraulic models provide insights for optimizing the operation of existing distribution systems, identifying expansion needs to service future developments, and analyzing water quality. Carollo’s approach emphasizes the role of hydraulic and water quality calibration in establishing a level of confidence in the hydraulic models. The calibration is performed to verify the model is simulating current field conditions.

Reservoir Water Quality and Thermal Stratification Testing

Most potable water distribution systems are built with water storage reservoirs distributed in various locations of the service area. These reservoirs store water to be supplied to the system during times of high water demand (e.g., peak daily demands or for fighting fires) and when the water system has been disrupted.

Potable water reservoirs are usually kept greater than 70 percent full at all times to maintain a source of water for fighting fires and other water supply emergencies. Water stored in reservoirs tends to warm due to the heat from the sun and rises toward the top of the tank.

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**Application Table**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value and Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reactor Volume, each</td>
<td>1,150 mL</td>
</tr>
<tr>
<td>Typical Range of Pipe Detention Times Simulated</td>
<td>2 hours to 1 week</td>
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<tr>
<td>Typical Range of Rotational Speeds</td>
<td>50 to 250 rpm</td>
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<tr>
<td>Electrical Requirements</td>
<td>Single-phase, 120-V, 60 Hz</td>
</tr>
<tr>
<td>Typical Rental Fee</td>
<td>$300 per month</td>
</tr>
</tbody>
</table>

Carollo uses a variety of state-of-the-art hydraulic modeling software, coupled with GIS, to help optimize the operation of distribution systems.
The cool and warm waters tend not to mix—a condition known as thermal stratification. As a result, the water at the top of the tank tends to age with time, leading to low disinfectant residuals. In the case of chloraminated distribution systems, these reservoirs can become sources of nitrification.

Carollo possesses the equipment and experience needed to identify and evaluate thermal stratification in drinking water reservoirs. For example, we tested the validity of a novel reservoir-mixing device at the Santa Clarita Water Company. Our test entailed measuring thermal stratification in 1-million-gallon, 2.5-million-gallon, and 4.0-million-gallon ground-set, welded steel reservoirs. We installed strings of HOBO Water Temp Pro remote automatic recording temperature probes to monitor temperature trends at various depths and locations in the reservoirs. We also verified the reservoir temperature data using a highly accurate, handheld meter that was lowered into the reservoirs at specific times to provide additional data on thermal stratification and the effectiveness of the reservoir mixer. The energy usage of the mixing device and the air temperature outside the reservoirs was also recorded. The results of this testing showed that the reservoirs would exhibit 6 degrees Celsius of thermal stratification on warmer days without mixing, and that the novel mixer would disrupt this stratification in about 12 hours using about 150 watts of power.

Coupled with our expertise and experience in distribution system modeling, which we use to identify reservoirs that are likely to have high water age, our reservoir testing capabilities provide Carollo’s clients with valuable information for maintaining the highest level of distribution system water quality possible.
### SELECT DISTRIBUTION SYSTEM PUBLICATIONS - PEER-REVIEWED


### SELECT DISTRIBUTION SYSTEM PUBLICATIONS-OTHER


WATER AND WASTEWATER EXPERTS

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

During our 86-year history, Carollo has successfully completed more than 25,000 projects for public sector clients. Carollo is currently ranked within Engineering News Record’s top 500 design firms. More importantly, ENR’s annual Source Book ranks Carollo among the top 10 firms for water and wastewater treatment plant design. Unlike many of our competitors, Carollo provides only water and wastewater engineering services.

With our focus on water and wastewater, we recruit nationwide and hire technical staff who have the extensive background and training specific to this field. For that reason, the quality and professional standing of our core group of water and wastewater professionals equals or exceeds that provided by some of the largest engineering firms in the U.S.

Resources

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. These individuals perform work solely on water and wastewater related facilities.
Carollo’s state-of-the-art computer network allows us to effectively communicate between offices and interface with almost any engineering software on the market today.

**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.** We recognize that the most critical element for a successful project is the project team. 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 partners 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.

**LEADERS IN WATER ENGINEERING**

Carollo has provided design and construction management services for more than 100 water treatment plants with a total capacity of more than 3.5 billion gallons per day, more than 1,000 miles of water pipeline ranging in size from 6 to 108 inches in diameter, and more than 100 water pumping stations with capacities as high as 600 mgd. We have recently completed or are performing ongoing water projects for many of the country’s major municipalities or special districts. A few examples of Carollo’s achievements include:

- Conceiving and developing the custom design approach for low-pressure membrane water treatment plant design. Carollo developed our own custom, nonproprietary, non-packaged pilot plant unit, which has been successfully tested in Kansas City, MO.
Engineering the fast-paced design/build expansion of the Palm Coast, FL, reverse osmosis (RO) water treatment plant from 3.2 to 9.6 mgd. Carollo completed preliminary design and obtained all permits just eight weeks after beginning work to help facilitate successful completion of this project in just 15 months.

Conducting the first U.S. testing and evaluation of electrodialysis reversal (EDR) for perchlorate treatment.

Achieving leadership in ultraviolet (UV) disinfection, first for wastewater applications in the western United States and now for UV drinking water applications. Carollo was the primary author of the USEPA UV Disinfection Guidance manual. We also developed and operate the world’s largest UV validation facility in Portland, OR.

Designing the preozonation and intermediate ozonation at two water treatment facilities for the City of Arlington, TX, using our computational fluid dynamic (CFD) modeling to optimize ozone contactor design. Carollo also conducted a joint research project with various utilities in the Phoenix, AZ, area to evaluate ozonation and biological filtration to meet long-term finished water quality goals, leading to design and construction of ozonation facilities in Gilbert and Peoria, AZ.

Designing, in a joint venture, the world’s largest ozone generation system at a water treatment facility in Las Vegas, NV.

**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.

A major factor in maintaining Carollo’s ability to integrate new technology is the Carollo Water Research Group (CWRG). The relationship between our design engineers and the CWRG is unique in the industry and serves as a company-wide resource for evaluating water quality and treatability data, performing pilot studies, developing design criteria, tailoring design solutions to water quality issues, and addressing regulatory compliance concerns.
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, some of which are highlighted in the table below.

### Representative Water Treatment Projects

<table>
<thead>
<tr>
<th>Client/Project</th>
<th>Capacity (mgd)</th>
<th>Conventional Treatment</th>
<th>Membranes</th>
<th>Ozone</th>
<th>UV Disinfection</th>
<th>Automation</th>
<th>Solids Handling</th>
<th>Chemical Handling</th>
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