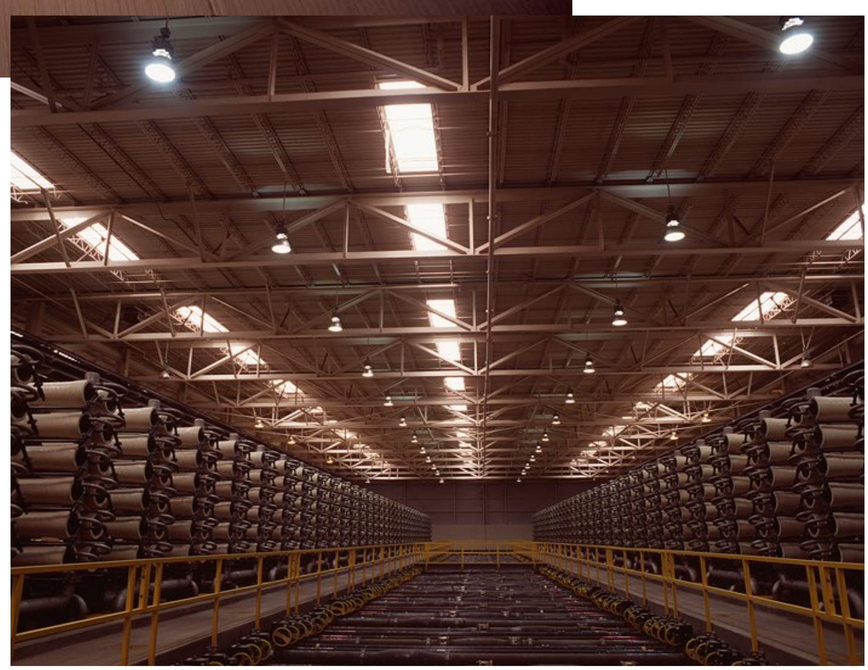
RECLAMATION

Managing Water in the West

Yuma Desalting Plant

Demonstration Run Report



U.S. Department of the Interior
Bureau of Reclamation
Lower Colorado Region

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Mission Statements

The mission of the Department of the Interior is to protect and provide access to our Nation's natural and cultural heritage and honor our trust responsibilities to Indian Tribes and our commitments to island communities.

The mission of the Bureau of Reclamation is to manage, develop, and protect water and related resources in an environmentally and economically sound manner in the interest of the American public.

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Preface

In early 2007 the Bureau of Reclamation (Reclamation) operated the Yuma Desalting Plant (Plant) at about ten percent of its full capacity in order to demonstrate the Plant's ability to function after being idle for 14 years, to provide information that to allow refinement of performance and cost models, and to meet other objectives. This report provides details on the objectives of the demonstration test, provides a record of how the demonstration was operated, and documents results of the demonstration run.

Costs are included in this report, but a distinction must be made between the cost to complete the demonstration and the cost to operate the desalting plant at a commercial scale.[1] While costs incurred to complete the demonstration run have been carefully documented and the demonstration provided new information on performance of various processes, the demonstration project was not intended to include the calculation of costs for a commercial scale plant operation. Such an analysis would require significantly more effort than is reported here.

Nevertheless, because of the high interest in obtaining an updated cost estimate for potential consideration of commercial scale operation using information from the demonstration project and other recent sources, an analysis of costs using general relationships was performed both for bringing the Yuma Desalting Plant up to an operational status and for annualized costs expressed in dollars an acre foot of water delivered to the Colorado River. Because of the preliminary nature of this analysis and variability of significant cost items, ranges of costs are provided. These cost ranges should be used with some caution because of the provisional approach used to obtain them. The ranges, however, are believed to reasonably encompass the various cost parameters.

[1] For purposes of this report and as it relates to the Yuma Desalting Plant, "commercial scale operation" is defined as the operation of the Plant at one-third capacity or greater.

Background

Constructed by the Bureau of Reclamation under the authority of the Colorado River Basin Salinity Control Act of June 24, 1974, the Yuma Desalting Plant has been operated only once—from July 31, 1992 to January 15, 1993, and that was at one-third capacity. The ability to meet salinity requirements under treaty with Mexico without operating the Plant and favorable hydrology on the Colorado River led to the decision to maintain the Plant in a ready reserve status since that time. During recent years, steady increases in water demand in each of the three lower Basin states coupled with the effects of a prolonged drought over the entire Colorado River Basin has prompted continued interest in Plant operation. However, results of the short 1992/1993 operation and modifications to the Plant that have occurred during the intervening 14 years caused some uncertainty as to how the Plant might perform under current conditions.

Because of these uncertainties and the encouragement on the part of Basin states to move forward with Plant operation, in January 2006 Reclamation Commissioner John Keys committed Reclamation to conducting a demonstration of Plant operation. The demonstration was then scheduled to occur in early 2007 and was primarily designed to ameliorate doubts regarding the operational condition of the Plant.

Demonstration Preparation

Commissioner Keys' commitment to a demonstration run of the Plant dictated a need to articulate the objectives of the demonstration, determine conditions under which the demonstration would be conducted, ensure availability of required equipment and materials, and determine regulatory requirements.

Objectives

Five objectives for the demonstration were established. First, the demonstration would confirm that the Plant could operate after a prolonged period of dormancy. Although actions have been taken over the years to insure that the Plant would remain in a condition that would allow operation given appropriate advance notice, a successful demonstration operation would provide assurance that those actions had been adequate to keep the Plant in a ready reserve condition.

The second objective was to validate cost and performance estimates. Operational costs and Plant performance have been modeled using data obtained from manufacturers, laboratory research and tests, and field experience of similar plants. The demonstration was designed to obtain actual cost and performance data that could be used for validation purposes.

The third objective was to demonstrate the use of current technology. Advances have been made in desalting processes since the Plant last operated in 1993. Many of these advances and technological refinements have been steadily incorporated into the Plant in anticipation of increasing efficiencies and costs, but have yet to be tested under operating conditions. Among the advances that were available for testing during the demonstration run were the use of polymers for coagulation and flocculation, the use of ferric sulfate in liquid form, and the use of digital control and monitoring equipment.

The fourth objective was to improve overall Plant readiness. The demonstration could be viewed as a "dry" or practice run that would allow a preview of what would be required for commercial scale operation. The demonstration would also provide insight into equipment condition that can only be obtained by actual operation. Plant readiness would be enhanced by the accelerated performance of maintenance items for the portions of the Plant to be used during the demonstration run.

The fifth and final objective was to measure potential changes in water chemistry occurring inside and outside of the plant as a result of plant operations. Reclamation would measure water chemistry within the United States. A parallel objective of interested non-federal parties was to monitor water chemistry in the Ciénega de Santa Clara in Mexico with a non-federal monitoring program independent of Reclamation's monitoring of water chemistry within the United States.

Guidelines

In order to accomplish the demonstration objectives and emulate, to the greatest extent possible, commercial scale operation, operational parameters were established. These parameters were used to help design the way the demonstration would be performed and the data to be collected during the demonstration.

Because the Plant is authorized to desalt Wellton-Mohawk Irrigation and Drainage District pumped groundwater, it was determined that water from the Main Outlet Drain Extension (MODE)[2] would be used as feed water for the demonstration. The Plant is located next to the MODE and the Colorado River, facilitating delivery of feed water to the Plant and the release of product water to the Colorado River.

The period of continuous operation required to adequately address the objectives was established at three months. Any shorter period would jeopardize the validity of the test and any longer time would significantly add to the cost. One of the considerations was the potential for increased regulatory requirements that might be associated with an operational period of longer than three months.

In order to balance the need to operate the demonstration under process parameters that fall within normal Plant operating ranges and to minimize costs, it was determined that the Plant should operate at about 10 percent of full capacity during the demonstration.

The Plant is equipped to use both Fluid Systems and Hydranautics reverse osmosis membranes. Membranes from both manufacturers have been in storage since the one-third capacity operation in 1992/1993. However, since the control block valve and actuator design deficiencies associated with the Hydranautics desalting train either were previously resolved or were determined to be able to be resolved prior to the early 2007 target for the demonstration run, that train was selected to be used for the demonstration. In addition, sufficient Hydranautics membranes were available on site for the demonstration run, eliminating the need for a procurement action.

In an effort to perform the demonstration in a manner consistent with the currently authorized purpose of the Plant, product water during the demonstration would be blended with water from the MODE and released to the Colorado River for delivery to Mexico. The blend recipe would be set so a maximum amount of bypass flow could be recovered while still allowing Reclamation to continue to meet the salinity requirement for water delivered to Mexico. This water, then, would be counted as

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[2] This water conveyance channel is the conduit for discharging drainage water from the Wellton-Mohawk Irrigation and Drainage District to the Ciénega de Santa Clara in Mexico. Downstream from the Plant, this channel is called the Bypass Drain and water it discharges to the Ciénega is known as bypass flow.

part of the water required to be delivered to Mexico under the Treaty of 1944 and would replace water that would have otherwise been released from system storage. The concentrate, or reject, stream would be discharged back to the MODE.

The Arizona Department of Environmental Quality asserted that both a discharge permit and an aquifer protection permit would be required for the demonstration run. Since the lead time for such permits associated with the operation of a desalination plant was uncertain, a back-up alternative that was considered was to simply return the product water to the MODE. This outcome would not have been desirable because it would not have contributed additional water to the Colorado River system. Permits were obtained in time so this alternative was not implemented.

A water sampling plan was developed that identified strategic points in the desalting process where samples would be taken and analyzed during performance of the demonstration run. These key points included feed water from the MODE, product water, blended water released to the Colorado River, reject stream, and MODE water after blending with the Plant reject flow. These data could then be compared with previously calculated and modeled values and used to validate or calibrate predictive models.

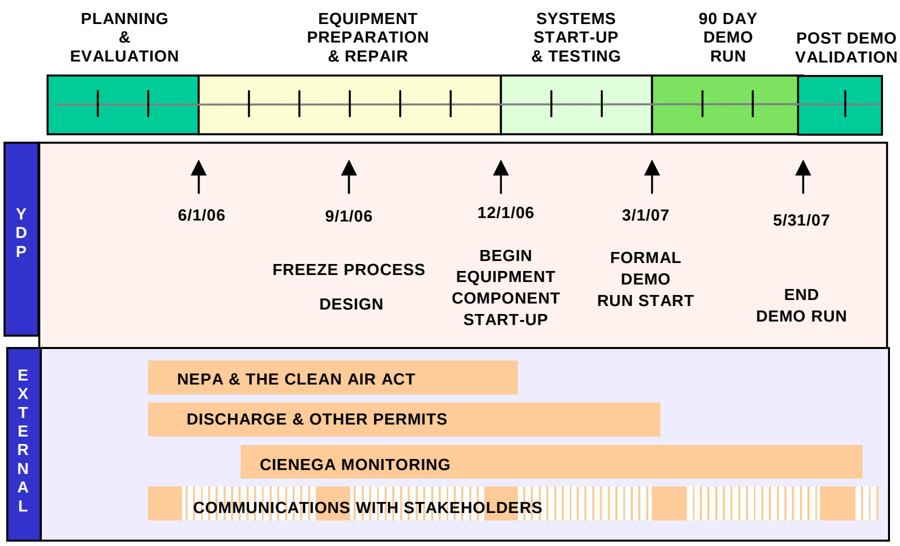
Current estimates of Plant operating costs are based on results of testing at the Water Quality Improvement Center—a research and development facility located at the Plant site, results of the 1992/1993 operation, equipment design information, and industry data. While these sources provide a valid foundation upon which to establish operation parameters and cost estimates, performance under actual conditions at the Plant can provide a greater level of confidence in Plant operational requirements, process performance, and costs. The demonstration run, then, was set up to collect additional data that will help refine these parameters and allow more accurate estimations of costs under commercial scale operation of the Plant.

Reclamation’s ongoing Bypass Flow Replacement or Recovery Study includes alternatives that feature operation of the Plant in several different configurations. Results of the demonstration run were anticipated to provide data that would improve the analysis and evaluation of alternatives in that report.

It was also determined early in the planning phase that communication with stakeholders and other interested parties would remain open during the preparation and operation of the demonstration and that results obtained during the demonstration run would be made available to the public.

Schedule

Preparation for the demonstration run was pursued along two tracks—on-site preparation at the Plant and external activities. On-site preparation included preparing equipment to operate, testing individual components, making any necessary adjustments or repairs, securing and training operators, obtaining chemicals, and contracting for electrical power. External preparation addressed policy and regulatory decisions and the actions necessary to implement those decisions. These included environmental compliance, discharge and other permits, consultation with Mexico through the International Boundary and Water Commission, and interaction with Colorado River Basin states, water users, and other stakeholders, including conservation interests. The figure below shows the schedule that was established for the phases of the demonstration and the on-site preparatory work that was required prior to beginning the test.



Prior to the demonstration run, each piece of equipment that was anticipated to be used in the demonstration was identified and inspected. Seals, packing, and other wear parts were replaced during the three phases that led up to the 3-month operation. Each piece of equipment was individually tested and evaluated to ensure that it was operating within appropriate standards and any necessary repairs were made. Once individual pieces of equipment were in operational condition, discrete systems were brought on-line, tested, and, if warranted, adjusted. Testing of these systems was performed in the sequence of flow, from the furthest upstream system starting at the MODE to the furthest downstream system at the discharge canal. The demonstration run phase began on March 1 and concluded on May 31, 2007. During the post demonstration period equipment was de-energized, vessels and pipes were dewatered, and reverse osmosis membranes were cleaned.

Technical Approach

Hydranautics Desalting Vessels

In order to operate at least at ten percent capacity, six Hydranautics control blocks would need to be used—four for first stage and two for second stage. Control blocks 11 through 6 were selected for use, although any of the other Hydranautics blocks could have been used since new control block valves and actuators had been installed for the entire Hydranautics section of the Plant.

Bright Blue Devices are Control Valves and Actuators

Each block contains 48 pressure vessels, with each vessel containing seven membranes. Three options were available as a source of the 2,016 membranes required for the demonstration—new membranes purchased specifically for this demonstration, unused membranes that have been stored at the Plant since they were purchased for the 1992/1993 operation, or membranes that were used during the 1992/1993 operation and have been stored at the Plant since that time. Because of the cost and lead time required for the procurement of new membranes, a combination of used and unused membranes that had been in storage were used for the demonstration. To the extent possible, unused membranes were utilized in the first stage of the desalting process and used membranes were utilized in the second stage. The decision to use the Hydranautics membranes in storage was based on the successful testing of both used and unused membranes during the preparation period.

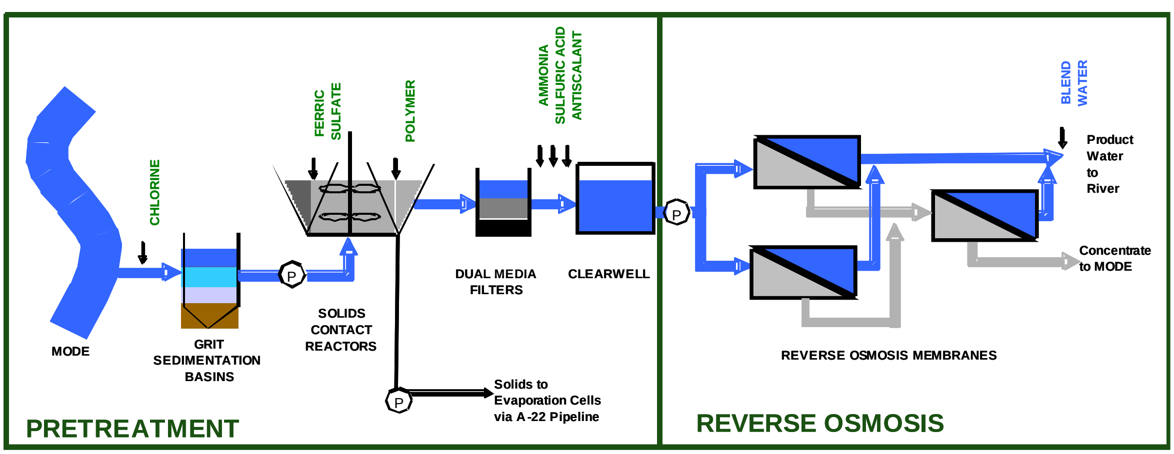
As stated earlier, a number of advances in water treatment processes have been made since 1993 when the Plant last operated and the decision was made to make the most use of these advances as practicable. As designed, the Plant uses lime and granular ferric sulfate to aid the coagulation and flocculation process. Because of promising results of using polymers and liquid ferric sulfate in tests at the Water Quality Improvement Center, lime was replaced with polymers and the granular form of ferric sulfate was replaced with a liquid form during the demonstration. If proved successful, this technical change could result in lower pretreatment costs by reducing sludge disposal volume, alleviating handling problems, and allowing more precise introduction of ferric sulfate into the reactor, thereby reducing the amount required while improving consistency of the chemical composition within the reactor.

As part of the process of resolving design deficiencies, aluminum-bronze control block valves and actuators were replaced in the Hydranautics portion of the Plant. The replacements are fabricated of stainless steel and the replacement was completed prior to beginning the demonstration run.

Another change from the original design was the movement of the injection points for sulfuric acid and ammonia upstream in the water treatment process. With the injection points placed just ahead of the clearwell, chemical mixing was improved and water in the clearwell, as well as the membrane portion of the Plant, benefited from the improved consistency in water chemistry.

A new control and monitoring system was installed prior to the demonstration run and was tested for performance. State-of-the-art digital instrumentation and control equipment allow for more points of measurement and more precise control of the desalting process.

A simplified schematic of the desalting process—broken down to the pretreatment and reverse osmosis portions—as used during the demonstration run is shown below.



Equipment Preparation

During the planning, equipment preparation, and systems testing phases of the schedule, all equipment that would either be used during the demonstration or would be relied upon as backup was identified and tested for operational performance. That equipment included:

- Pretreatment Equipment
    - Intake traveling screen east
    - Intake traveling screen west
    - Grit sedimentation basin #1
    - Grit sedimentation basin #4
    - Intake pump #1
    - Intake pump #5
    - Solids contact reactor #2
    - Solids contact reactor #3
    - Dual media gravity filter #7
    - Dual media gravity filter #8
    - Clearwell
- Reverse Osmosis Equipment
    - High pressure reverse osmosis pump #1
    - High pressure reverse osmosis pump #2
    - High pressure reverse osmosis pump #3
    - High pressure reverse osmosis pump #4
    - Hydranautics control blocks #11 through #16
        - First stage control blocks are #11 through #14
        - Second stage control blocks are #15 and #16
- Chemical Feed Systems
    - Chlorine
    - Ferric sulfate
    - Polymer
    - Ammonia
    - Sulfuric acid
    - Anti-scalant

This equipment was, for the most part, found to be in a condition that would be expected for a plant that had been maintained but not operated in 14 years. Two pipes, however, were found to be damaged to an extent that unanticipated time-consuming repairs were required. A 72-inch diameter underground pipe that conveys water between the grit sedimentation basins and the solids contact reactor deteriorated at one location to a condition which required a patch. Deterioration was believed to be the result of prolonged exposure to ground water. An 8-inch wide seal was placed around the entire circumference of the pipe at the location of greatest damage. This patch successfully eliminated leakage and there were no performance issues with this pipe during the demonstration.

Spalling of Concrete Pipe Lining

The other location of a pipe that needed an unanticipated repair was the 42-inch diameter pipe that extends from the dual media gravity filters to a weir box. A 12-foot section of this pipe experienced significant spalling of the concrete lining where fragments, chips, or slabs of concrete had loosened and separated from the pipe. Since this pipe was designed for continuous interior coverage by water and it had been dewatered during the 14 years of Plant dormancy, it is speculated that prolonged exposure to air contributed to the lining deterioration. After installing a temporary lining replacement, the pipe performed satisfactorily during the demonstration.

When the Plant ceased its 9-month period of operation in 1993, engineers and other technical personnel were still actively engaged in identifying portions of the Plant that were not performing according to design specifications. These findings came to be known as design deficiencies and it was recognized that they would have to be resolved before the Plant could be operated as originally intended[3]. Of the 18 design deficiencies that have been identified since Plant operation in 1993, nine have been resolved. In order to conduct the three-month demonstration operation of the Plant, six of the nine remaining deficiencies needed to be addressed either permanently or temporarily prior to the demonstration run. The list below identifies each of these design deficiencies and how it was addressed.

[3] For a description of these design deficiencies, see Yuma Desalting Plant Readiness Assessment, Haddon Jackson Associates, Inc., October 2002; also 2004 Assessment Update.

Design Deficiency	Method of Addressing for the Demo
Replace high pressure Reverse Osmosis pumps	Rebuilt two pumps prior to the demo
Replace control block valves and actuators	Replaced equipment for Blocks 11 – 16 prior to the demo
Repair ammonia system	Temporary system used for the demo
Replace failed segment of reject piping	Repaired before and during the demo
Replace Silt Density Index equipment	Manual Silt Density Index tests performed during the demo
Install MODE II blend system	Blending performed manually during the demo

The Plant's water treatment process consists of a number of stages with each stage removing smaller particles than the prior stage, beginning with grit and other large particles at the grit sedimentation basins and ending with salt molecules at the reverse osmosis membranes. Because of this required sequence, systems startup and testing must also be done in that order. Prior to beginning the demonstration, each of the systems was tested independently, starting at the upstream end of the treatment process. These individual system tests were completed in late February 2007, prior to commencement of the demonstration run.

Power and Labor Preparation

Since the existing power contract for the Yuma Desalting Plant facility was insufficient to meet the additional power requirements for the demonstration, attempts were made to secure a firm price contract to meet this need. A firm price offer of $57 per MWh was obtained, but because that price was higher than historical costs over the past several years for the months of March through May, spot market power was purchased for the demonstration. This resulted in an average cost during the three months of about $53 per MWh.

Five additional water treatment plant operators were required for the demonstration run. These operators were provided by the contractor Reclamation uses for operation and maintenance of the Plant and the Water Quality Improvement Center. Operators were brought on during systems startup and testing in order to assist in that work, become familiar with the Plant, and complete necessary training.

Regulatory and Outreach Preparation

Federal regulatory matters were addressed in preparation for the demonstration run. With respect to the National Environmental Policy Act (NEPA), the rules allow a categorical exclusion for research activities and for routine planning investigations. After consultation with compliance specialists it was determined that a short-term operation of the Plant at about ten percent of full capacity in order to collect data, test equipment and procedures, and provide information for planning purposes met both the letter and spirit of NEPA's categorical exclusion provisions. This decision was supported by conservation interests based within the United States.

The Clean Air Act requires facilities that use certain listed substances to have a Risk Management Plan and Process Safety Management Program in place and in use when any listed substance is present in quantities at or exceeding certain thresholds. The Plan and Program are administered by the Environmental Protection Agency and the Occupational Safety and Health Administration, respectively. Chlorine (a listed substance) is used in the Plant's water treatment process for disinfection and more than 2,000 pounds (the threshold listed in the regulations) was required to be on-site during the demonstration; therefore, a Plan and Program were prepared and implemented for this chemical.

The Arizona Department of Environmental Quality asserted permit authority over the demonstration run, including a discharge permit to be issued under delegated federal authority and an aquifer protection permit to be issued under state law. Reclamation filed the application for a temporary aquifer protection permit in July 2006. An application for operation of the demonstration under Arizona's *de minimus* general discharge permit was filed in September 2006. On February 26, 2007 the Arizona Department of Environmental Quality granted Reclamation permission under Arizona's *de minimus* provisions to discharge product water blended with untreated MODE water to the Colorado River for the demonstration operation. On that same date, Reclamation was granted a temporary aquifer protection permit for the demonstration run.

Prior to initiating the demonstration, Reclamation consulted with key stakeholders, including the Lower and Upper Colorado River Basin States, Central Arizona Water Conservation District, Southern Nevada Water Authority, Environmental Defense, the Pacific Institute, the Sonoran Institute, and Mexico. Discussions with the Basin States took place during routine meetings that regularly occur between representatives of the States and Reclamation. A Workgroup specifically created by the Central Arizona Water Conservation District (CAWCD) to address the Yuma Desalting Plant/Ciénega de Santa Clara issues was used to consult with the conservation interests. Mexico was kept informed of the demonstration operation status through normal International Boundary and Water Commission meeting processes.

Demonstration Results

Safety

Safety was a primary consideration, both during the preparation period and during the demonstration run. Normal safety procedures that Reclamation enforces at the Plant were effective in preventing accidents and no safety incidents were reported during that period.

Safe operation of the demonstration posed additional challenges. Proximity of Yuma Area Office (which shares the Plant site) personnel who do not have work responsibilities directly associated with Plant operation and high interest by stakeholders in touring the Plant during the demonstration had to be reconciled with potential safety hazards such as pressurized pipes, energized electrical equipment, and use of industrial chemicals. While these potential hazards are common to any process industrial plant, access by the public during the demonstration operation and the proximity of employees both familiar and unfamiliar with direct plant operations required special attention to ensure adequate protection and insure a safe environment for all visitors, operating personnel, and personnel in the Yuma Area Office.

During the demonstration run preparation and operation, access to parts of the 60-acre Yuma Desalting Plant site was restricted to personnel who were directly involved in the demonstration. Off-limit areas were in place for nearly six months—two months during system start-up and testing, three months of demonstration operation, and several weeks after completion of the demonstration while certain vessels were dewatered, equipment was de-energized, and chemicals were removed.

Limited exceptions to this restriction occurred on March 20, 2007 when nearly 300 people were at the site for the official demonstration ceremony and during tours provided by Reclamation upon request. Tours were particularly popular; more than 700 visitors toured the Plant during the demonstration operation in groups of typically 6 to 10 people. Since a formal tour request and scheduling process was never implemented, senior managers and technical personnel were often called upon to participate in tours on short notice. In spite of these conditions, safety of people and security of the Plant were not compromised and the demonstration was completed without experiencing an accident or significant security episode.

Process Flow

As previously stated, membranes have been stored at the Yuma Desalting Plant since it last operated in 1993. Some of those membranes had been used during the 1992/1993 operation and some had been stored without having ever been installed in a membrane vessel. These membranes are designed to produce a product water quality of 150 to 300 mg/l total dissolved solids. A typical membrane will begin operation at the lower end of that range, and then move toward the upper end over time. After storage for over 14 years, the combined total of all the demonstration membranes—used and unused—produced an average product total dissolved solids concentration of 252 mg/l. During the demonstration, the membranes were operated at a pressure of about 300 pounds per square inch. Detailed compilation and analysis of data collected during the demonstration run was completed by Reclamation and Reclamation's operation and maintenance contractor. Although the Plant is designed for energy recovery on the reject side of the membranes vessels, that feature was not used during the demonstration because at least one-third capacity operation is required to take advantage of the energy recovery units.

Over the duration of the demonstration, a total of 4,349 acre-feet of water with an average salinity concentration of 1,155 mg/l was discharged to the Colorado River for delivery to Mexico. This water was made up of 2,632 acre-feet of product from the Plant at an average salinity concentration of 252 mg/l blended with 1,717 acre-feet of MODE water at an average salinity concentration of 2,539 mg/l. Under normal Plant operation, the blending ratio would be determined by the requirement to meet salinity limits established by Minute 242 of the Treaty of 1944 for Colorado River water delivered to Mexico. However, for the demonstration run, blend water from the MODE was used in proportions necessary to meet pH levels required by the Arizona Department of Environmental Quality discharge permit but still within the salinity limits of Minute 242.

The demonstration run period from March 1, 2007 through May 31, 2007 spanned a total of 2,208 hours. The pretreatment portion of the Plant—from the intake to the clearwell—ran continuously for the entire 2,208 hours. The desalting portion of the process had a total operating time for the demonstration of 2,164 hours, for an on-stream factor of 98 percent. There were four outages totaling 44 hours in the desalting section of the process. The root cause of three of the four outages was leaks in the aluminum-bronze piping. Combined, the duration of these leak outages was 41.5 hours. Attempts were made to repair the leaks during the outages. Some of these attempts were successful, some were not. None of the leaks, however, jeopardized the demonstration. Water leaks are not unusual for a water treatment facility and the Plant's drain galleries handled the leakage volume without problems. A fourth outage—an unscheduled one—occurred as a result of human error. An operator performing routine service on the Yuma Area Office's service water system, which provides cooling water for the reverse osmosis pumps, left a service water pump in manual mode rather than automatic mode. As a result, the reverse osmosis pump lost its cooling water supply and the pump automatically tripped off-line. That outage lasted two-and-a half hours. Although two-and-a-half hours of production were lost, there was no impact to the membranes since they were never left in a dry state.

During the course of the demonstration, four other unusual operating events occurred.

- An instrument that measures the level of the sulfuric acid in the Plant's acid storage tank failed. Instrumentation readings indicated that the tank was partially full when, in fact, it was nearly empty. Plant operation continued for two hours without acid until an already scheduled acid delivery arrived. The instrument was repaired and operating procedures were modified to include manual sight-glass readings for the tank level. There was no impact to the desalting process or membranes because the clearwell volume is so large compared to the volume of water going through the membranes that water chemistry actually changed very little during the two-hour period.

- Several days into the demonstration run the flow in the MODE decreased unexpectedly as a result of a partial MODE outage. This outage was for necessary maintenance of the MODE. In order to maintain sufficient pressure (head) to allow the blending of Plant product water with untreated MODE water prior to discharge into the Colorado River, gates in the MODE were partially closed. The gate adjustment increased the MODE water level so that adequate head could be maintained.

- During the last month of the demonstration, one of the three backwash sump pumps for the dual media gravity filters exhibited unusually high vibration. Although the pump continued to perform satisfactorily, such vibration is not typical. This pump is now scheduled for disassembly and repair. The other two backwash sump pumps both seized and failed during the demonstration run preparation phase and were refurbished prior to commencing the demonstration. Both of these refurbished pumps performed well and without incident during the demonstration.

- During the final month of the demonstration run, the rake at the bottom of the solids contact reactor stopped rotating because of an unexpectedly rapid buildup of sludge. Since this event occurred late in the demonstration and the rate of sludge accumulation was known, it was determined that space in the solids contact reactor would more than handle the volume of sludge that would accumulate prior to the end of the demonstration. Because it would have been a significant effort to attempt to remove the sludge, restart the rake, and adjust the solids contact reactor process, the sludge was simply allowed to accumulate in the reactor until completion of the demonstration run.

Aluminum-Bronze Pipe

Over 11,000 linear feet of aluminum-bronze pipe is installed in the Plant. It has long been known that aluminum-bronze pipe could present an operational problem because some of that piping leaked during operation of the Plant in 1992/1993. Research and operational experience at thousands of desalination plants in use today indicate that stainless steel, spun fiberglass, and polyvinyl chloride provide performance reliability superior to that of aluminum-bronze.

During the demonstration start-up and operation, the Plant experienced pipe leaks at nine locations, three of which caused process outages as explained earlier. Eight of the nine leaks occurred at welds in the piping. The ninth leak was in a pipe wall. Six of the nine leaks were successfully repaired, but repeated attempts to repair the other three proved unsuccessful, confirming welding expert's assertions that aluminum-bronze is one of the most challenging alloys on which to perform field welds. As pointed out previously, leak volume was very small compared to process flow and there were no adverse impacts on the desalting operation.

Leak in Aluminum-Bronze Pipe during Demonstration Operation

Independent of the demonstration project, a comprehensive assessment of the Plant piping was performed under contract during 2007 (CH2MHill, 2008). This assessment included x-ray examination of a statistically significant sample of pipe welds, most of which were found to be substandard. Based on results of the assessment, experience during the demonstration run, and current industry knowledge, Reclamation believes that all aluminum-bronze pipe will need to be replaced.

Pretreatment

The most significant operating challenge during the demonstration run was optimizing the performance of the pretreatment portion of the Plant. The original Plant design contemplated the use of lime and ferric sulfate for coagulation and flocculation with the added benefit of partial softening of the feed water. However, this requires large quantities of either hydrated lime [$Ca(OH)_2$] or quicklime (CaO) and produces large quantities of sludge that must be either regenerated or disposed of. Pilot testing over the past several years has demonstrated that the use of a polymer as an agent for coagulation and flocculation is effective and can result in significant reductions in material handling and disposal volumes. Scaling up the use of polymers from laboratory pilot tests to operation at ten percent of Plant capacity was a challenge and a process of experimentation.

During the demonstration, polymers, along with ferric sulfate, were added to water in the solids contact reactor. These additives react with particulates in the water, causing small particles to stick together and form clumps (coagulation and flocculation) that sink to the floor of the reactor. The floor of this round structure slopes toward the center and a rotating rake continually sweeps the accumulated sludge into this depression. Periodically, a blow-down procedure is used to force the accumulated sludge out of the center of the reactor and into a disposal system.

Two different polymers were tried during the demonstration operation, both separately and in combination with one another. The optimal mix and dosages of polymers were not established during the demonstration run and additional testing is necessary. The testing of polymers during the demonstration run did not adversely impact the quality of water provided to the reverse osmosis membranes, since surplus dual media gravity filter capacity and more frequent backwashing of those filters allowed for sufficient particulate removal of pretreated water prior to the membranes.

Effect of Operation on Water Chemistry

During the demonstration run Reclamation monitored the water chemistry of the flow discharged to the Colorado River from the YDP. Discharged water was in full compliance with the Clean Water Act. Monitoring was conducted in accordance with the discharge and aquifer protection permits issued by the Arizona Department of Environmental Quality for the demonstration run of the YDP. Parameters monitored included pH, nitrate, nitrite, total nitrogen, total phosphorous, residual chlorine, metals and phenols (15 compounds), volatile organic compounds (28 compounds), acids (11 compounds), base and neutral compounds (46 compounds), and pesticides (25 compounds). Monitoring results were reported to the ADEQ.

Water chemistry at the Ciénega de Santa Clara was monitored in a non-federal program before, during, and after the operation of the YDP. The non-federal monitoring program was funded by the CAWCD, designed and implemented by the Centro de Investigación en Alimentación y Desarrollo (CIAD) in Mexico, and overseen by the University of Arizona. This monitoring program provided some baseline data regarding water chemistry in the Ciénega. In addition, results indicate that “the 3-month, 10%-capacity, test-run of the YDP did not significantly affect water quality in the Ciénega de Santa Clara. In particular, salinity levels in the CSC [Ciénega de Santa Clara] during the test-run were not significantly different from salinity levels before and after the test-run.” (Flessa, 2007) Flessa (2007) also concluded that “salinity . . . is the most important aspect of water quality affecting the biological habitats of the Cienega de Santa Clara”, but that from the demonstration run monitoring program “it is not possible to predict changes in water quality resulting from longer duration or higher capacity operation of the YDP.”

Costs for the Demonstration Run

Careful records were kept of labor, supplies, equipment, energy, and material quantities and costs for both the preparation period and the actual demonstration operation.

Two major sources of labor were utilized for the demonstration run—Reclamation's operation and maintenance contractor and Reclamation employees at the Yuma Area Office. Reclamation's contractor had been retained for a number of years to maintain the Plant and supplied maintenance and operation employees for the Plant preparation activities and the demonstration run. During demonstration preparation and operation Reclamation was responsible for overall management and oversight and provided engineering and chemistry expertise. A breakdown of labor cost is shown on the following table.

Labor Cost

Phase	Contractor	Reclamation	Total
Preparation	$ 865,031	$ 386,181	$1,251,212
Demonstration	$ 332,478	$ 122,448	$ 454,926
Total	**$1,197,509**	**$ 508,629**	**$1,706,138**

Costs in the table above do not include labor costs for actions to obtain required permits and meet regulatory requirements. Much of those regulatory costs were incurred by contractors who assisted in the NEPA compliance process, obtaining discharge and aquifer protection permits from the Arizona Department of Environmental Quality, developing sampling and analysis protocols for permit compliance, and assisting in the construction and implementation of the Risk Management Plan and Process Safety Management Program. These costs were broken out separately, along with other costs, as shown on the table below.

The first item in the table below (Labor) presents the same costs as shown in the Labor Cost table above, further broken down into the Preparation and Demonstration phases. Labor costs include administrative, technical, and management support, as well as on-site labor.

Cost by Item

Item	Preparation Phase	Demonstration Phase
Labor	$1,251,212	$ 454,926
Permitting & Regulatory Compliance	$ 151,083	$ 0
Temporary Systems	$ 36,726	$ 0
Chemicals	$ 78,808	$ 299,595
Electrical Power	$ 26,404	$ 203,660
Wear Parts and Supplies	$ 151,319	$ 76,179
Total	**$1,695,552**	**$1,034,360**

Because of the level of Plant operation during the demonstration, special systems for polymer, anti-scalant, and ammonia injection were required. These systems were procured only for the duration of the demonstration preparation and operation and are shown as a preparation cost. Because they were only temporary features, they were either skid-mounted or mounted on trailers for ease of installation and removal.

Temporary Ammonia Injection System

Chemicals used prior to commencing the demonstration run were utilized for treatment process testing and adjustment. Chemicals used before and during the run included anhydrous chlorine, ferric sulfate, two types of polymers, sulfuric acid, ammonia, and an anti-scalant. By quantity, the most used chemical was sulfuric acid; 1,028 tons were used during the demonstration run. Sulfuric acid also accounted for about 60 percent of total chemical costs during the demonstration operation.

About 495 megawatt-hours of electricity were used in preparing for the demonstration and an estimated 3,819 megawatt-hours were consumed during the three-month run. During this period the average cost of spot market electrical power was about $53 a megawatt-hour.

Wear parts and supplies included seals, gaskets, paint and coatings, fittings, lubricants, conduit, wire, equipment parts, and similar items that were required both before and during the actual demonstration.

Cost Estimates for Commercial Scale Operation

Although it is recognized that a linear extrapolation cannot be made from costs for the demonstration run to costs for commercial scale Plant operation, data from the demonstration run helped validate previous models and cost estimates for commercial scale Plant operation at various capacities.

While a genuine effort was made to use data from the demonstration run and other recent studies in the refinement of cost estimates for preparation and operation of the Plant at a commercial scale, time and funding constraints limited the level of detail that could go into that effort. The following cost ranges, using only general relationships, are thought to reasonably represent cost estimates for operation at one-third, two-thirds, and full capacity, although they are quite preliminary in nature. The general way in which costs were derived did not allow a specific breakdown by component.

The following table shows general ranges for initial costs required to prepare the Plant for commercial scale or full scale operation based on information from the demonstration run and other activities that were undertaken to determine the most current Plant requirements.

YDP Initial Costs Required Prior to Operation

Level of Operation	**Cost, million**
One-Third	$25 – 32
Two-Thirds	$36 – 42
Full Capacity	$39 – 50

These costs are higher than those presented in the 2004 Readiness Assessment[4] and the 2005 report to Congress (Reclamation, 2005). For example, the high end of the full capacity range increased from $28 million in the 2004 assessment to $50 million for the current estimate. The primary reason for this increase is the replacement of the Plant's aluminum-bronze pipe, estimated to cost about $16 million for full capacity operation. Another $5 million is estimated to be required for other actions that have been identified since 2005 as being necessary prior to commercial operation of the Plant, including

- seismic upgrades to the desalting building,
- repairs to the railroad that is used to bring material to the Plant,
- repairs to the concrete lining of the MODE/Bypass Drain, both in the United States and in Mexico (the United States has maintenance responsibility for the entire length of the channel),
- additional monitoring and control instrumentation that allows for more precise chemical use and quicker, more accurate detection of process deviations,
- repair of the existing cathodic protection system for pipes, and
- upgrading to acoustic Doppler flow meters on the high pressure piping.

[4] The costs reported in 2005 to Congress were developed in 2004 Readiness Assessment report.

In addition, price increases for reverse osmosis membranes has contributed about another $1 million to the one-time cost of Plant operation at commercial scale or full capacity.

While the demonstration run showed that membranes that have been in storage for the past 14 years are still in good enough condition to provide adequate performance, the cost for purchasing all new membranes was used in the initial cost table above. There are three reasons for assuming all new membranes will need to be obtained at Plant startup. First, there are only enough membranes in storage to supply one-third of the Plant, so new membranes would need to be purchased for the other two-thirds of the Plant. Second, the procurement lead time is such that by the time the final membranes are delivered to the Plant, additional membranes would be necessary. And, third, there is no way of knowing how long the 20-year-old membranes currently in storage will perform adequately.

The following table shows the estimated cost range for blended water delivered to the Colorado River for commercial scale or full operation of the Plant. The annualized cost is the sum of annual operating costs and amortization of the initial one-time cost. Water delivered to the Colorado River as contemplated under the original authorization is a blend of product water from the membranes mixed with enough MODE water to optimize the quantity released to the river while staying within the salinity requirements of Minute 242. This blended quantity varies depending upon assumptions for the process recovery factor and the on-stream factor.

YDP Estimated Annual Cost Range

Level of Operation	Cost, acre-foot
One-Third	$491 – 890
Two-Thirds	$358 – 617
Full Capacity	$322 – 556

Because a portion of these costs reflects a five-year amortization of the initial startup costs shown in the table on the previous page (which incorporate the additional cost items—$22 million in the case of the high end of the full capacity range), these annual costs are also somewhat higher than those previously reported. This had an especially significant impact on the cost of water for the Plant operation at one-third of full capacity.

The cost ranges above account for known uncertainties in estimating key components, such as power, process recovery efficiency, on-stream factor, and amortization period. Current market volatility in the pricing of some components, such as nickel in stainless steel, construction materials, and some chemicals, such as sulfuric acid, will influence future costs, if such volatility persists.

The costs developed for this report are applicable only for operation of the Plant using as feed water exclusively Wellton-Mohawk Irrigation and Drainage District groundwater diverted from the MODE and product is blended with MODE water before being discharged into the Colorado River. To the extent allowed by law, there are other operational possibilities which use other sources of feed water, other pretreatment processes, or other use of Plant product water (released to the Colorado River, potable water use, or use for agricultural irrigation.) Costs for these other operational possibilities would require refinement of existing costs for certain features and separate development of costs for other features.

Epitome

After a year of preparation, a demonstration of Yuma Desalting Plant operation at about 10 percent of capacity was successfully performed between March 1 and May 31, 2007. This demonstration provided information on preparation required for Plant operation, confirmed that—with normal equipment rehabilitation—the Plant can operate after many years of dormancy, advanced Plant readiness, provided information on costs, presented opportunities for testing technical advances, and allowed for monitoring water chemistry within the United States and, in a non-federal program, at the Cienega during Plant operation at 10 percent capacity.

The desalting process had an on-stream factor of over 98 percent, with the longest outages attributed to leaks in the aluminum-bronze piping system. Other operating events occurred, although they did not result in process down time. Polymers were tested in the pretreatment stage in place of lime. These tests indicated that the use of polymers holds promise, but more testing is required before a recommendation can be made to replace lime with polymers.

The permitting process was more complex than originally expected and will need to receive attention if further Plant operation is contemplated.

Total cost of preparation and demonstration operation was $2,729,912, with $1,034,360 of that for the operational phase alone. The highest cost items for operation were labor, chemicals, and electric power, in that order. Because of the nature of this test, that order does not necessarily represent the relative order of costs for commercial scale operation.

Using information from the demonstration run and other sources, cost of water delivered to the Colorado River from the Plant operating at full capacity was estimated to range from $322 to $556 an acre-foot.

Summary

The Yuma Desalting Plant has not been operated since 1993 when one third of the Plant was operated for a 9-month period. Increasing water demands on the Colorado River in the Lower Basin and low watershed runoff during the record dry years between 2000 and 2007 increased interest on the part of Colorado River Basin states in pursuing operation of the Plant. In response to that interest, Reclamation agreed to a three-month demonstration of Plant operation at approximately 10 percent capacity.

Objectives

Five objectives were identified for this demonstration operation:

- Show that the Plant could run.
- Validate cost and performance estimates.
- Demonstrate the Plant's use of current technologies.
- Improve overall Plant readiness.
- Allow for the measurement of water chemistry changes.

The design and implementation of the demonstration run, which began on March 1, 2007 and was completed on May 31, 2007, were focused on meeting each of those objectives.

Equipment and Systems

The Plant is designed to desalt water from the MODE, which is supplied by groundwater pumping in the Wellton-Mohawk Irrigation and Drainage District. Pumping rates are typically based on the need to maintain a sufficiently low water table to allow for commercial agriculture and stable infrastructure, such as roads and building foundations. While recent pumping has averaged about 108,000 acre-feet a year, fluctuations can occur over the year.

During the demonstration, the pretreatment portion of the Plant operated continuously, while the desalting portion had an on-stream factor of 98 percent. Down time on the desalting part of the treatment process was due to four outages, three to attempt repair of pipe leaks and one due to operator error which led to shut-down of the high pressure membrane pumps. Significant contributors to the high on-stream factor were proper maintenance of the Plant equipment during its ready-reserve status and careful preparation of the equipment prior to initiation of the demonstration run. This experience suggests that Plant readiness would be enhanced if the preventative maintenance program was changed to increase the frequency of functional testing of individual pieces of equipment as well as entire systems.

Nine leaks in the aluminum-bronze piping occurred during the three-month demonstration run; 94 percent of the outage time during the run was the direct result of these leaks. While it was previously known that aluminum-bronze had not proved to be a good material choice for use at the Plant, the demonstration operation confirmed the extent of the problem. After the demonstration run, an independent assessment of the piping system by a contractor established its scope and scale, leading to the belief that replacement of all the aluminum-bronze is necessary prior to commercial scale operation of the Plant.

Experimentation with polymers as a coagulation and flocculation agent in the solids contact reactor led to the conclusion that more testing is required on this promising process.

During the demonstration operation, 4,349 acre-feet of blended water at a salinity concentration of 1,155 mg/l was discharged to the Colorado River for delivery to Mexico. This water was made up of 2,632 acre-feet of product from the desalting process at an average salinity of 252 mg/l blended with 1,717 acre-feet of MODE water at an average salinity of 2,539 mg/l.

Permits

For the demonstration run Reclamation acquired permits, necessary under the Clean Water Act from the ADEQ. The acquisition of the permits was complicated by the unusual nature of the operation and facility. These challenges required extra effort on the part of both Reclamation and ADEQ and resulted in the permitting activity requiring the longest preparation lead time. Because the Plant is a desalination plant treating agricultural return flow at a site with a mix of operating and dormant facilities, consideration should be given to determining the applicable law and appropriate compliance for any future operations.

Sustained operation of the Plant may require permits from the Arizona Department of Environmental Quality. Early coordination with ADEQ is recommended.

Water Chemistry Monitoring

While operating the plant Reclamation monitored the chemistry of water returned to the Colorado River and in compliance with the permits. Well over 100 water quality parameters were monitored during the run and results were reported to the ADEQ.

The Central Arizona Water Conservation District funded an effort to monitor water chemistry in the Ciénega before, during, and after the demonstration run. The monitoring program was implemented by a conservation entity in Mexico, while the University of Arizona performed contractual oversight and documented program results. This effort provided some baseline data regarding Ciénega water chemistry.

In addition, results provided to Reclamation indicated that demonstration operation of the Plant did not significantly affect water chemistry in the Ciénega de Santa Clara, although the impact of commercial scale or full capacity operation could not be established.

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Costs

All costs associated with the demonstration were carefully recorded in a way that they could be broken down by phase and line item. Total cost to prepare for the demonstration was about $1,700,000, while the demonstration itself cost just a little over $1,000,000. Labor was the highest cost item for the preparation phase, followed by permitting/regulatory compliance, then wear parts and supplies. Labor was also the largest cost for the demonstration run, but was followed more closely by chemicals and electric power.

Preliminary cost ranges for commercial scale start-up and operation of the Plant were estimated using information from the demonstration run as well as other recent assessments. While costs compiled for the demonstration run accurately reflect the demonstration experience, those costs cannot simply be extrapolated to estimate commercial scale operation. Rather than a direct, linear application to Plant operation, both cost and performance information acquired during the demonstration would have to be used as inputs to existing Plant operational models in order to adequately refine estimates of Plant start-up and operating costs. Adjustment and application of those models based on demonstration results were beyond the available time and budget allocated for the demonstration project. However, due to the high interest in updated commercial scale operation costs, preliminary cost ranges were estimated for both initial one-time costs and for total annual costs. Those cost ranges and a comparison with costs presented in the 2005 report to Congress (using 2004 costs)[5] are shown on the table below.

[5] The costs reported in 2005 to Congress were developed in 2004 Readiness Assessment report.

Comparison of Cost Estimates between 2004 and Present

Level of Operation	2004 Initial Cost, million	2004 Annualized Cost acre-foot	2007 Initial Cost, million	2007 Annualized Cost acre-foot
One-third Capacity	$9 – 11	$428 – 684	$25 – 32	$491 – 890
Two-thirds Capacity	$16 – 19	$323 – 506	$36 – 42	$358 – 617
Full Capacity	$23 - 28	$307 - 482	$39 – 50	$322 – 556

The major reason for the higher costs in 2007 is the inclusion of replacement of all the aluminum-bronze piping in the Plant prior to operation. That accounts for about $16 million of the initial cost difference between the current $50 million estimate and the $28 million 2004 estimate at the high end of the full capacity cost range. Requirements not previously anticipated (rebuild supply railroad, seismic upgrade of buildings, rebuild pipe cathodic protection system, etc.) contributed another $5 million to that cost difference. Another factor was a price increase in reverse osmosis membranes.

Conclusion

Each of the five objectives established for the demonstration run were met during the 90-day operation. The demonstration confirmed that the Plant could operate successfully after sitting idle for an extended period of time, allowed opportunities for testing current technology, and provided information for updated cost estimates. The demonstration was completed with few unexpected events. Using data developed from demonstration results, unit cost of water delivered to the Colorado River is estimated to be between $322 and $556 an acre-foot for full capacity operation.

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