New Technologies and Split Treatment Result in Increased Production Capacity and Improved System Performance for Clearwater

Colin Hobbs, Craig Montgomery, Jorge Arevalo, Fred Hemerick, and Lan-Anh Nguyen

The City of Clearwater (City) owns and operates the reverse osmosis (RO) water treatment plant No. 1 (plant) that was originally constructed in 2003. Similar to many brackish water RO facilities, the City blends pretreated raw water with RO permeate to maximize production while minimizing operational costs. In the case of this plant, the City blends 1 mil gal per day (mgd) of pretreated blend water with 2 mgd of RO permeate; however, the City's potable water demands exceeded the permitted capacity of the plant. As such, the City relied on Pinellas County to augment its potable water supplies. Concerned with losing more control over the treatment, quality, and cost of its potable water supplies as demands increase, the City sought to increase its potable water independence. To this end, it retained the services of CDM Smith to increase the production capacity of the plant by 50 percent.

While the consulting engineering firm that originally designed the plant considered its future expansion, CDM Smith's vision of the expansion differed significantly. Per the original design, expansion of the plant was predicated upon the installation of additional treatment units, including two new dual-media pressure filter units, one new membrane feed pump, one new RO train, one new blended water transfer pump, and other ancillary systems. As this approach simply called for the duplication of existing treatment processes, no improvements in plant performance or operational enhancements were expected. Furthermore, in order to accommodate the new membrane process equipment, extensive and costly modifications to the existing pre-engineered membrane process building would be required.

Following a comprehensive evaluation of the existing plant, CDM Smith developed an alternate approach to the expansion, one that focused on improving and enhancing plant operations while simultaneously increasing its production capacity. Through a series of extensive studies designed to evaluate the performance of various processes, an enhanced split-treatment process emerged as the best approach to meet the City's needs. Unique features of this project include the implementation of a new arsenic adsorption system, the use of new 440-sq-ft membrane elements to eliminate the necessity of a new RO train and associated building modifications, and the elimination of the ferric chloride coagulation process.

This article presents and discusses the original treatment process, factors that were critical to the success of the project, the approach to the process performance studies, the data collected throughout these studies, and the approach to the design of the expansion. In addition, challenges encountered and overcome throughout the course of this project, lessons learned, and select full-scale operating data will also be presented.

Colin Hobbs, Ph.D., P.E., BCEE, is senior environmental engineer; Craig Montgomery, P.E., is senior environmental engineer; and Jorge Arevalo, Ph.D., P.E., is environmental engineer with CDM Smith. Fred Hemerick is water production coordinator and Lan-Anh Nguyen, P.E., is senior professional engineer with City of Clearwater.

The reverse osmosis water treatment plant No. 1 arsenic adsorption system.

The reverse osmosis water treatment plant No. 1 decant and residual holding system.

The feed, with expanded stainless manifolds, on the reverse osmosis skids.

The then-new membrane feed pumps.

The new reverse osmosis cleaning pump.

Original Treatment Process

The plant was originally designed and constructed to produce a maximum of 3 mgd of potable water from brackish groundwater supplies obtained from the Upper Floridan aquifer. Water withdrawn from this region was characterized as mildly brackish (total dissolved solids concentration ranging from 600 mg/L to 1,000 mg/L) with elevated concentrations of iron (0.3 to 0.5 mg/L), arsenic (20 to 40 ug/L), and total organic carbon (2.4 to 3.9 mg/L). As such, the treatment process was tailored to remove these specific constituents and generally consisted of pretreatment (prechlorination, coagulation, and pressure filtration); RO membrane treatment (antiscalant addition, dechlorination, cartridge filtration, and RO); post-treatment (permeate pH adjustment, blending, primary disinfection, corrosion control, and secondary disinfection); and finished water storage and high-service pumping (Figure 1).

Pretreatment

Prechlorination. Naturally occurring arsenic in the native groundwater existed as undissociated arsenite (trivalent arsenic in the form of H_2AsO_3) at ambient pH values. As the compound's neutral charge significantly hindered its removal, the arsenite was oxidized to arsenate (pentavalent arsenic in the form of either $H_2AsO_4^-$ or $HAsO_4^{2-}$, dependent on pH) through the addition of sodium hypochlorite (NaOCl), which was injected into an above-grade section of piping downstream of the raw water booster pump station. Turbulence induced by fluid flow through the piping system dispersed the chemical through the process stream. Plant staff estimated the average and maximum sodium hypochlorite dosages to be 2.5 mg/L as chlorine (Cl_2) and 5.0 mg/L as Cl_2, respectively, as limitations of the instrumentation and control system precluded the direct measurement of prechlorination dosages.

Coagulation. The coagulation of oxidized arsenic was accomplished through the injection of ferric chloride ($FeCl_3$) into an above-grade section of piping downstream of the prechlorination sodium hypochlorite injection point, with mixing accomplished by a static plate mixer. Uncontrolled flocculation occurred in the subsequent piping system and in the headspace of the dual-media pressure filter vessels. Plant staff reported the average and maximum ferric chloride dosages to be 0.9 mg/L as $FeCl_3$ and 1.8 mg/L as $FeCl_3$, respectively.

Dual-Media Pressure Filtration. Arsenic-containing ferric hydroxide floc particles were removed from the process stream through four 12-ft-diameter pressure filters. Each vessel consisted of 9 in. of support gravel, 32 in. of silica sand, and 18 in. of anthracite. Through a series of extensive studies, the City determined that backwashing the pressure filters every 36 to 48 hours optimized the performance of the plant. Backwashing the pressure filters at this frequency prevented the breakthrough of turbidity, minimized headloss development across the pressure filters, extended the life of the cartridge filters, and extended the operating time between chemical cleaning events for the RO system.

When the plant was operated at its maximum permitted finished water production rate

Continued on page 68

From left to right: the four existing dual media filters, the arsenic adsorbers, the backwash holding tank, the booster pumps, and decant system.

The modified and expanded reverse osmosis skids.

The new ground storage tanks.

Continued from page 67

of 3 mgd, each of the four pressure filters operated at a filtration rate of 5.5 gal per minute (gpm) per sq ft. This filtration rate increased to 7.3 gpm/sq ft when one filter was removed from service for backwashing. Immediately following the filtration process, the filtrate was divided into two separate process streams: the blend stream, which was directed to the blend tanks for blending with RO permeate; and the RO feed stream, which was directed to the RO process for additional treatment.

Reverse Osmosis Membrane Treatment

Antiscalant Addition. The addition of a proprietary antiscalant product (AWC A-102 Plus, as offered by American Water Chemicals Inc.) prior to membrane treatment reduced the potential for sparingly soluble salts to precipitate within the RO process. Antiscalant was injected into the RO feed stream immediately upstream of an above-grade stainless steel static mixer located within the process bay of the membrane building. Plant staff reported the average and maximum antiscalant dosages to be 2.9 mg/L and 4.5 mg/L, respectively. Both dosages were as 100 percent product.

Dechlorination. Any chlorine residual present in the filtrate was eliminated prior to RO membrane treatment through the addition of sodium bisulfite ($NaHSO_3$), which was injected into the RO feed stream immediately upstream of an above-grade stainless steel static mixer located within the process bay of the membrane building. Plant staff reported the average and maximum sodium bisulfite dosages to be 2.7 mg/L as $NaHSO_3$ and 6.6 mg/L as $NaHSO_3$, respectively.

Cartridge Filtration. Fine suspended solids were removed from the RO feed stream through cartridge filtration, which was provided by two stainless steel cartridge filter vessels, each of which was equipped with 86 cartridge filters (30 in. long and 2.5 in. in diameter) with a nominal pore size of 1 micron. Cartridge filters were removed and replaced when the differential pressure across the filters reached approximately 5 pounds per sq in. (psi) to 7 psi which, for this facility, generally occurred on a monthly basis. When the plant was operated at its maximum permitted finished water production rate of 3 mgd, the cartridge filters operated at a filtration rate of 3.45 gpm per 10 in. of filter length.

Reverse Osmosis. The RO process produced a high-quality product water (i.e., permeate) through the rejection and concentration of dissolved solids and dissolved organic carbon on the feed/concentrate side of the membranes. This process consisted of two, two-stage RO units, each with a dedicated feed pump. Each feed pump was designed to deliver 924 gpm to its RO unit at a total dynamic head of 409 ft and was equipped with a 150-horsepower (HP) motor and a variable frequency drive. Each RO unit was designed to produce a maximum of 1 mgd of permeate at a recovery rate of 78 percent and contained a total of 30 pressure vessels. The vessels were arranged in a 22:8 array and each one housed seven 400-sq-ft thin-film composite membrane elements. The performance and productivity of the RO units were maintained by periodic chemical cleaning events. Historically, chemical cleaning events occurred on a monthly basis. When the plant was operated at its maximum permitted finished water production rate of 3 mgd, each of the RO units operated at a flux rate of 11.9 gal per sq ft of active membrane surface area per day (gfd).

Post-Treatment

Permeate pH Adjustment. The reduction in the corrosive nature of the permeate stream was accomplished, in part, through the addition of sodium hydroxide (NaOH) and the subsequent increase in pH. The sodium hydroxide was injected into an elevated composite permeate header within the process bay of the membrane building; plant staff reported the average dosages to be 7.5 mg/L. Limitations of the instrumentation and control system precluded the direct measurement of the maximum sodium hydroxide dosage; however, plant staff estimated the maximum dosage to be 15 mg/L as NaOH.

Blending and Transfer Pumping. Blending of RO permeate and pretreated blend water also reduced the corrosive nature of the permeate stream. Blending occurred in two 10,000-gal blend tanks, which were arranged in series. When the plant operated at its maximum permitted finished water production rate of 3 mgd, the blend tanks provided a theoretical hydraulic retention time of 9.6 minutes. Transfer of the blended water from the second blend tank to the ground storage tank was provided by three end-suction centrifugal transfer pumps. Each transfer pump was designed to deliver 1,000 gpm at a total dynamic head of 47 ft and was equipped with a 20-HP constant-speed motor.

Primary Disinfection. Primary disinfection of the blended water was accomplished through the addition of sodium hypochlorite (NaOCl), which was injected into the first blend tank, and turbulence induced by falling water and fluid flow dispersed the chemical throughout the blended water. Plant staff reported the average sodium hypochlorite dosage to be 2.5 mg/L as Cl_2. Limitations of the instrumentation and control system precluded the direct measurement of the maximum sodium hypochlorite dosage; however, plant staff estimated the maximum dosage to be 5.0 mg/L as Cl_2.

Continued on page 70

Continued from page 68

Corrosion Control. Corrosion within the distribution system was controlled through the addition of a proprietary polyphosphate-based corrosion inhibitor (Linear2, as offered by Sper Chemical Corp.). The corrosion inhibitor was injected into an above-grade section of piping upstream of the high-service pump station, and the turbulence induced by fluid flow through the piping system and by the high-service pumps dispersed the corrosion inhibitor throughout the blended water. Plant staff reported the average corrosion inhibitor dosage to be 3 mg/L as 100 percent product. Limitations of the instrumentation and control system precluded the direct measurement of the maximum corrosion inhibitor dosage; however, plant staff estimated the maximum dosage to be 6 mg/L as 100 percent product.

Secondary Disinfection. Secondary disinfection (i.e., monochloramination) of the blended water was accomplished through the addition of sodium hypochlorite and ammonium hydroxide (NH_4OH). Secondary disinfection chemicals were injected into an above-grade section of piping upstream of the high-service pump station, and the turbulence induced by fluid flow through the piping system and by the high-service pumps dispersed these chemicals throughout the blended water. Plant staff reported the average sodium hypochlorite and average ammonium hydroxide dosages to be 3.5 mg/L as Cl_2 and 0.9 mg/L as NH_4OH, respectively. Plant staff estimated the maximum sodium hypochlorite and ammonium hydroxide dosages to be 5.0 mg/L as Cl_2 and 1.5 mg/L as NH_4OH, respectively, as limitations of the instrumentation and control system precluded their direct measurement.

Storage and High-Service Pumping. A single 5-mil-gal (MG) ground storage tank provided storage of blended water supplies, and finished water was pumped into the distribution system by three horizontal split-case centrifugal pumps. Each high-service pump was designed to deliver 1,850 gpm at a total dynamic head of 125 ft and was equipped with a 100-HP constant speed motor.

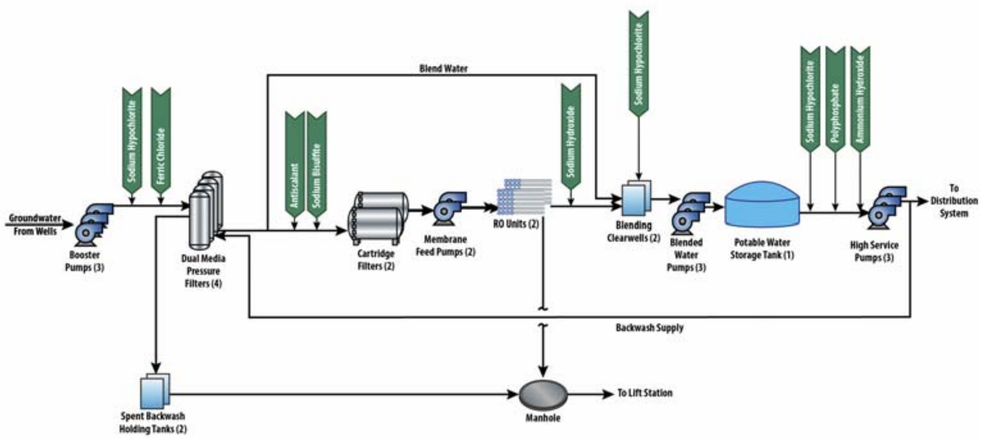

Figure 1. Original Treatment Process

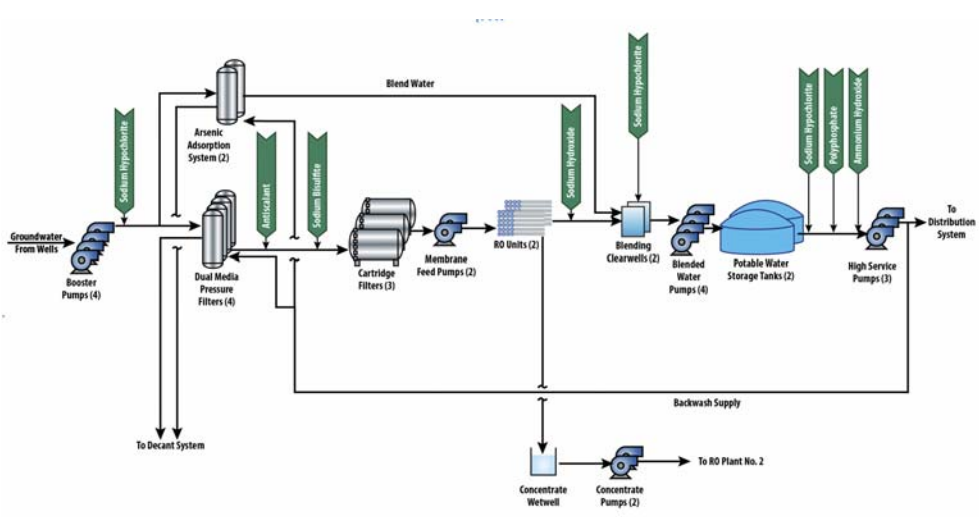

Figure 2. Enhanced Split-Treatment Process

Critical Success Factors for the Project

During CDM Smith's evaluation of the original facility, and through a collaborative predesign workshop, the City identified the following factors as critical to the success of the project:

- Increase the finished water production capacity of the plant from 3 mgd to 4.5 mgd. The increased capacity was to consist of 1.5 mgd of pretreated blend water and 3 mgd of RO permeate.
- Reduce the arsenic concentration of the blend and finished waters.
- Increase the filtration time/reduce the backwash frequency for the dual-media pressure filtration process.
- Reduce the volume of spent backwash water generated by the dual-media pressure filtration process.
- Increase the operating time between chemical cleaning events for the RO system.

Identification and Evaluation of Conceptual Treatment Processes

As the expansion concept of the original design was based upon the installation of additional treatment units, no improvements in operations were expected. Therefore, the City and CDM Smith engaged in a series of collaborative workshops to identify conceptual treatment processes and/or process modifications that were expected to satisfy all of the City's identified criteria. Conceptual treatment processes and process modifications identified for further evaluation are described as follows:

- Modified Coagulation Process – Modifications considered for the existing coagulation process ranged from increasing the ferric chloride dosage and/or increasing the flocculation time to enhance arsenic removal to eliminating the addition of ferric chloride to increase filtration time of the dual-media pressure filters.
- Modified Filtration Process – The primary modification considered for the existing filtration process focused on an alternate media configuration to reduce the fouling potential of the RO feed stream and to increase the filtration time of the dual-media pressure filters.
- Arsenic Adsorption Process – This concept focused on a new adsorption process to remove arsenic from the process stream.
- Modified RO Process – The primary modification considered for the existing RO process fo-

cused on operation at elevated flux rates. If implemented, this alternative would require the replacement of the existing 400-sq-ft membrane elements with new 440-sq-ft membrane elements, the replacement of the membrane feed pumps with larger capacity units, and other ancillary improvements to the RO skids.

- Split-Treatment Process – This concept generally focused on splitting the treatment process into two separate treatment trains: one treatment train specifically designed to minimize the arsenic concentration of the blend water, and one treatment train specifically designed to enhance RO operations. If implemented, this alternative would allow each treatment train to be optimized independently of the other train.

The performance of the conceptual treatment processes and process modifications identified was evaluated through a series of benchtop, pilot-scale, and full-scale studies. These studies were used to screen these concepts and guide the design of the expansion. Details of each of these studies are presented.

Dual-Media Pressure Filter Pilot Study – The impact of critical operating parameters on filter performance was evaluated during a 12-week pilot study. Critical operating parameters included filtration rate, ferric chloride dosage, flocculation energy/time, and media configuration. Filter performance was measured in terms of arsenic removal, iron removal, turbidity removal, and filtration time. Significant results of this study are summarized:

- The quality of the filtrate was generally independent of the filtration rate for the range of conditions evaluated (2.3 gpm/sq ft to 11.0 gpm/sq ft).
- Arsenic removal percentages generally increased with ferric chloride dosage.
- Increased flocculation time (up to 15 minutes of additional flocculation time) did not result in improved arsenic removal percentages.
- Filtrate turbidity and filter headloss values increased more rapidly with time at elevated ferric chloride dosages.
- Pilot-scale columns that utilized an alternate media configuration (i.e., 12 in. of sand overlaid by 38 in. of anthracite) generally produced superior quality filtrate at reduced headloss values when compared to pilot-scale columns, which utilized the existing media configuration (i.e. 32 in. of sand overlaid by 18 in. of anthracite).

Reverse Osmosis Pilot Study – The primary purpose of this pilot study was to evaluate the feasibility of increasing the permeate production capacity of the plant by replacing the existing membrane elements (400 sq ft each) with similar performing high surface area membrane elements (440 sq ft each) and operating the system at elevated flux-rates (i.e., 16.2 gfd). The 12-week study was conducted in three distinct phases:

- The first phase of the study utilized chlorinated, coagulated, and pressure-filtered raw water from the full-scale facility as the source of feed water to simulate RO system operation at elevated flux rates utilizing current pretreatment processes.
- The second phase of the study utilized untreated raw water from the full-scale facility as the source of feed water to simulate RO system operation at elevated flux rates utilizing minimal pretreatment processes (i.e., scale inhibition and cartridge filtration).
- The third phase of the study utilized chlorinated raw water from the full-scale facility as the source of the feed water to simulate RO system operation at elevated flux rates utilizing reduced pretreatment processes (i.e., prechlorination, dechlorination, scale inhibition, and cartridge filtration).

Significant results of this study are summarized:

- Operation of the RO system at elevated flux rates utilizing the current pretreatment process (i.e., phase 1) did not show any significant signs of fouling or scaling. Dissolved and total arsenic concentrations of the permeate stream were consistently below the detection limit of 1 ug/L.
- Operation of the RO system at elevated flux rates utilizing untreated raw water (i.e., phase 2) was feasible; however, arsenic concentrations in the permeate samples generally averaged between 3 ug/L and 7 ug/L.
- Operation of the RO system at elevated flux rates utilizing reduced pretreatment processes (i.e., phase 3) resulted in rapid ferric hydroxide fouling of the cartridge filters and of the RO membrane elements.

Increased Ferric Chloride Dosage Full-Scale Study – Results of the dual-media pressure filter pilot study indicated a direct correlation between ferric chloride dosages and arsenic removal percentages; however, operation of the plant at elevated ferric chloride dosages raised significant concerns related to the RO system. Of specific concern was the potential increase in the fouling potential of the filtrate due to increased iron concentrations and accelerated breakthrough of turbidity. As such, the City, with consent from the Florida Department of Environmental Protection (FDEP), conducted a full-scale study to assess the impacts of operating the plant at elevated ferric chloride dosages. The full-scale study was conducted at a ferric chloride dosage of 2.5 mg/L as $FeCl_3$ (approximately three times the average dosage of 0.9 mg/L as $FeCl_3$) and lasted a total of four days. Significant results of this study are summarized:

- The arsenic removal percentages of the pretreatment process increased from approximately 60 percent to 80 percent.
- The differential pressure across the cartridge filters increased more than 4 psi.
- The silt density index of the feed water increased from less than 1 to an unmeasurable value.
- The membrane system feed pressure increased approximately 4 psi.
- The differential pressure across the membrane system increased approximately 5 psi.

Arsenic Adsorption System Benchtop Study – The feasibility of utilizing a proprietary adsorptive media (i.e., Bayoxide E33, as offered by Severn Trent) for arsenic removal was evaluated in a benchtop study. Significant results of this study are summarized:

- The Bayoxide E33 adsorptive media effectively removed arsenic contained in the prechlorinated raw water to values below 5 ug/L.
- Approximately 40,000 bed volumes of prechlorinated raw water were treated with the Bayoxide E33 media prior to reaching breakthrough (i.e., 10 ug/L of arsenic in the effluent).
- Approximately 53,000 bed volumes of prechlorinate raw water were treated with the Bayoxide E33 media prior to reaching exhaustion (i.e., effluent arsenic concentration equal to the influent arsenic concentration).

Elimination of Ferric Chloride Full-Scale Study – The impact of discontinuing ferric chloride addition upstream of the dual-media pressure filtration and RO processes was evaluated during a 12-day full-scale study. The City, with FDEP's consent, suspended the addition of ferric chloride upstream of the pressure filters. With the exception of the discontinuation of the ferric chloride dosing, operation of all other pretreatment processes (i.e., prechlorination, dual-media pressure filtration, dechlorination, scale inhibition, and cartridge filtration) remained consistent with historical operating conditions. Significant results of this study are summarized:

- The rate at which the headloss across the dual-media pressure filters increased was reduced after the discontinuation of ferric chloride addition.
- The RO system rejected the oxidized arsenic and produced permeate with arsenic concentrations of approximately 5 ug/L, half of the regulated maximum contaminant level of 10 ug/L.

Continued on page 72

Continued from page 71

- The silt density index of the feed water remained consistent with historical values.

Enhanced Split-Treatment Process

Based upon the results of the studies presented, the City and CDM Smith concluded that a split-treatment process for the expanded plant (i.e., one treatment train specifically designed to minimize the arsenic concentration of the blend water and one treatment train specifically designed to enhance RO operations) was the best approach. The blend water treatment train was to consist of prechlorination (existing) and adsorption (new) processes to maximize arsenic removal prior to blending. The RO treatment train was to consist of prechlorination (existing), pressure filtration (existing), antiscalant addition (existing), dechlorination (existing), cartridge filtration (existing), and RO (modified) processes. As the enhanced split-treatment process no longer relied on a coagulation process for arsenic removal, the addition of ferric chloride was discontinued; figure 2 shows the process flow diagram for the enhanced process. As many of the treatment processes are similar to existing processes described previously, the subsequent narrative will focus on new and/or modified processes.

Blend Water Treatment Train

As with the original treatment process, oxidation of naturally occurring arsenic was accomplished in the prechlorination process through the addition of sodium hypochlorite. Following that addition, the prechlorinated groundwater is divided and directed to two separate treatment trains. Oxidized arsenic contained in the blend water is removed through a new adsorption process. The new arsenic adsorption process consists of two 14-ft-diameter pressure vessels, each of which contains 3.3 ft of Bayoxide E33 adsorptive media and associated appurtenances. In order to provide maximum operational flexibility, the arsenic adsorption system was designed and configured to operate in series (to maximize media usage and minimize effluent arsenic concentration) and in parallel (to maximize water production and minimize pressure loss). Since the arsenic adsorption system was commissioned in November 2013, it has operated in series and has consistently produced a blend water with an arsenic concentration below 5 ug/L (greater than 80 percent arsenic removal). After treating more than 500 MG of water (approximately 67,000 bed volumes) over more than 500 days of operation, the Bayoxide E33 adsorptive media was replaced in the lead vessel. Following the replacement of the media, valves were manipulated to reverse the lead/lag position of the vessels, and the system was returned to service. On average, the arsenic adsorption system was backwashed every 30 hours.

Reverse Osmosis Treatment Train

Following the prechlorination process, a portion of the oxidized arsenic and a majority of the oxidized iron are removed from the RO feed stream in the dual-media filtration process. While the process still consists of four 12-ft-diameter pressure filter vessels with 9 in. of support gravel, 32 in. of silica sand, and 18 in. of anthracite, the discontinuation of ferric chloride addition increased the filtration time between backwashing events from 36 to 48 hours to 48 to 60 hours. In addition, the system continues to remove more than 95 percent of the turbidity contained in the influent stream (2.5 nephelometric turbidity units [NTU] on average) and consistently produces effluent with turbidity less than 0.1 NTU.

Consistent with the prior treatment process, feedwater for the modified RO system is dosed with an antiscalant, dechlorinated, and cartridge-filtered prior to membrane treatment; however, both the membrane treatment process and equipment were modified in order to provide the required permeate production capacity. Modifications included: the replacement of the 400-sq-ft membrane elements with new 440-sq-ft membrane elements, the replacement of the membrane feed pumps with larger capacity units (each unit designed to deliver 1,328 gpm at a total dynamic head of 420 ft), increasing the permeate flux rate from 11.9 gfd to 16.2 gfd, and other ancillary improvements (i.e., piping, valving, etc.) to the RO skids.

While each modified RO unit was designed and tested to operate at a permeate production rate of 1.5 mgd, the City elected to operate each RO unit at a permeate production rate of 1.25 mgd. This decision was based on the results of an extensive optimization study that focused on water quality, membrane cleaning frequency, and total cost of operation. Upon the completion of the optimization study, each of the modified RO units consistently produced 1.25 mgd of permeate, with less than 35 mg/L of total dissolved solids and less than 2 ug/L of arsenic, at a pressure of 125 psi. These values correspond to a specific productivity of 0.108 gfd/psi. In addition, operating times between chemical cleaning events generally range from six to 10 weeks. For comparison, prior to this project, each of the RO units produced 1.0 mgd of permeate, with 55 mg/L of total dissolved solids and 2 ug/L of arsenic at a pressure of 110 psi (0.108 gfd/psi), and were chemically cleaned on a monthly basis.

Ancillary Systems

While the project included modifications to numerous ancillary systems (i.e., the addition of a new raw water booster pump, the replacement of the three existing blended water transfer pumps and the addition of one new blended water transfer pump, the demolition of the existing 5-MG finished water storage tank, and the construction of two new baffled 3-MG finished water storage tanks, etc.), none of these modifications were associated with a significant change in the treatment process. As such, details of these modifications will not be presented.

Postconstruction Modifications

Upon the successful completion of this project, normal operations resumed at the City's newly expanded plant. During the initial operating period, the City identified several systems that warranted modification to enhance operations and performance. Concerns regarding the initial operation of each of these systems, as well as the modifications designed and implemented by the City to improve its operations and performance, are summarized.

- Dual Media Filtration System – Modifications designed and constructed for the dual-media filtration system required the operators to manually close a butterfly valve in order to direct the filtrate to the RO system; however, during the commissioning phase of the project, the City discovered that start-up and shutdown procedures were significantly improved when this valve was throttled. As such, the City replaced this manual butterfly valve with a modulating v-port ball valve. In addition to improving start-up and shutdown procedures, this modulating valve allows the City to divert a portion of the filtrate to the blend stream, as allowed by water quality, in order to maximize finished water production.
- Reverse Osmosis System – As previously stated, each modified RO unit was designed and tested to operate at a permeate production rate of 1.5 mgd; however, the City elected to operate each RO unit at a permeate production rate of 1.25 mgd to increase the operating time between chemical cleaning events and reduce the total cost of operation.
- 4-Log Virus Inactivation – Following the completion of this project, the City revised and resubmitted its 4-log virus inactivation documentation to FDEP. As a result, the City was able to reduce the prechlorination dosage, the sodium bisulfite dosage for dechlorination, and the number of monitoring points.
- Decant System – The City completed numerous modifications of the decant system to enhance its operation and performance. As a result, the city is able to successfully recycle more than 80 percent of the spent backwash water for maintaining the performance of the

dual media pressure filters and the arsenic adsorption system.

Recommendations for Similar Projects

This project, as with any multidisciplinary project, was complicated. However, the degree of complexity was magnified due to several specific features. While the meticulous and methodical manner in which this team approached this project ensured its success, the following recommendations are offered to those who encounter projects with one or more of the following features:

- *Implementation of New Treatment Processes or Modification of Existing Treatment Processes* – The design and execution of appropriate benchtop, pilot, and/or full-scale studies to verify process performance and enhance operations is crucial for projects of this nature, which involve the implementation of new treatment processes or the modification of existing treatment processes. Data obtained from these studies should be utilized to guide the design of the proposed improvements.
- *Modification of Existing Reverse Osmosis Units* – As RO skids are typically designed to operate within a relatively narrow range of conditions, the modification of an existing RO skid to increase its production capacity by 50 percent is not an insignificant undertaking. While major system parameters, such as flux, recovery, flow, pressure, etc., are quickly and easily defined by design engineers, parameters "internal" to the RO skid, such as pressure drops through feed/concentrate ports of the pressure vessels, flow profiles through the pressure vessels, and pressure drops through manifolds, etc., are often "out of sight, out of mind." Nevertheless, it is imperative to analyze and evaluate these internal parameters when attempting to modify the operating conditions of an existing RO skid to ensure postmodification operations are balanced and stable. When attempting such modifications, it is strongly recommended to work with a qualified company that specializes in the design and fabrication of RO systems.
- *Expansion of Existing Facilities* – During the course of the project, numerous issues related to instrumentation and control logic arose that could have had significant and adverse impacts to the operation of the existing plant. As with any construction project of this type, close coordination among design engineers, system suppliers, system integrators, and plant staff is critical to the overall success of the project.

Summary

Operation of the expanded plant over the past 16 months has clearly demonstrated the success of this project. Data collected during this period of time confirmed that each of the City's critical success factors were realized.

While numerous aspects contributed to the success of this project, those which most significantly influenced it include: a truly collaborative relationship between CDM Smith and the City; an open-minded approach to treatment alternatives; the willingness to deviate from the status quo, explore alternate treatment technologies, and modify existing treatment processes; the commitment to complete extensive benchtop, pilot-scale, and full-scale demonstration tests to confirm process performance; and the dedication of City personnel to optimize and enhance plant operations.