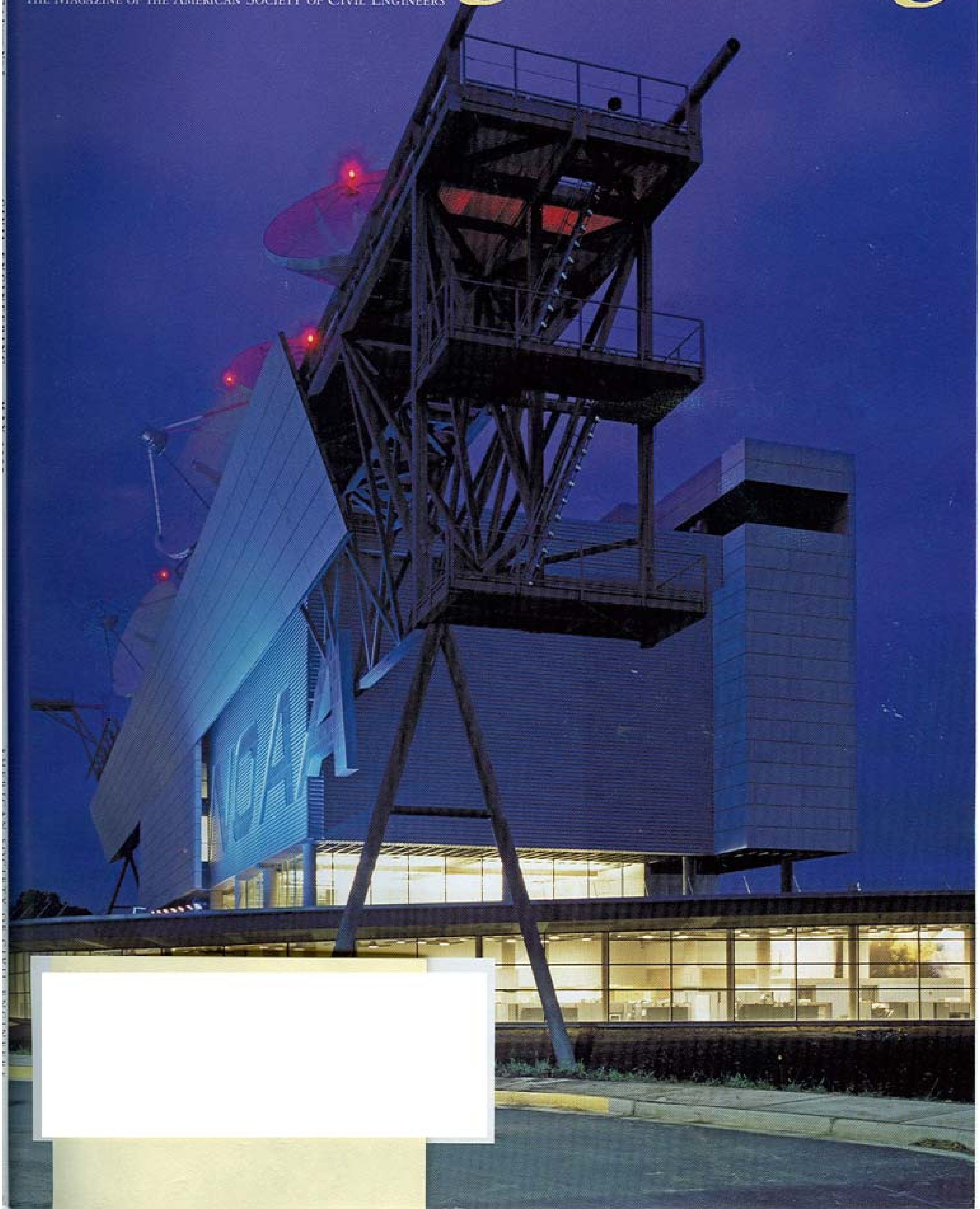
May 2007 • Volume 77 • Number 5

Civil Engineering

The Magazine of the American Society of Civil Engineers



Joel T. Darnell, M.ASCE, HDR | Shiner Moseley

Contents

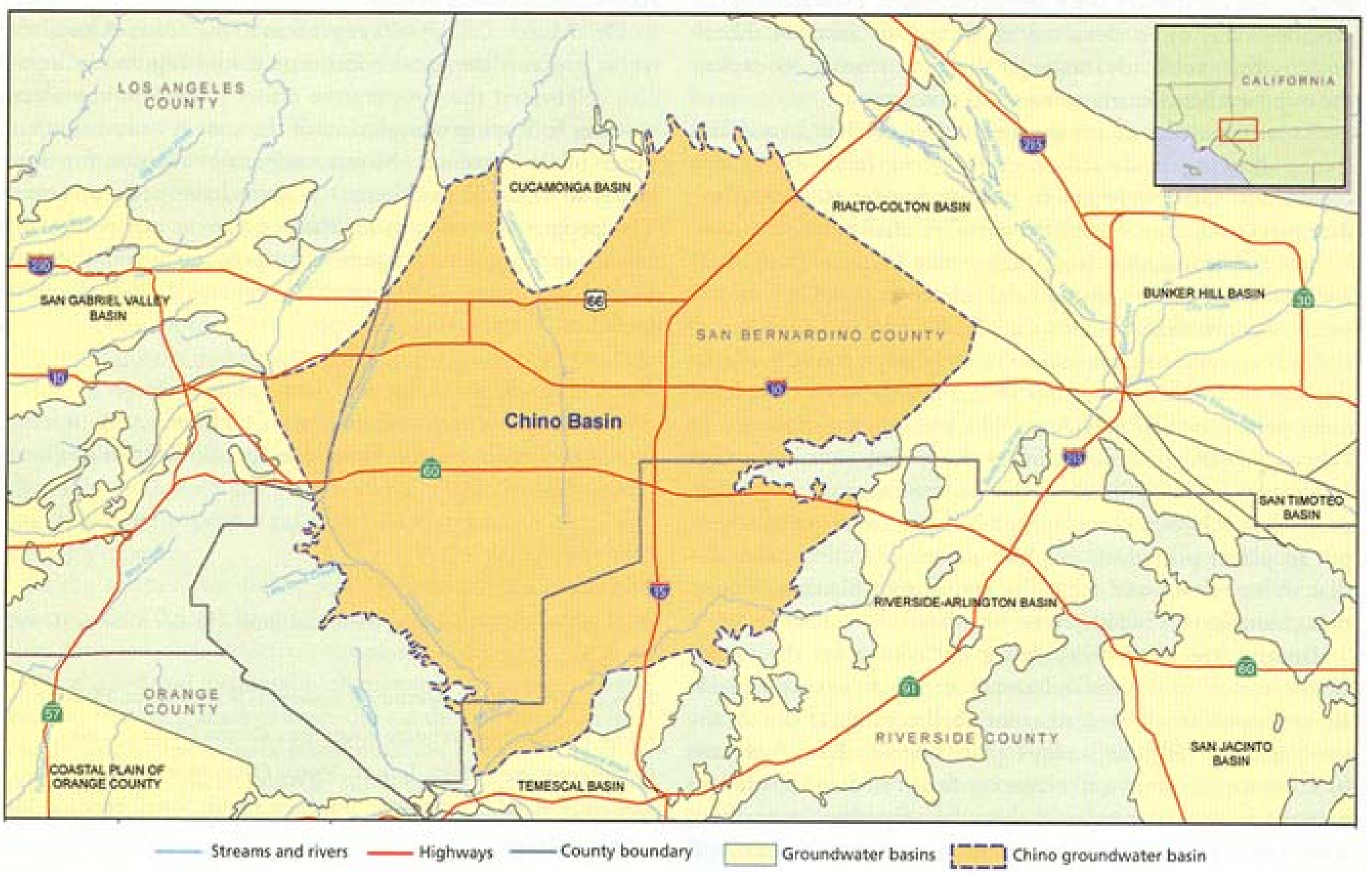
May 2007 • Volume 77 • Number 5

FEATURES

PRESERVING THE Chino Basin

Created to provide a high-quality source of drinking water for California's burgeoning Inland Empire, the two advanced treatment facilities that constitute the Chino Desalters Project also help to maintain the quality of the region's critical groundwater supply. **By Cindy L. Miller, P.E., M.ASCE, Scott Burton, P.E., A.M.ASCE, and Ken Manning**

Figure 1



RBF Consulting, all

Located approximately 40 mi (64 km) from the Pacific Ocean and downtown Los Angeles, the area of Southern California known as the Inland Empire has a long, rich history linked inextricably to water. Since the 19th century, the region has been a major center for agriculture, including citrus groves, dairy farms, and wineries. However, land formerly serving agriculture is being converted for residential, commercial, and industrial use at an unprecedented rate. In the past 10 years, the Inland Empire has been one of Southern California's fastest-growing regions. Whether a seat of agriculture or suburban growth, this region has long required and will continue to require affordable water of high quality.

The Chino groundwater basin extends beneath a portion of the Inland Empire, encompassing roughly 220 sq mi (570 km^2) of the upper Santa Ana River watershed (see figure 1). One of the largest groundwater basins in Southern California, the Chino has an immense water storage capacity—roughly 6 million acre-ft (7.4 billion m^3). (Although the basin is capable of storing an additional 1 million acre-ft [1.2 billion m^3], issues relating to water quality and various physical features prevent the effective use of this extra capacity.) Given its capacity, the Chino basin plays an integral role in meeting water needs locally as well as statewide.

Nearly three decades ago, parties with an interest in the Chino basin, responding to declines in the quantity and quality of the basin's groundwater, initiated an ambitious effort to manage the basin in a comprehensive fashion. Ultimately, this endeavor led to the development of the Chino Desalters Project, which includes two desalters that pump groundwater from the Chino basin and generate nearly 25,000 acre-ft (30.8 million m^3) of high-quality drinking water per year.

The Santa Ana River—the Chino basin's southern boundary—receives groundwater flowing from the basin. Although approximately 300 agricultural entities continue to extract groundwater from the Chino basin, cities and other water districts are fast becoming the recipients of much of the basin's groundwater.

The Chino groundwater basin has been and continues to be a reliable source of high-quality water over most of its area. However, the many years of domestic and agricultural pumping have taken their toll. Until 1978, the basin's water levels were declining at alarming rates. Over time, irrigated agriculture and practices related to managing dairy waste caused the concentration of total dissolved solids (TDS) and nitrate in the groundwater to increase throughout the basin, particularly in the south near the cities of Ontario, Chino, and Chino Hills, as well as the community of Jurupa and areas near the Santa Ana River.

In 1978 a California superior court, in addressing issues raised by Chino basin stakeholders, issued a ruling that established an organization known as the Chino Basin Watermaster to oversee the basin's management. To alleviate the basin's overdraft condition, several immediate steps were taken, including defining the groundwater basin's "safe yield," or the amount of water that can be extracted from the aquifer without causing groundwater depletion; establishing pumping rights, including innovative provisions for transferring water rights as land is converted from agricultural to urban uses; and providing for the acquisition of replacement water in the event of overproduction.

The Chino Basin Watermaster's implementation of the 1978 ruling has succeeded in stabilizing and restoring groundwater levels and storage. However, the ruling extended far beyond those goals. In February 1998 the court directed the Chino Basin Watermaster to develop and implement the comprehensive basin management program that had been called for in the 1978 ruling. Known as the Optimum Basin Management Program (OBMP), the effort is an extensive and detailed framework for the long-term management of the basin's resources. One of the steps in the OBMP is managing the effects on the basin from turning agricultural land to urban uses. Another involves developing a plan to use groundwater in areas where degraded water has been found, for example, the southern part of the Chino basin.

The Chino Basin Watermaster recognized that as land use in the southern part of the basin changed, the urban users might not be able to

Since the project's beginning, the CDA has set goals for finished water quality that are much more stringent than federal and state drinking water standards.

pump as much water as the agricultural users because of the high levels of TDS and nitrate in the groundwater and the resulting high cost that would be incurred in treating the groundwater for human consumption. This potential reduction in pumping was recognized as a threat to the region's local water supply in that it would decrease the basin's safe yield and require the importation of water from California's State Water Project. Furthermore, the resulting increased discharge of groundwater from the Chino basin into the Santa Ana River would degrade the river's water quality, negatively affecting downstream users. Therefore, the OBMP drafted an aggressive plan to maintain pumping levels in the Chino basin's southern region to establish hydraulic control—that is, prevent groundwater flows to the river—and to develop regional facilities for collecting and treating degraded groundwater in the southern Chino basin. This treated water would be available to local agencies and would benefit the larger region as well by preserving the basin's safe yield.

The Chino Basin Watermaster established a long-term goal of pumping 40,000 acre-ft (49.3 million m^3) of highly degraded groundwater per year out of the lower Chino basin to achieve hydraulic control in the basin. At present the Chino desalters pump nearly 28,000 acre-ft (34.5 million m^3) of groundwater per year from the lower Chino basin.

Since its formation, in September 2001, the Chino Basin Desalter Authority (CDA) has been responsible for implementing the Chino Desalters Project. The CDA was set up by virtue of an agreement on the part of the member agencies, which primarily are the water retailers that purchase water from the Chino desalters. These agencies include the Jurupa Community Services District, the Santa Ana River Water Company, the Inland Empire Utilities Agency (IEUA), and the cities of Chino, Chino Hills, Norco, and Ontario.

The agreement set the percentage of CDA ownership and the corresponding annual water delivery entitlement for each agency, as indicated in figure 2. Each retail agency subsequently entered into water purchase agreements with the CDA. To ensure the authority's financial stability, the individual entities agreed to pay for a certain amount of water regardless of whether they actually took delivery of it or not. As a wholesaler of water and a provider of regional wastewater treatment, the IEUA does not receive water from the desalters. However, as a constituent agency of the CDA, the IEUA does play an integral role in the management of the Chino basin and is responsible for managing the CDA's finances and operating the first of the two desalters, the Chino I Desalter.

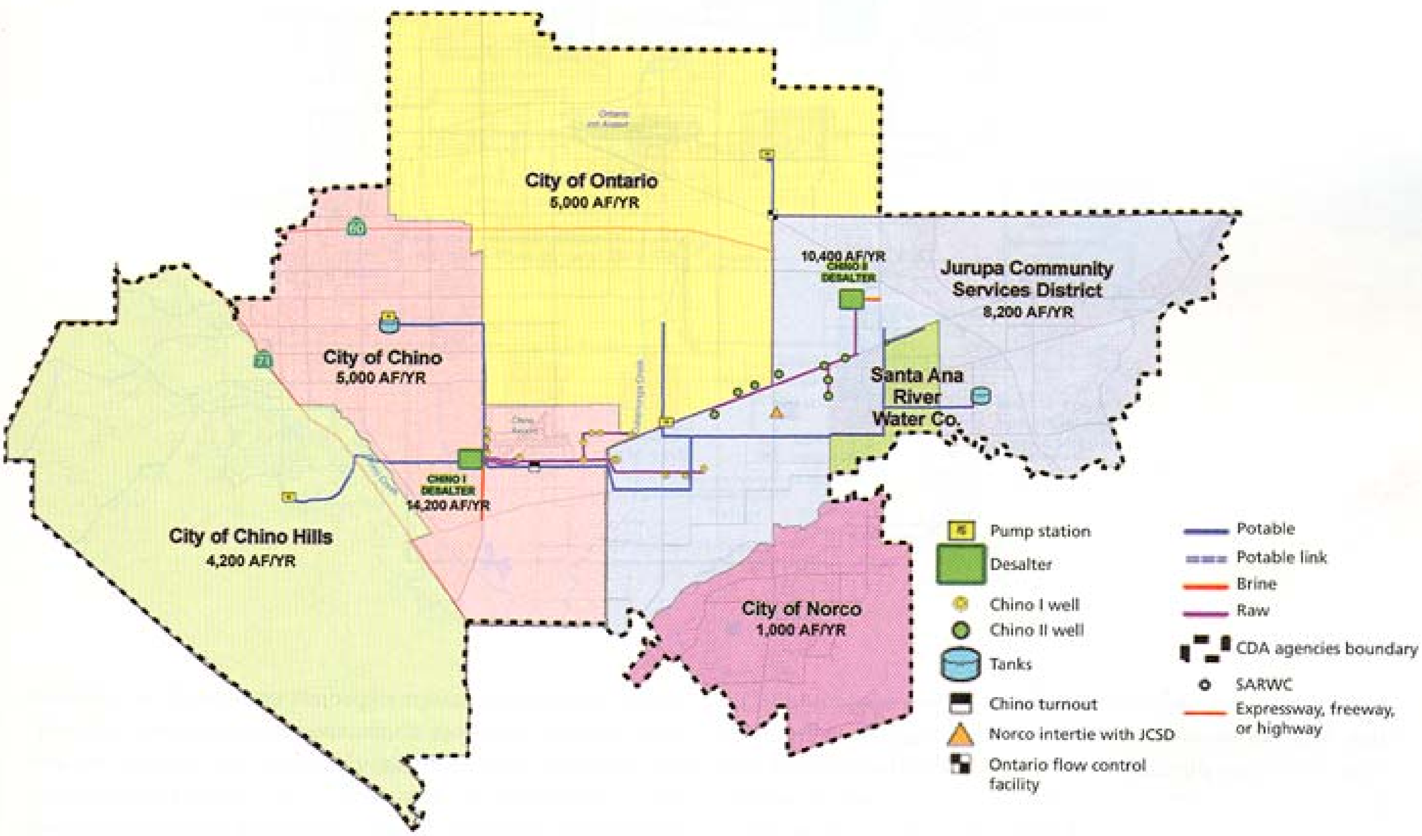
The CDA's member agencies all have a vested interest in the successful management of the Chino basin's groundwater resources. Moreover, the CDA member agencies have included this water source in the plans they have created to meet the needs related to the region's rapid growth and to provide redundant water supplies. The CDA's goal is to produce a safe and reliable source of potable water as economically as possible for delivery to the member agencies, based on their percentage of ownership of the CDA.

Designed to produce 24,600 acre-ft (30.3 million m^3) of drinking water per year, the Chino Desalters Project comprises facilities that span most of the lower Chino basin, as shown in figure 2. Using reverse-osmosis (RO) membranes and anion-exchange technology in a parallel configuration, the project has a daily production rate of 24.2 mgd (92,000 m^3/d), as shown schematically in the process flow diagrams (see figures 3 and 4). The RO technology removes TDS and nitrates, while the anion-exchange technology targets nitrates. Each treatment technology generates brine that must be disposed of in an environmentally responsible manner. Brine from the Chino desalters is conveyed to the Santa Ana Regional Interceptor, a pipeline designed to convey 30 mgd (113,550 m^3/d) of treated, but nonreclaimable, wastewater from the upper Santa Ana River basin to the Pacific Ocean.

To ensure that annual delivery obligations are met, the desalters were designed to produce 10 percent more drinking water than the CDA is required to produce. This extra allotment meets needs during off-line servicing and annual maintenance and repairs.

Since the project's beginning, the CDA has set goals for finished water quality that are much more stringent than federal and state drinking water standards. This has been done for two reasons: to meet the water quality needs of the retail agencies and, in keeping with the OBMP, to improve the basin's groundwater quality by removing TDS and nitrates. Source water sampled from near the Chino I Desalter's well field has been found to contain high levels of TDS (reaching

Figure 2



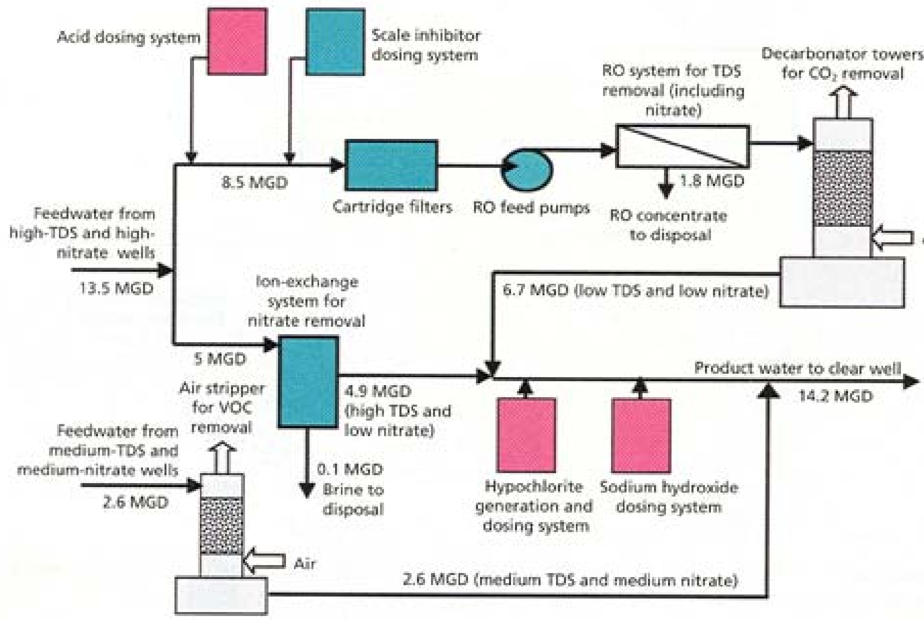
1,300 mg/L) with nitrate (measured as NO_3^{-2}) levels exceeding 230 mg/L. Source water from the area of the Chino II Desalter's well field has been found to have TDS levels reaching 1,100 mg/L and nitrate levels exceeding 200 mg/L. By comparison, the CDA's goals for finished water are 350 mg/L for TDS and 25 mg/L for nitrates, measured as NO_3^{-2}.

Constructed in 1999 and 2000, the Chino I Desalter initially employed only RO technology and had an annual capacity of 9,200 acre-ft (11.3 million m^3). As part of an expansion that was completed by the end of 2005, the desalter was augmented with a parallel anion-exchange system expressly designed to remove nitrates. The expansion boosted the facility's annual production capacity by 5,000 acre-ft (6.2 million m^3), giving it a daily production rate of 14.2 mgd (53,700 m^3/d).

As currently operated, the Chino I Desalter includes 14 source water wells, approximately 7 mi (11 km) of raw water pipeline, four RO trains that each produce 1.67 mgd (6,300 m^3/d) of permeate, and four anion-exchange fixed-bed vessels—three operating and one on standby—that each produce approximately 1.6 mgd (6,000 m^3/d) of effluent. As much as 2.6 mgd (9,800 m^3/d) of additional production comes in the form of water from source wells with lower levels of nitrates and TDS. Although this water requires treatment via an air stripper to remove volatile organic compounds, it then bypasses the RO and anion-exchange processes and is blended with their effluent. In addition to the supply wells and treatment systems, the Chino I Desalter includes off-site delivery facilities consisting of three booster pump stations, two reservoirs, and more than 14 mi (22.5 km) of pipelines for delivering product water.

Completed in the spring of 2006, the Chino II Desalter is designed to produce 10,400 acre-ft (12.8 million m^3) a year and to have a daily rate of 10 mgd (37,850 m^3/d). Of this amount, 6 mgd (22,700 m^3/d) is produced via RO membranes and 4 mgd (15,100 m^3/d) is produced via an anion-exchange system. The Chino II Desalter includes eight wells—the average production rate per well being 1,800 gpm (6,800 L/min)—and approximately 5 mi (8 km) of raw water pipelines. Three RO trains each produce 2 mgd (7,600 m^3/d) of permeate, while four anion-exchange fixed-bed vessels—three in operation and one on standby—each produce approximately 1.33 mgd (4,900 m^3/d) of effluent. Because the RO and anion-exchange processes produce finished water with such low

Figure 3



levels of TDS and nitrates, the plant includes a separate pipeline that bypasses the treatment process and brings flows from the main raw water pipeline to be blended with the treated water. This approach offers greater flexibility and lower treatment operating costs while taking production above the nominal capacity of 10 mgd (37,850 m^3/d).

The Chino II Desalter's system for delivering product water includes almost 2 mi (3.2 km) of transmission mains, a booster pump station, and stations that control flow and reduce pressure so that water can be delivered at pressures matching those of the member agencies' distribution systems.

A number of treatment options were evaluated for the desalters, including using only RO membranes as well as using RO either in parallel or in series with anion-exchange technology. An economic analysis indicated that employing RO membranes in parallel with anion exchange in the proportions indicated above would be the most economical way of meeting the CDA's goals for finished water quality. In particular, the analysis determined that RO technology had the highest capital cost, energy requirements, and costs related to brine disposal. Therefore, the design maximized the use of anion exchange for nitrate removal and employed RO technology to the extent needed to meet TDS goals.

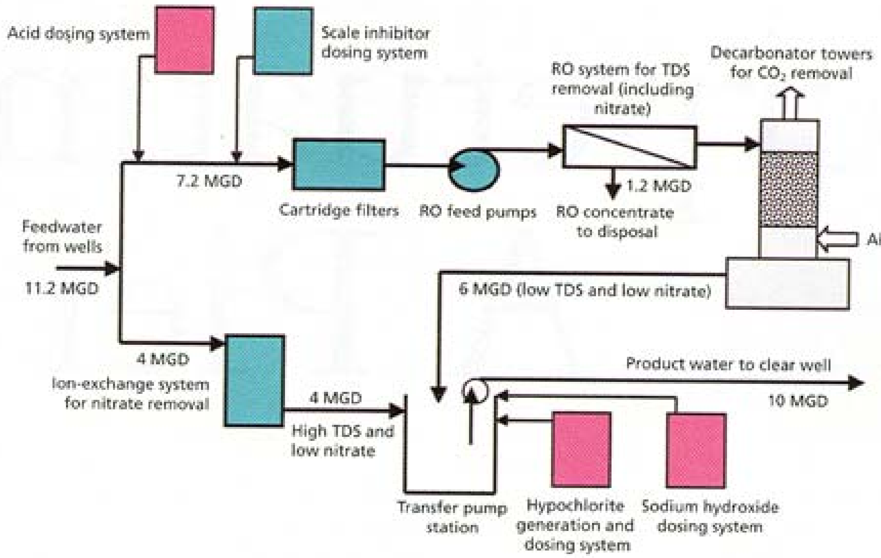
Implementation of both desalters required more than seven years, beginning with planning and encompassing environmental documentation and preliminary design, final design, bidding, construction, start-up, and commissioning. During that time, the CDA and its engineering consultant, RBF Consulting, of Irvine, California, faced a variety of challenges, including a change in project ownership, an intensive evaluation of numerous alternatives as part of the early project planning, rapid land development and changes in land use, rapidly rising property values, a change in the project scope, rapid increases in the costs of material and labor, and the need to manage more than 20 construction contracts, most of them simultaneously.

Begun by the Santa Ana Watershed Project Authority, a special district whose mission is to plan and build facilities to protect the water quality of the Santa Ana River watershed, the project was acquired by the CDA in January 2002. The change in ownership required that the engineering consultant evaluate a new set of alternatives to meet new project goals in a short amount of time.

The CDA was formed while the project was in its early planning phase. Because of time limits associated with grant funding, the project needed to proceed despite the fact that the CDA's formation had not yet been finalized. However, conducting early project planning during the CDA's formation complicated efforts to achieve consensus with regard to project objectives and preferred project alternatives.

After completing project planning, the CDA had to carve out space for its facilities in areas already planned and designated for development, as a local real estate boom had begun. Along with difficulties in finding property for its planned facilities, the CDA faced an early budget crunch when property that had been selling six months earlier for \$80,000 per acre suddenly rose to \$200,000 per acre and later increased to more than \$300,000 per acre. The rapidly

Figure 4



rising property values emboldened landowners to demand from the CDA extra amenities, including requests that it provide special decorative structures, fencing, landscaping, and other improvements. Of course, such features increased the project's cost and required additional time so that the CDA could negotiate and, in several instances, initiate eminent domain proceedings.

As construction prices continued to climb, the CDA decided to reevaluate its preferred project alternative, even though environmental documentation had been completed and final design was well under way. However, this reevaluation was necessary to cut project costs. Ultimately, the CDA saved millions of dollars in pipeline costs by using member agencies' existing facilities to transport water to the member agencies that are farthest from the desalters.

Despite cost savings realized through the CDA's project reevaluation, construction costs continued to climb during the project design and construction phase, complicating efforts to forecast long-term budgets and requiring several adjustments to the overall CDA project budget.

To reduce project costs, the CDA originally intended to have its various member agencies manage the construction contracts internally. However, the number of concurrent contracts required the CDA to seek help from its engineering consultant. Even with this additional resource, the CDA staff members had their hands full managing all the contracts and complying with the added reporting requirements related to the grant funding.

Combined, the Chino I and Chino II desalters are achieving their rated production capacities, and member agencies are on schedule to receive more than 98 percent of their contractual entitlements in the current fiscal year. However, as the members of the CDA's operations staff have familiarized themselves with the new facilities and the facilities have had a chance to be "broken in," refinements to the systems' operations have been necessary to optimize the desalters in terms of efficiency and reliability. This cooperative effort by the project's engineering consultants and the CDA continues today.

Funding the project was challenging, given the cost associated with the large volume of groundwater being extracted, the high level of treatment required to meet the CDA's goals, and the extent of off-site facilities required to deliver water to member agencies. Securing project funding was therefore of overriding importance. Although the cost to produce the water is higher than the current cost of obtaining water from the State Water Project, participation in several grant funding programs has enabled the CDA to produce water at rates that one day will prove to be at least comparable to that of imported water. For example, production costs for a portion of water produced at the Chino I Desalter are currently offset at a rate of $250/acre-ft by the Los Angeles–based Metropolitan Water District of Southern California, a consortium of 26 cities and water districts that provides drinking water to parts of six California counties. The rebate is offered as part of the district's Local Resources Program, which facilitates the development of local water supplies so as to reduce demand for the district's imported water. *(continued on page 81)* (continued from page 61) The CDA also received $48 million in grant funding that was made available by virtue of the State of California's Costa-Machado Water Act of 2000, also known as Proposition 13. As part of that law's funding requirements, the CDA must pay at least 23 percent of the project's total capital cost.

The CDA delivers water to its member agencies through a combination of facilities, some of which it owns itself and others owned jointly with other agencies. It also uses facilities wholly owned by other agencies. In several instances member agencies integrated the CDA delivery facilities into their master plans to accomplish multiple objectives more economically. Examples of this include member agencies paying to increase the size of their pipelines, arranging for a pump station to handle potable water for the CDA and recycled water for a member agency, and constructing a pump station that one day will be converted to deliver water from a different pressure zone as development expands and changes the community's water needs.

Under the terms of the agreement that created the CDA, the facilities required for the delivery of CDA water may be modified, provided that the CDA is not adversely affected. In these instances, joint facility agreements have been implemented to define facility ownership and cost sharing, including operating and maintenance costs. The cities of Norco and Ontario and the Santa Ana River Water Company receive water from a combination of dedicated CDA-owned facilities and facilities owned by other agencies. Essentially, water for these three agencies is pumped from the desalters into the distribution system of one member agency—the Jurupa Community Services District—and an equivalent volume of water is delivered to different locations. The delivered water is actually a blend of CDA water and water from other (continued on page 82)

(continued from page 81) sources. The CDA established a transportation agreement to define such conditions of water delivery as water quality, rate of delivery, and financial terms. This approach has enabled the CDA to avoid spending millions of dollars to construct pipelines solely for delivering its water.

When the CDA acquired the original Chino I Desalter from the Santa Ana Watershed Project Authority, the facilities were delivering water to four of the seven CDA member agencies. The CDA purchased the desalter for $64.5 million and shortly thereafter began expanding it and constructing the Chino II Desalter. The capital costs associated with those projects totaled approximately $92.5 million. This amount was partially offset by $48 million in grant funding. Therefore, the CDA financed approximately $109 million in project costs that must be repaid during a fixed period from revenue that the CDA generates from its water sales.

Meanwhile, subsequent capital improvements are paid for in the year in which the expenditures are made. Costs related to fixed and variable operations and maintenance constitute the largest component of the authority's budget, more than 60 percent. However, the rebate from the Metropolitan Water District of Southern California amounts to $98/acre-ft, bringing the total cost to $680/acre-ft.

Facilities constructed by the CDA go a long way in meeting the OBMP's goal of achieving the hydraulic control necessary to ensure a long-term, stable, and safe yield in the basin while also protecting the Santa Ana River's water quality. However, more is required to meet the OBMP's target of pumping 40,000 acre-ft (49.3 million m^3) of highly degraded groundwater out of the lower Chino basin each year and treating it. The OBMP requires that another 12,500 acre-ft (15.4 million m^3) of groundwater be pumped each year, an amount sufficient to produce approximately 11,000 acre-ft (13.6 million m^3) of drinking water. This additional capacity is expected to result in the CDA's final expansion effort.

This final expansion poses even greater challenges for the CDA, because the Chino Basin Watermaster's requirements related to the placement of wells to accomplish hydraulic control and prevent degraded water from entering the Santa Ana River are not confined to TDS and nitrate. Attention is also being given to capturing several plumes containing volatile organic compounds that are headed toward some of the CDA's existing and proposed wells.

The success of the project's final chapter will hinge on the extent to which future project costs can be controlled by strategic planning and cooperation by the CDA's member agencies and other stakeholders in the Chino basin. Other key factors will include maximizing existing facilities, obtaining new grant funding to help offset project costs, and developing new agreements or renewing existing agreements with the Metropolitan Water District of Southern California.

The willingness of member agencies to participate in the desalter expansion's final phase is contingent upon the cost of the water that would result from the expansion compared with the cost of other water supply options, which vary from agency to agency. The CDA, the IEUA, and the Western Municipal Water District—another stakeholder in the Chino basin that requires an additional water supply—are pursuing multiple opportunities for grant funding, as well as other funding mechanisms that will help ensure the final expansion's financial viability. The CDA's final expansion project is in the initial planning stages. However, the Chino Basin Watermaster has set 2012 as a deadline for completing the final expansion. ■

Cindy L. Miller, P.E., M.ASCE, is a vice president and project manager for RBF Consulting in Irvine, California. Scott Burton, P.E., A.M.ASCE, is the assistant utilities director for the City of Ontario, California, and the coordinator of the Chino Basin Desalter Authority. Ken Manning is the chief executive officer of the Chino Basin Watermaster in Rancho Cucamonga, California.

PROJECT CREDITS

Owner: Chino Basin Desalter Authority, comprising the City of Chino, the City of Chino Hills, the City of Ontario, the City of Norco, the Jurupa Community Services District, the Santa Ana River Water Company, and the Inland Empire Utilities Agency

Original owner of Chino I Desalter: Santa Ana Watershed Project Authority, Riverside, California

Implementation of Optimum Basin Management Program: Chino Basin Watermaster

Facility permitting: California Department of Health Services

Well placement and design criteria coordination: Wildermuth Environmental, Inc., Lake Forest, California

Engineering consultant: RBF Consulting, Irvine, California

Reverse-osmosis consultant: Separation Processes, Inc., Carlsbad, California

Local consultant: Albert A. Webb Associates, Riverside, California

Process consultant: Malcolm Pirnie, Inc., White Plains, New York

Geohydrology consultant: Geoscience Support Services, Inc., Upland, California

California Environmental Quality Act compliance: Tom Dodson and Associates, San Bernardino, California

Proposition 13 grant funding: California State Water Resources Control Board

Additional project funding: Metropolitan Water District of Southern California