King Abdullah Economic City (KAEC) is a newly planned city along the Kingdom of Saudi Arabia’s Red Sea coast that will grow from a current population of 5,000 to over 110,000 by 2030 and an ultimate population of 1.75 million by 2045. The city development is managed by Emaar, the Economic City (EEC), which needed a variety of engineering services to support development of the new city. After already having HDR support with planning and designing their transportation, power and financial systems, EEC hired us in 2015 for all their potable water system supply and distribution needs, a key public utility in this hot, arid environment.

We quickly put together an international team of our firm’s most senior experts in the United States, Saudi Arabia and the United Arab Emirates to support EEC in the planning, designing and bidding of the city’s potable water system. This team was managed from our Abu Dhabi and Mahwah, New Jersey, offices.

**Water Demand Projections and Initial Water System Layout**

We initially supported EEC by establishing water demand projections for the City over the planning period. Planning by others had already projected population growth patterns and land uses (residential, commercial, industrial, etc.) for the 155-square-kilometer (60-square-mile) urban area. We used this information to develop detailed annual water demands that the City can reference as it grows from a small village into one of the largest cities in the Arabian Peninsula. The water demand projections took into account local cultural water demand patterns, future improved water conservation measures, and offsetting potable water use with reuse water to the greatest extent possible.
After the projections were identified, our team laid out the entire water supply, transmission and distribution system and phased its development to coordinate with the transportation and power system extensions that others within HDR were simultaneously developing. The basis of the plan called for construction of two desalination plants. The first is the coastal Desalination Plant-1 with an initial potable water production capacity of 60,000 cubic meters per day (m³/day) or 16 million gallons per day (mgd). It will reach an ultimate capacity of 600,000 m³/day (159 mgd) in 23 years. After Desalination Plant-1 is built out, EEC will commission Desalination Plant-2 at an inland location for an ultimate capacity of 640,000 m³/day (169 mgd). The treated water would then be stored in reservoirs and pumped throughout the system using variable speed booster pump stations. The pump stations would maintain the distribution system pressure, a standard practice in the Middle East, since elevated storage tanks for pressure maintenance is very uncommon.

**Initial Water Supply Identification**

KAEC’s location on the shore of the Red Sea means that seawater is a readily available water supply for Desalination Plant-1. However, seawater desalination is an expensive and technically complex process, so EEC requested that we determine whether alternative, lower-cost water sources could be used first and defer seawater desalination to a later date. We investigated the feasibility of using groundwater to supply part or all of KAEC’s initial water demands. Through a review of available published literature and survey of other water suppliers in the region, groundwater supply appeared very limited. In addition, geologic conditions in the area have resulted in the available groundwater resources typically having salinities exceeding 90,000 milligrams per liter (mg/L) of total dissolved solids — over twice the salinity of the adjacent seawater. This water quality would make groundwater desalination even more complex than seawater desalination. Given the quality of water in the limited groundwater resources, the Red Sea is the only viable water supply available to the new city. As a result, both Desalination Plant-1 and Desalination Plant-2 were planned to be seawater treatment facilities.

**Environmental Issues**

The Desalination Plant-1 design had several unique water quality and environmental challenges that are rarely encountered in North American desalination facilities. The first water quality issue was that the Red Sea salinity is 45,000 mg/L, about 25 percent higher than the Atlantic and Pacific Oceans. This higher salt content meant that the desalination step had to be larger and operate at higher pressures than typical U.S. installations.

Another issue was that the intake location was near the Port of KAEC, a major international shipping port, and its associated shipping lanes. Other Saudi desalination facilities have found that hydrocarbons can leak from passing vessels, which can then cause substantial fouling issues in the desalination membranes. In addition, the ships’ propellers can stir up the sea bed and cause high turbidity.

KAEC is sited along a part of the Saudi Red Sea coast that abuts large and active coral beds. As part of EEC’s commitment to reducing environmental impacts, they authorized us to conduct a comprehensive biological survey of the area to determine the diversity of the aquatic life and identify the site-specific water quality characteristics that will be used to guide the treatment system design. Our survey found that near-shore area was habitat to 45 types of coral, including four identified as being vulnerable to extinction; 36 types of fish; and multiple green sea turtles. In addition, our investigative team found extensive algae in the near-surface waters that dropped off considerably farther.

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offshore and at depths below 12 meters. Thankfully, detectable hydrocarbons were not found in the water; however, one of the aquatic soil sediments did contain a group of manmade chemicals, polychlorinated biphenyls (PCBs), likely due to dumping from a passing vessel long ago.

**Desalination Treatment Plant Design**

Once these challenges were identified, our team came together to deliver the project design. We worked closely with EEC staff to identify the parcels of land where Desalination Plant-1 would be located and how it would interconnect with the water system as well as support utilities like road access, electricity, natural gas and sanitary sewer. In addition, we collaborated closely to have land and bathymetric surveys and geotechnical investigations completed.

Our designers had to design the intake and outfall at locations that met the following requirements:

1. Shortest distance through the coral beds to minimize environmental impacts;
2. Far enough offshore to limit fish impingement by the intake and brine toxicity impacts by the outfall;
3. Not so far offshore as to enter the shipping lanes and be potentially impacted by passing ships;
4. Shallow enough to be maintained by divers;
5. Deep enough to not be impacted by surface algae; and
6. Have the lowest capital costs.

The design of the raw water pumping station was a considerable technical challenge. It had to be sized to account for both the potable water produced by the desalination plant as well as brine.
The desalination design included cartridge filtration and ultrafiltration membranes. The DAF process was specifically selected as it was the best technology to remove hydrocarbons and provide additional protection against algae and biological material that could be exuded from the coral at certain times of the year. Ultrafiltration will be used for particle removal prior to the desalinating membranes. We selected ultrafiltration over the more commonly used pressure sand filtration since it provides much better filtered water quality than pressure filters and can better handle water quality upsets. As with the other raw water systems, both the DAF and ultrafiltration systems had to be designed with careful attention to seawater corrosion.

The desalination design included cartridge filtration and 1.7-pass reverse osmosis (RO) system, with each pass consisting of three stages of RO elements to maximize water efficiency. The 1.7-pass design meant that up to 70 percent of the permeate from the first RO pass had to be reprocessed through a second pass of three-stage RO elements. The multiple-pass design was found to be the only way to bring the boron concentrations down under 0.5 mg/L and protect the city’s vegetation when irrigated. This configuration will result in an overall system recovery of 41 percent. All of these RO passes and stages will mean very large electrical usage and costs. To partially offset these costs, the RO system was designed with isobaric energy recovery devices that will transfer 90 percent of the wasted pressure in the RO concentrate into the RO feed water, thereby reducing the RO pumping costs.

Pure desalinated water is very corrosive to concrete, cement mortar and bare metals. It will need to be conditioned to minimize damage to the city’s transmission system and individual customer plumbing. We designed a finished water conditioning system consisting of lime feed for alkalinity addition followed by carbon dioxide addition for pH control. Our team also developed a chlorination feed system to maintain disinfection, and master-planned an ultraviolet system for additional disinfection, if required in the future.

In addition to the copious volume of RO brine, these treatment systems also generate a considerable amount of chemical sludges and cleaning wastes. We designed a system of storage equalizing/neutralizing tanks, gravity thickeners and belt filter presses to handle all of these residuals in the smallest possible footprint.

Once these processes were sized and laid out, we then developed the numerous ancillary systems to make the Desalination Plant-1 a complete design. These systems included incoming and backup power supply and distribution, controls and instrumentation, architectural design, site/civil layout and site security, and structural design. One key ancillary system that was added to the project was solar power. KAEC benefits from abundant sunlight, and the use of solar power will further reduce electrical use at the plant. We designed solar panels on all available building and reservoir rooftops.

Desalination Treatment Plant Procurement

Once our team completed 30 percent design, EEC opted to procure the project by simultaneous, concurrent bidding as either a single Build-Own-Operate-Transfer (BOOT) project with a contract duration of 10 years, or two separate contracts consisting of a design-build contract and a separate operations contract (D-B+O). To assist with this procurement, we supported KAEC by preparing several contract documents. Our contracting experts prepared the construction master services agreement templates for EEC’s legal staff to use and finalize. In addition, we prepared the bidder minimum qualifications and evaluation criteria for both the BOOT and D-B+O procurements.

While the construction front-end documents were being prepared, our operations specialists prepared the operations, asset management and condition assessment/evaluation contract requirements for the post-construction phase of the project. The contract language spelled out the specific operational requirements, and incurred penalties, that the successful bidder agreed to: producing the required potable water quantity and quality; keeping safe working environments; having trained staff and policies to handle emergencies; and maintaining good condition of the project site and equipment.

Project Execution

EEC has released the contract documents for BOOT vs. D-B+O bidding, and our team is providing support in reviewing bidder questions and issuing addenda as necessary. Upon the conclusion of the bidding period, our global water experts will be in charge of reviewing all technical components of the received bids and providing technical recommendations to EEC for both the procurement method and the selected bidder.

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