Rapid Design and Construction of a Membrane Water Treatment Plant to Treat Water Quality Issues

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The City of New Braunfels is a rapidly growing community located on the Interstate 35 corridor in Texas, between San Antonio and Austin. In May 2015, construction was completed on a 3.74-mil-gal-per-day (mgd) well field intended to draw water from the Trinity aquifer to supply 25 percent of the average daily water demand for New Braunfels Utilities (NBU). Based on water quality observed in test wells, and during interim approval sampling, the wells would only require treatment using disinfection before distribution. During start-up, the new wells produced discolored water characterized by periodic spikes in turbidity and hydrogen sulfide, which limited NBU's ability to use the wells as a water supply source.

After encountering water quality issues at start-up, subsequent sampling in November 2015 revealed aluminum and iron concentrations above the secondary maximum contaminant levels established by the U.S. Environmental Protection Agency (EPA) and the Texas Commission on Environmental Quality (TCEQ), as well as the presence of coliform bacteria and *E. coli.* Since turbidity spikes appeared to occur or increase in severity following rain events, NBU operators suspected the groundwater to be under the direct influence of surface water (GUI).

Freese and Nichols Inc. (FNI) developed a complex sampling plan to confirm that the Trinity wells were influenced by surface water and to provide a more-complete characterization of raw water quality to serve as a basis for treatment design. Eight weeks of sampling took place in late summer/early fall of 2016.

Once conclusive evidence of surface water influence was collected, recommendations were provided for treatment approaches to NBU, with membrane filtration emerging as the approach best-suited for treating water subject to rapid shifts in quality and turbidity spikes caused by very fine particles with poor settleability. A preliminary engineering report for the 3.74-mgd membrane treatment system was submitted to NBU in May 2017 and it decided to move forward with the project with the goal of having the system operational before summer 2018 peak water demands. The total proposed schedule allowed only 15 months for design, piloting, construction, and commissioning of the plant.

To meet the accelerated design schedule, the construction manager at risk (CMAR) project delivery method was selected, the membrane manufacturer was preselected, and piloting of the membrane took place concurrently with the design. As NBU needed water from the Trinity Well Field to meet water supply demand during the summers of 2017 and 2018 while the project was being designed and constructed, FNI worked with the preselected membrane manufacturer, Pall Water, to provide a trailer-mounted membrane system capable of supplying 1.15 mgd of filtered water to NBU customers during the high-demand summer months. As the project site was located in an environmentally sensitive area—the Edwards Aquifer Recharge Zone—multiple coordination meetings with regulatory authorities were held during design to obtain approval for the temporary trailer-mounted membrane system and to ensure that the design of the permanent system met all the relevant requirements.

This article provides insight on techniques that can be used to facilitate rapid design and construction of a new water facility, including:

- Using the CMAR project delivery method to help meet an accelerated schedule.
- Holding biweekly review meetings with the owner and the CMAR to quickly incorporate design updates.
- Preselecting a membrane manufacturer and conducting membrane piloting concurrently with design.
- Using a trailer-mounted membrane system on a temporary basis to meet customer demands during the summer months, which are typically the period of highest demand.
- Coordinating with regulatory authorities during design to ensure that projects meet all relevant requirements.

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Water Quality Sampling And Treatment Selection

Water Quality Sampling

In addition to issues with turbidity, which could be visually observed, various water quality sampling events detected aluminum, iron, and hydrogen sulfide above their respective regulatory limits, as well as the presence of *E. coli.* Due to the apparent correlation between rain events and turbidity levels, the project team suspected that the wells were likely GUI wells; however, the project team wanted to develop a definite correlation (if present) so that the cause of the water quality issues would be known. Additionally, more data were needed to characterize raw water quality and evaluate potential treatment options.

The project team developed a sampling plan that would help determine whether the wells were GUI. The sampling plan consisted of the following components:

- Collect additional data on aluminum, iron, hydrogen sulfide, and *E. coli* levels during dry and wet weather conditions.
- Collect data from online turbidimeters installed at each well and compare with data from U.S. Geological Survey (USGS) monitoring stations, noting any correlations.
- Complete a microscopic particulate analysis (MPA) during dry and wet weather conditions.

At the conclusion of the sampling period, the project team had collected strong evidence that the wells were GUI. Concentrations of aluminum, iron, and *E. coli* counts tended to be elevated 24 to 36 hours following rain events and then to decrease over time. A correlation was found between turbidity in the wells and flow in the Dry Comal Creek, which is typically dry unless heavy rain occurs (Figure 1).

Flow in the creek was more useful to correlate with water quality data than precipitation, as flow did not manifest in the creek unless rainfall was sufficiently heavy to saturate soils and generate a significant amount of runoff. Additionally, flow in the creek was measured continuously in 15-minute increments, while precipitation could only be found as daily totals and varied significantly over small distances. Finally, the dry weather MPA indicated a low risk for surface water contamination, while the wet weather MPA (Figure 2) indicated a high risk for surface water contamination, as *Cryptosporidium* oocysts were present.

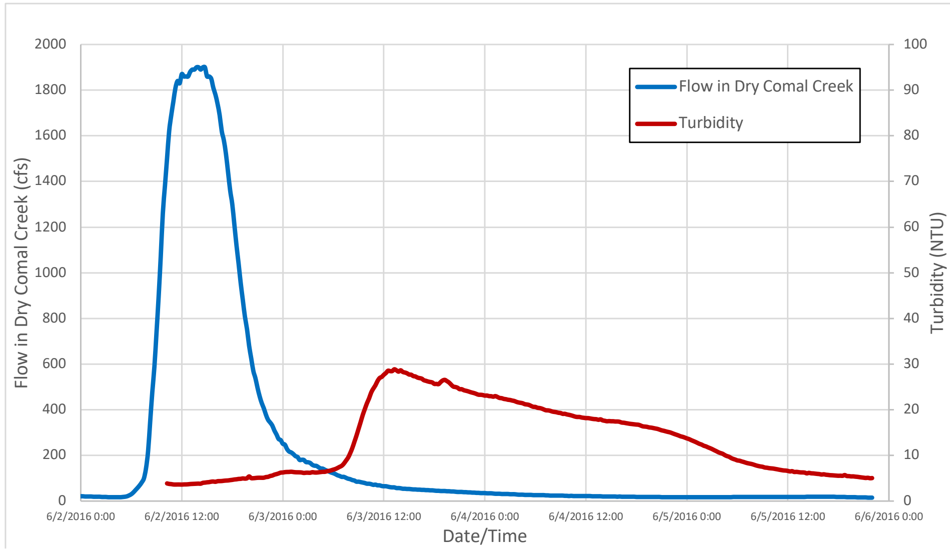

Figure 1. Flow in Dry Comal Creek and Turbidity in Well 4 (June 2016)

Figure 2. Wet Weather Microscopic Particulate Analysis

Treatment Selection

The project team evaluated four options for treating water at the Trinity Well Field:

- Conventional surface water treatment plant
- Pre-engineered package treatment plant
- Cartridge filters
- Microfiltration membrane system

These options were evaluated based on robustness, expandability, footprint size, staffing requirements, residuals handling, schedule, and life cycle cost. Following the evaluation, a membrane filtration system was selected for treating water at the Trinity Well Field. The primary reasons for selecting membranes were as follows:

- *Best-Suited Technology for Treating Raw Water Quality* – The water from the Trinity Well Field consistently had low levels of turbidity, and a particle-size distribution analysis revealed that the turbidity was comprised primarily of very small particles (1 to 5 microns) that exhibited poor settleability characteristics. Jar testing indicated that large doses of coagulant (~100 mg/L) would be needed to settle the particles, and even then, the maximum turbidity reduction achieved was 75 percent. Additionally, water from the wells was subject to extreme spikes in turbidity following rain events, anywhere from 20 to 100 nephelometric turbidity units (NTU). A membrane treatment system was selected as the most-effective treatment approach because it could easily remove the small particles contributing to turbidity and accommodate spikes in raw water turbidity with more frequent backwashing.
- *Easy Expandability* – During final design, the membrane system was sized to treat the full well field flow of 3.74 mgd with one rack out of service for backwashing; however, the racks were oversized by 20 percent so that additional modules could be added if raw water quality worsened over time and backwash frequency became excessive. Space was also left in the membrane building for additional racks to facilitate easy expansion if more wells are drilled in the future.
- *Small Footprint* – Of the treatment options considered, the membrane system had the smallest footprint after the cartridge filters. Additionally, the only deep excavation required was for the lift station, which was needed for all treatment options. Limiting footprint size and the amount of excavation was important because the site has hard limestone 1 to 6 ft below grade, making excavation more expensive than typical projects.
- *Cost and Schedule* – The life cycle cost for polymeric membranes was the lowest of all the options considered. Although the capital cost of cartridge filters was significantly lower than other options, a cartridge filter pilot test found that the cartridges plugged in a matter of hours when exposed to the typical low turbidity that is present in the wells, which made cartridge filters the highest life cycle cost option due to the frequency of cartridge replacement that would be required. The schedule for completing design and construction of a membrane system was longer than for cartridge filters, but various strategies were used to accelerate the schedule, as discussed further.

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Strategies for Facilitating Rapid Design And Delivery

Water supplied from the Trinity Well Field was needed when the project was brought online in 2015, but continuing water quality issues limited its use. Additionally, the project team collected enough data to be reasonably sure that the wells were GUI by the end of summer 2016, and the wells were officially designated as GUI by the state's regulatory authority in a letter dated March 14, 2017. Once treatment options had been evaluated and membranes were selected to provide treatment, NBU needed design and construction to proceed as quickly as possible to avoid running out of water in the high-demand summer months. Multiple strategies were used to facilitate rapid design and construction, including alternative project delivery, frequent design review meetings, preselecting a membrane manufacturer, installing a temporary trailer-mounted membrane system to provide water during high-demand summer months, and increased coordination with regulatory authorities throughout the design phase.

Table 1. Competitive Sealed Proposals Advantages and Disadvantages

Competitive Sealed Proposals (CSP)	
Advantages	**Disadvantages**
• Best value, not low bid price • Best-qualified contractor • Selection made based on predetermined criteria • Opportunity to include modifications to the proposal during the negotiation phase	• May not be lowest price • Opportunity for collaboration limited to negotiation phase

Table 2. Construction Manager at Risk Advantages and Disadvantages

Construction Manager at Risk (CMAR)	
Advantages	**Disadvantages**
• Timely and cost-effective procurement process • Can select based on nonprice factors • Accelerated project schedule; construction can start prior to completion of design • Contractor input into design, schedule, and cost estimating • Life cycle costing, operability, and ease of maintenance considerations easily incorporated into design • Can reduce overall project risk compared to design-bid-build due to preconstruction services • Can reduce design misunderstandings, requests for information (RFIs), and change orders • Earlier cost certainty; GMP provided during design; open book GMP and construction procurement; full transparency • Design according to budget	• May not be lowest price • Potential new procurement method for owner; may have a learning curve initially • Procurement advisor and preconstruction services is an additional cost • Engineer may reject some CMAR input as the engineer of record

Alternative Project Delivery

Multiple project delivery options were considered for construction of the project facilities, including traditional design-bid-build, competitive sealed proposals (CSP), and CMAR. The CSP is a selection process in which the owner requests proposals at the completion of design, ranks the offerors, negotiates on the final contract price, and then awards a contract to the selected contractor. It allows the owner to choose a contractor based on submitted qualifications and a proposed schedule, as well as cost.

With CMAR, a construction manager is selected during the design phase (typically around 30 percent design) and provides input on cost and constructability during final design. The CMAR provides a guaranteed maximum price (GMP) to the owner near the end of the design phase and is responsible for covering the cost difference if the total construction cost is above the GMP. In Texas, the CMAR acts as the project construction manager and is required to bid out all construction elements of the project, typically in multiple bid packages, but is allowed to self-perform the work if they are the lowest bidder for an element.

Summaries of the advantages and disadvantages of CSP and CMAR delivery methods are presented in Tables 1 and 2.

The CMAR project delivery method was selected for the project, which allowed it to be split into multiple construction packages. The CMAR worked with the project team to develop three bid packages, as follows:

- *Membrane Equipment Package* – This construction package consisted of all equipment to be provided by the preselected membrane manufacturer, Pall Water, including feed pumps and variable frequency drives (VFDs), prefiltration strainers, membrane racks and modules, backwash pumps, blowers and VFDs, air compressor system, clean-in-place chemical transfer pumps and skid, inlet and filtrate turbidimeters, and various ancillary equipment needed for the membrane treatment system.
- *Site Work, Building, and Lift Station Package* – The site work consisted of clearing approximately 1.6 acres of undisturbed land on the existing Trinity Well Field site to make room for the membrane treatment system building and facilities. This construction package also included the prefabricated metal building, wastewater lift station, and force main.
- *Facility Construction Package* – This package

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included construction of all components of the membrane treatment system facilities, including electrical equipment, backwash recycle pumps and tanks, chemical tanks, process piping, concrete feed water tank, backwash clarifier, and access roads and paving.

Splitting the project into different bid packages allowed the CMAR to mitigate long equipment lead times and get an early start on site work, which helped reduce the overall duration of construction. The CMAR provided value engineering input throughout final design, which helped keep the final project cost within NBU's budget. Finally, using a CMAR reduced risk to the owner by locking in a GMP for the project near the end of final design.

Biweekly Design Review Meetings

It's common for the engineer to submit in-progress drawings to the owner at specified intervals, usually at 30, 60, and 90 percent. The owner reviews the drawings and provides comments to the engineer, which are then incorporated into the work. For this project, the project team decided to replace these standard submittals with biweekly meetings among the engineer, the owner, and the CMAR. The engineer would bring the most-recent updates to the project drawings to the meeting, and the project team would review them together. This allowed the engineering team to receive design feedback, constructability reviews, and value engineering ideas as the project progressed, which greatly sped up the design schedule and helped keep the project under budget.

Preselecting a Membrane Manufacturer

One method for reducing design time was to preselect the membrane manufacturer, which sped up the design by eliminating the need for alternate designs to accommodate different manufacturers. It also helped the project team refine the layout of the membrane system and building more quickly by requiring submittal of equipment layout drawings from the selected manufacturer early in the design. Each of the membrane systems considered had different layouts and cleaning methods, so knowing which system was being supplied early in the design allowed the final plans and specifications to be better defined. To facilitate equipment preselection, a set of procurement documents was assembled and released as a request for proposals. The equipment manufacturer was selected through a competitive sealed proposal process; the contract documents clearly specified the conditions for preselection and the performance requirements of the equipment being prepurchased.

Figure 3. Temporary Trailer-Mounted Pall Water Aria FAST Membrane System Installation in New Braunfels, Texas

Temporary Trailer-Mounted Membrane System

Although design and construction proceeded rapidly, NBU had planned on utilizing water from the Trinity Well Field to send to customers in 2015. A target of May 2018 was set for substantial completion of construction of the new membrane system, but NBU was concerned about having enough water to meet demand during summer 2017. To meet this interim demand, a trailer-mounted membrane system was rented from Pall Water to treat water from one of the highest-producing wells onsite. The trailer-mounted membrane system was a Pall Water Aria™ FAST system, which had recently been approved for emergency use in Cisco, Texas, following a flood event. The system utilized Pall Water microfiltration membranes, which demonstrated 5.68 log removal of *Cryptosporidium* in a challenge test approved by TCEQ, thereby meeting treatment requirements for a Bin 4 classification as defined in the Long-Term 2 Enhanced Surface Water Treatment Rule. Additionally, the Pall Water Aria FAST system had a "full system" National Sanitation Foundation (NSF) 61 certification.

Normally, a pilot would be used to determine the flux at which a facility would be rated, but as this was a temporary rental system, a facility rating was not necessary. Furthermore, Pall Water's system was conservatively designed to produce 800 gal per minute (gpm) of treated water at a variety of possible raw water qualities.

All of these factors allowed the project team to make a case for accelerated regulatory review, which was granted due to the emergency nature of the project. Additionally, use of the trailer-mounted system had the added advantage of providing NBU operators with hands-on experience operating a Pall membrane system before completion of the permanent water treatment plant. The temporary membrane system is shown in Figure 3.

Coordinating With Regulatory Authorities Throughout Design

Regulatory approval is a common component of projects, and if not managed properly, it can significantly impact the schedule. Various aspects of this project required review and approval by different regulatory agencies, including TCEQ, the City of New Braunfels, and the Edwards Aquifer Authority (EAA), the latter because the site is located in an environmentally sensitive aquifer recharge area. To mitigate possible schedule

Table 3. Regulatory Submittal Tracker Example

Item No.	Permit/Authorization/ Approval	Agency	Status	Responsible Party	Regulatory Contact	Supporting Documents	Submittal Date*	Approval Date*	Fee	Notes
1	WPAP	TCEQ	Approved	FNI	SA Regional Office	Site plan, BMPs, geologic report	7/18/2017	11/7/2017	$6,500	Comments expected between 8/18 and 9/18

impacts, the project team developed a regulatory submittal tracker, which was used to determine when documents needed to be submitted to avoid project delays and to ensure that responses to questions from regulatory reviewers were submitted in a timely fashion. Table 3 shows an example of the regulatory tracker.

In addition to using a regulatory submittal tracker, the project team met with all relevant regulatory entities prior to starting design in order to develop a clear understanding of what was expected. One example of how this coordination led to further time savings is evidenced in TCEQ granting permission for the project team to decouple the results of the membrane pilot from the plan review process. The standard TCEQ regulatory approval process for a membrane drinking water treatment plant is to first review a membrane pilot protocol, then the membrane pilot results, and finally the membrane system design plans and specifications. Only when approval is received for the design plans and specifications can construction begin, and the review duration for each step typically ranges from 60 to 100 days, making this a lengthy process.

By meeting with TCEQ before starting design and explaining the emergency nature of the project, the project team obtained permission from TCEQ to submit the design plans and specifications prior to completing the membrane pilot, with the understanding that the plant's rated treatment capacity would not be assigned until the pilot results were reviewed. The risk in this approach was that the membranes may not have performed as well as expected, leading to a lower-rated plant capacity, but this risk was mitigated by leaving space for additional membranes on each rack. Additionally, the owner was protected by the contract documents, which established a minimum-rated capacity for the membrane plant without increasing the GMP.

This is a project-specific example, but preliminary meetings with regulatory authorities can be helpful when undertaking an emergency project to put the project on the reviewers' radar and give them context for any requests for an expedited review.

Conclusion

Delivering this project on an accelerated schedule required close collaboration among the project team members, which consisted of the owner, the engineer, and the CMAR. The following techniques were used to help accelerate the design:

- Use of the CMAR project delivery method to allow construction to begin before the design phase was complete.
- Biweekly design review meetings in which the owner and CMAR provided design feedback, constructability reviews, and value engineering ideas to the engineer.
- Preselection of a membrane manufacturer to reduce uncertainty and eliminate the need for alternate designs.
- Installation of a temporary trailer-mounted membrane system to meet peak demands during the summer months.
- Preliminary meetings with relevant regulatory agencies to understand the review process and required submittals, and utilizing a regulatory submittal tracker to anticipate the impact of regulatory review periods on schedule and mitigate when possible.