was installed 10-12 feet below the bottom of the Agua Fria Riverbed and the new force main is installed at a depth of 25 feet within the same 30-foot easement. Continuing from the east side of the river, the force mains continue east approximately 1,300 feet to North 115th Avenue where the alignments depart. The existing ACP force main extends further east and turns north for approximately one mile where it is bordered by a commercial shopping center, an apartment complex, and then by a residential neighborhood until it crosses Union Hills Drive. The new force main alignment turns north along the east side of North 115th Avenue to Union Hills Drive. At this point, the alignments of the force mains reunite and head north another 1.5 miles and cross Beardsley Road to the headworks of the NWVWRF as detailed in Figure 1.

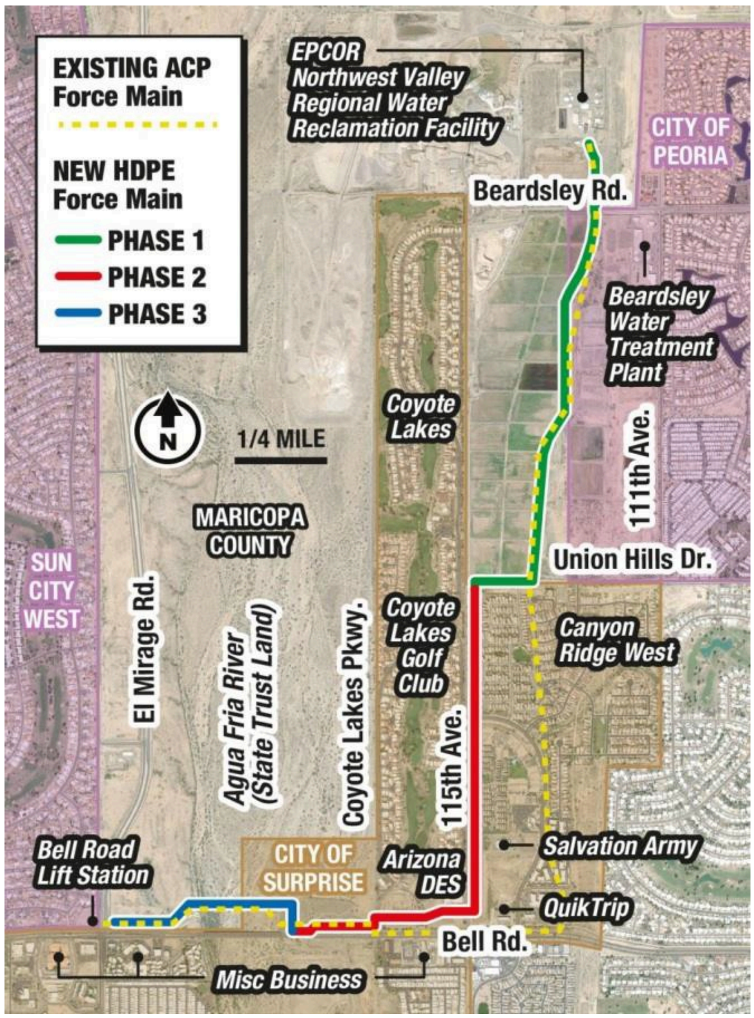

Figure 1 – Project Map Overview

PROJECT APPROACH

In the fall of 2015 EPCOR procured GHD to finalize the approach and design needed to execute this project. Immediately after the design process began, GHD identified three issues that could ultimately prevent the project from reaching the completion goal of less than one year. Those critical issues included the following:

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1. The Arizona Department of Transportation (ADOT) interchange construction at Grand Avenue and Bell Road caused a moratorium to be issued by the City of Surprise on all other construction projects that would cause major traffic impacts. This meant that a force main alignment in the North 115th Avenue right-of-way would not be permitted.
2. Delays with ASLD easement modification application provided concerns that an alternative river crossing method would need to be used.
3. The completion of the feasibility of the entire alignment had not been completed and many questions had to be answered quickly. There was too much to risk to procure through design-bid-build. All three parties would have to engage in accepting some portion of the risk in order for the project to be successful.

Based on those complexities GHD recommended that EPCOR consider changing the project delivery method from design-bid-build to a Construction Manager at Risk (CMAR). EPCOR evaluated the benefits of that procurement method and quickly executed the CMAR selection process. GHD participated in the selection process, which was completed quickly with the release of the RFQ to selection in only 18 days.

Achen Gardner was selected based on their substantial CMAR experience. Achen Gardner's primary CMAR preconstruction services included collaborating with EPCOR and GHD to complete constructability reviews, utility stakeholder coordination, estimating services, subcontractor and supplier selection, and to prepare the Construction Guaranteed Maximum Price (GMP) Proposals for each phase. The final project team is represented graphically by role and phase in the figure below.

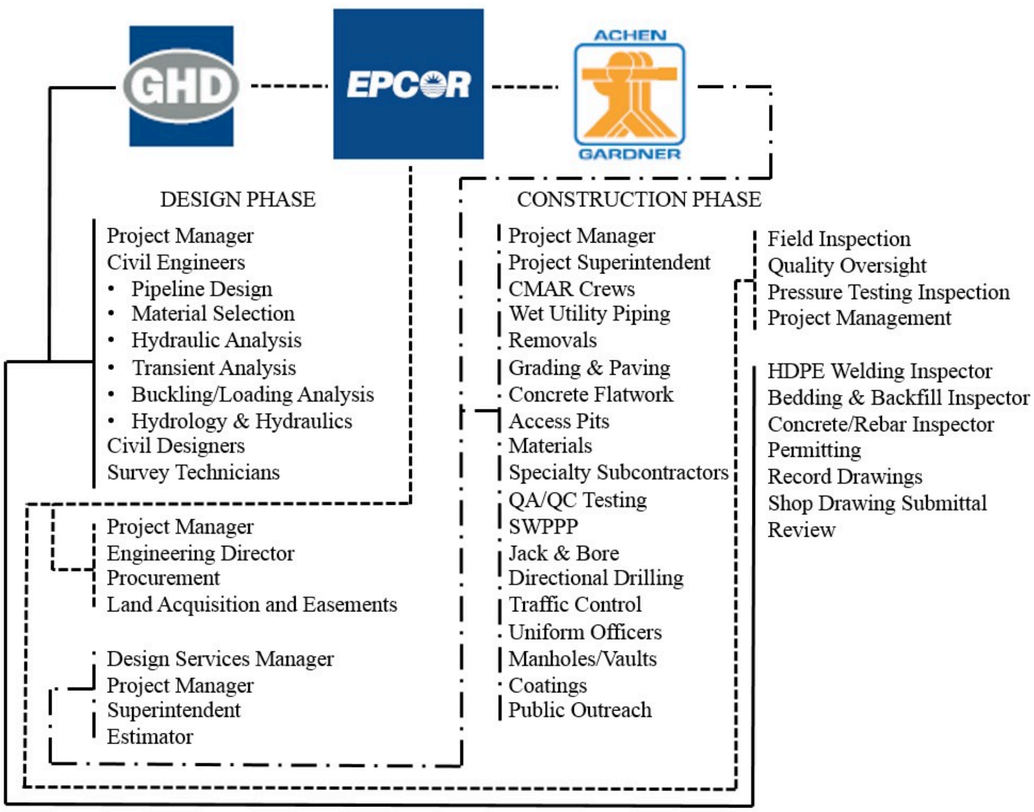

Figure 2 – Project Team Organizational Chart

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The major team member roles and responsibilities are discussed below. At the end of this project it was confirmed that this method of alternative project delivery provided the tools and networks needed to appropriately share the project risk from the conception to construction and forced the Owner, Engineer, and Contractor to jointly make decisions for what was best for the project.

PUBLIC AND ENVIRONMENTAL CONSIDERATIONS

The impacts of this project on neighboring residents, businesses, and communities were considered and addressed from multiple perspectives staring with the decision to rebuild confidence in the critical infrastructure that serves the Sun City West community. The next decision was to move the primary conveyance corridor away from the existing ACP force main alignment between Bell Road and Union Hills Drive, which is bordered on both sides by a commercial shopping center, an apartment complex, and a residential neighborhood. This portion of the ACP alignment has higher risk for environmental impact relating to unplanned repairs and is prone to higher maintenance costs. The new force main alignment was decidedly selected along less impactful routes. Next the project team engaged with the community stakeholders to review and gain approvals for the project, as listed in the table below.

Agency	Ph1	Ph2	Ph3
Arizona Department of Environmental Quality	X	X	X
Army Corps of Engineers			X
Arizona Department of Transportation		X	X
Arizona State Land Department			X
Arizona Public Service	X	X	
City of Surprise	X	X	X
City of Peoria	X		
EPCOR NW Valley Regional Water Reclamation Facility	X		
Flood Control District of Maricopa County (FCDMC)		X	X
Maricopa Department of Transportation	X	X	
Maricopa County Environmental Services Department (MCESD)	X	X	X
Tucson Electric Power	X	X	
3rd Party Utility Companies	X	X	X

Table 1 – Stakeholders by Phase

CMAR CONTRIBUTIONS

Achen-Gardner's primary CMAR pre-construction services included collaborating with EPCOR and GHD to complete the following items critical to expediting the project's design and construction while ensuring EPCOR's quality and budget expectations were met.

Project Phasing Having a CMAR as part of the design team facilitated the design and construction to be separated into three phases, which shortened the project timeline. This allowed Achen-Gardner to begin construction on Phase 1 of the project before the design of Phase 2 was complete. This was repeated with the start of construction of Phase 2 prior to the final design of Phase 3.

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Identification and Analysis of Alternative Alignments Achen-Gardner understood that the team needed a CMAR firm to assist in evaluating all possible alternate alignments in order to finalize a constructible yet cost effective design. Achen-Gardner was able to quickly evaluate the constructability of, and produce cost estimates for, the many different pipe alignments that were considered. For example, evaluations were developed for alignment and constructability options for how to get from Coyote Lakes Entrance to the west side of Agua Fria River and under/across the Agua Fria River, as depicted in the figure below.

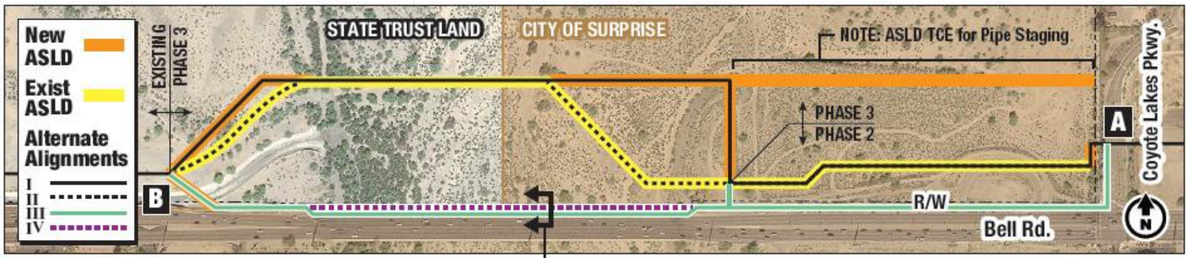

Figure 3 – Phase 3 and Phase 2 Alignment Evaluation

The feasibility of the Agua Fria River crossing was of particular concern to EPCOR because the integrity of the existing AC force main needed to be maintained during installation of the new HDPE force main within the same 30-foot easement. Achen-Gardner evaluated several different construction methods for the Agua Fria River crossing, and provided confidence that the selected directional drilling method would be feasible, and successfully protect the existing AC main.

Construction Guaranteed Maximum Price Development Once the designs were finalized for each phase of the construction, Achen Gardner developed a construction Guaranteed Maximum Price (GMP) for each phase. This included open-book bids from multiple suppliers and sub- contractors, negotiated overhead rates, and completion dates.

Tie-ins to Existing Force Main Operational shut-down and tie-in plans were evaluated by Achen Gardner, GHD and EPCOR during the pre-construction services which were extremely critical as the existing force main can only be shut down for approximately 4 hours for tie-ins. For this reason, it was critical to confirm alternate alignments and tie-in locations to minimize construction duration and ensure the timely tie-over of new facilities. This included Achen Gardner performing mock shut-downs to ensure delays are avoided during construction.

UNIQUE DESIGN ELEMENTS

Pipe Materials Evaluation Different materials were considered for the proposed force main. Typical materials considered in wastewater force mains include epoxy coated ductile iron pipe (DIP), epoxy coated reinforced concrete pipe, polyvinyl chloride pipe (PVC) and high-density polyethylene (HDPE) materials. Each of those options was initially considered based on constructability, resistance to the corrosive nature of wastewater and cost. The concrete and DIP pipe materials were found to provide excellent structural performance but was not a good solution for the horizontal directional drilling construction anticipated and had concerns regarding the longevity of the epoxy coating in contact with the wastewater and anticipated hydrogen sulfide concentrations. Additionally, the rigid nature of those materials causes

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higher transient wave speed and higher surge pressures. Likewise the PVC pipe material shared similar concerns due to the rigid nature of the material. The benefits of those materials was that length of continual trench openings could be reduced during construction as compared with the HDPE material in which multiple 40-foot lengths of the pipe must be fused and placed in the trench as a whole. The HDPE pipe material was found to have a higher resistance and longer life cycle for conveying wastewater, considering the effects of air being introduced to the system from air valves. Therefore the HDPE material was selected for the entire proposed force main based on the predicted hydraulic and transient performance of the system, and on constructability requirements that include a minimum DR required for the horizontal directional drilling technique used in both phase 2 and phase 3.

Thermal De-Rating Based on the predicted operating system pressures, the proper HDPE material was evaluated to determine the actual pressure rating of the material based on the design temperature. In review of the HDPE material specifications for the selected supplier of the pipe, it is noted that there is a de-rating factor for pressure strength at temperatures above 80 degrees F. In an effort to be conservative, EPCOR has directed that the HDPE pipe for the proposed force main to be designed for water and air temperatures in the neighborhood of 100o F, therefore the design operational temperature for the replacement force main is 100o F. GHD reviewed the material design specifications with the selected product provider for the HDPE pipe material and incorporated a pressure de-rating, based on the manufactures guidelines for the material.

PE4710 HDPE pipe as manufacturer by Performance Pipe was selected for the project. Based on that material, the hydrostatic design basis for fluid temperatures between 73o F and 140o F is 1,000 psi, where the hydrostatic design basis for fluid up to 73o F is 1,600 psi. The temperature design factors as provided by the material manufacturer indicate the Hydrostatic Design Stress for polyethylene was established by testing at 73o F. A property of Polyethylene (PE) materials is that as temperature increase, PE material has lower resistance to load and the pressure rating decreases. Therefore a Temperature Design Factor needs to be included to adjust the pressure rating for the application temperature.

Based on the goals for the for the pipe to be designed for water and air temperatures of 100o F, a design factor if 0.78 was used for the pressure rating. Additionally an environmental application factor (AF) was included, where the specific manufacturer used water to determine the basis of the hydrostatic design stress where for this application of a wastewater the environmental application factor of 1.0 was used.

Based on the hydrostatic design stress, temperature design factor, environmental application factor and dimension ratio the pressure ration was determined for each phase. Additionally a safety factor of 5% of the working pressure was maintained and the HDPE pipe DR was selected considering the thermal de-rating anticipated.

Hydraulic and Transient Analysis A Hydraulic analyses of the proposed force main was completed to determine the pressure and velocity ranges that the system will experience and the total dynamic head requirements for the system. The anticipated flow was developed based on the existing and proposed pumping conditions for the existing lift station and the cycle time of the wet well at the existing lift station were evaluated. Three pumping scenarios were evaluated and the results revealed a range of 3,500 gpm to 5,350 gpm is conveyed through the system.

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A transient analysis was also completed to predict the maximum pressures for the new force main. The purpose of this analysis was to evaluate the pipe material selection, alignment optimization, and to predict the size and location of surge mitigation techniques. This analysis consisted of creating common and occasional surges in the system to predict maximum pressures and possible negative pressures that may occur in the system during expected operational events, such as pump cycling, pump trips or valve operation. For the purpose of the analysis, these events were divided into two different categories, including Recurring Surges which represent pump cycling and pump trips due to power loss, and Occasional Surges that represent valve operation.

A transient event occurs when an abrupt change in the velocity of a flowing liquid in a pipe generates a pressure wave. The velocity wave equation was used to determine the predicted transient pressure, based on the bulk modulus of fluid at working temperature, the dynamic instantaneous effective modulus of pipe material and the pipe dimension ratio(s). Part of the force main material evaluation revealed that HDPE was an optimal material for resistance to the corrosive nature of the wastewater, constructability, and reduced transient wave speed, where the wave speeds calculated for HDPE material pipe are significantly lower than wave speeds for rigid materials such as ductile iron and steel pipe, which has wave speeds between 3,000 ft/s and 5,000 ft/s for similar pipe dimensional ratios. The lower wave speed results in a dampening of the transients in the system as compared to utilizing a rigid material. The resulting transient surge pressure was calculated from the wave velocity and the predicted sudden change in fluid velocity. The transient surge pressures, based on the approach described above were then calculated for a range of anticipated system working pipeline velocities from 0.5 feet per second (fps) to 5.0 fps.

The transient pressures were also solved in a transient model, utilizing KYPipe 2012 SURGE software to verify the magnitude of the largest pressures associated with the predicted transient events, and to identify any negative pressures that could cause cavitation. That transient model analysis revealed the magnitude, frequency and location of any adverse effects from the recurring and occasional surge events predicted in the proposed conveyance system. The transient evaluation only considered two of the three hydraulic scenarios including the lowest and highest flow rates. The maximum system working pressures and velocities predicted were considered in the alignment, material selection and construction of the proposed force main.

Scour Analysis The Flood Control District of Maricopa County (FCDMC) required an evaluation on the long-term scour for the proposed force main alignment at the crossing of the Agua Fria River. This took into account the historic stream bed profile. The upstream location included interaction with the upstream end of the spur dike but did not include the scour interaction of the bridge piers or bridge abutments. The results of this analysis defined the minimum force main depth of the river crossing which was approximately 25-feet.

Pipe Loading A unique consideration for this project was associated with the proximity of the force main to existing and future electric transmission mains within phase 2 where there is an existing transmission corridor along the east side of the proposed force main, and a future corridor along the west side on phase 2.

The electric utility providers in that corridor required that the design accommodate loading from a 250 ton crane throughout that corridor, as this is the anticipated loading for future

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electric transmission construction. The electric utility providers requested recommendations for third party testing for compaction during construction, and inspection administration which the Achen Gardner coordinated for the project team.

The anticipated loading conditions were evaluated by GHD to confirm that the proposed HDPE force main would not be impacted. This included vertical dead and live loading calculations and compares those with the proposed force main pipe design capacity for vertical and surcharge loading. Backfill and bedding design recommendations and inspection for quality assurance and oversight during construction were also provided. That evaluation considered the soil prism load as a conservative method for dead loads, and considered this location is used for flood water conveyance, so the influence of water and saturated soils was included. The Timoshenko Equation was used to solve for the soil pressure at a point directly under a distributed load considering the impact factor, wheel load, contact area, equivalent radius and the depth of cover to the crown of the pipe. All of this was evaluated for both the weight of the anticipated 250-ton crane, plus the lift weight of 250-tons. Then check for the live loading for the pressure at all points along the proposed force main considered the Boussinesq Equation to find the pressure transmitted from a wheel load to a point that is not along the line of action of the load for unpaved areas. The relationship between the distance from the loading point and the top of the pipe is represented in the figure below.

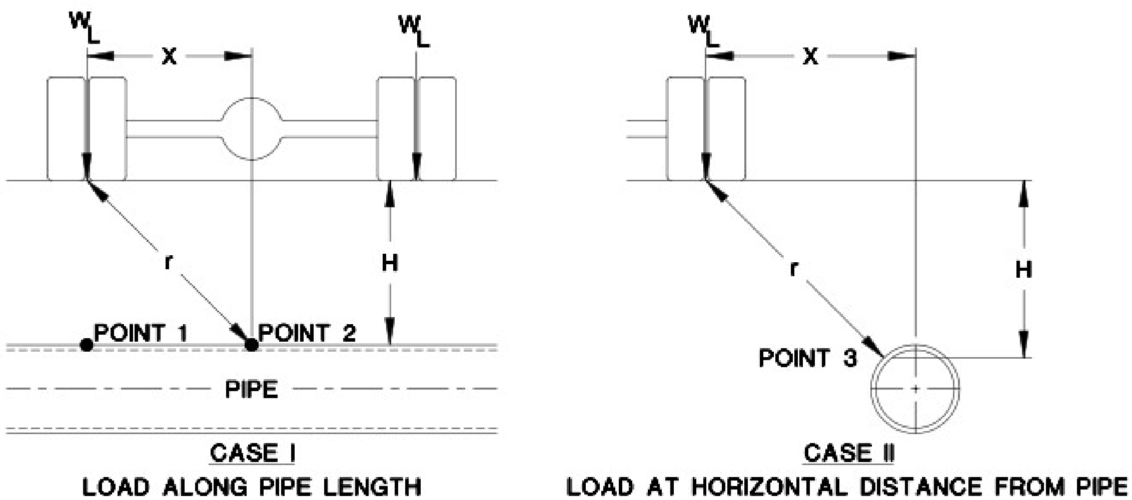

Figure 4 - Loading from Indirectly Above Pipe

Finally the combined anticipated dead and live loads in this area was completed and used to confirm the HDPE pipe DR selection.

Pipe Buckling When the force main is full, it is free from collapse, however during time of maintenance it is anticipated that the force main could be drained. Therefore the force main pipe was designed to resist localized buckling while under the combined effect of external pressure and a very temporary full vacuum. It is critical to provide an adequate margin of safety. The approach for achieving this objective was complete by using Luscher's Equation with solves for the allowable constrained buckling pressure by evaluating the soil support factor, soil reaction modulus, and a safety factor. Additionally a buoyancy reduction factor was considered as a function of the buckling pressure and the HDPE pipe DR was then selected so that the allowable buckling pressure of the HDPE pipe was greater than the vertical pressure of the live and dead loads.

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The proposed HDPE force main was design in accordance with the American Water Works Association (AWWA) Manual of Practice 55 (M-55) "PE Pipe – Design and Installation". This manual defined the "Design Window" in which applications that fall within this window require no calculations other than constrained buckling which was presented above. Additionally if the pipe is limited to DR 21 or lower, such as in this case, the constrained buckling calculation has a safety factor of at least 2, and no calculations are required. Per the calculations completed for this design, a safety factor of 3 was used.

UNIQUE START UP ELEMENTS

EPCOR planned to maintain the old 18-inch ACP as a reserve force main, and thus, needed to flush out the approximate 240,000 gallons of raw sewage still contained in the old pipe. To accomplish this, EPCOR rented 10 semi-trailer water tanks (21,000 gallon capacity, each) and a portable pump that could provide a flow of 3000 gpm through the old force main, and stationed them at the Bell Road Lift Station site. The 10 portable tanks were filled with water and chlorine was added so that the tanks contained a 50-60 mg/l solution of chlorinated water. The 10 tanks were plumbed to a common 10-inch discharge header which fed the portable pump.

Two days after the old ACP force main had been isolated, the Bell Road Lift Station wet well was pumped down, the pumps were turned off, and the valves were operated to isolate the new HDPE force main and place the old force main back into service. The pump were connected to a bypass header and began pumping the super-chlorinated water from the portable tanks through the old force main. The flushing operation continued for about 75 minutes with 225,000 gallons flushed through the ACP force main. The level of the wet well at the Bell Road Lift Station required that the pumps be re-started, so the old force main was re-isolated and normal operation of the new HDPE force main resumed. The flushing operation of the old force main was still 15,000 gallons shy of a full flush, so the rented tanks were re-filled with super-chlorinated water, and the flushing operation was repeated later that afternoon with a flush of 180,000 gallons at 3100 gpm. In total, 405,000 gallons of chlorinated water was flushed through the old 18-inch ACP force main at nearly 4 feet-per-second, and then isolated from service, full of clean water. The old ACP force main remains out-of-service with, and fully charged with water, waiting for use as a stand-by redundancy during future maintenance of the new force main.

CONCLUSION

The new HDPE Bell Road Force Main was successfully completed and placed into service in early November 2016, less than 11 months from the time Achen-Gardner was brought on as project CMAR. Utilizing the CMAR alternative project delivery method was the key tool to unite design and construction efforts with the owner's accelerated schedule, all while maintaining operation of the existing 2.5 MGD wastewater system. EPCOR now has renewed confidence and redundancy with a critical connection to the Sun City West Wastewater District.

The Owner, Contractor and Engineer leveraged the benefits from the expertise of each team member to on-board stakeholders and regulators, maximize efficiency and constructability, find innovative solutions to maintain schedule and quality, which in whole created a custom fit solution in just over twelve months from concept to completed construction of over 3 continuous miles of large dimeter sewer force main. These results demonstrate the value in

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both considering alternative project delivery and including construction professionals early in the concept and design process to assist in identifying and mitigating risks during construction. Regardless of our role on a project, we are all responsible for protecting the health and safety of our communities and delivering and maintaining quality infrastructure. This project is an example of finding success by engaging early in the decision making process to identify and assign project risks and working as a holistic team and ultimately reducing the overall cost, increase the performance of the infrastructure, and reducing the overall project schedule.

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City of Houston 30-Inch Water Transmission Main Replaced by Compressed Fit HDPE Pipe Lining

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Abstract

City of Houston needed to renew a critical 30-inch well collection pipeline. The Steel Cylinder Reinforced Concrete (SCRC) and Prestressed Concrete Cylinder Pipe (PCCP) water main required replacement of approximately 7,600 linear feet, near the Katy Addicks Pump Station along Scenic Ridge Drive.

The existing 30-inch diameter transmission main is 37 years old and beginning to show numerous operational problems due to joint leaks. This paper will outline the design phase and selection process as open cut, slip lining, pipe bursting, cured in place pipe and a compressive tight fitting high density polyethylene pipe (Swagelining) were considered.

The design criteria required a fully structural Class IV solution capable of 60 psi operating pressure. Overall, the hydraulic cross section needed to be maintained as large as possible requiring an I.D. of liner 28-inch or greater within the 30-inch I.D. host pipe. The optimized design included maintaining various other parameters such as vacuum pressures, live loads and ground water.

Among many factors, the compression tight fitting HDPE pipe process was selected because it is trenchless and less disruptive to the residents, required less time for installation, offered a long design life with the new HDPE pipe and was less expensive. Also, the implementation schedule could be accomplished in low water demand season.

This paper will also outline the construction phase, including the compression fit process, the pipe installations performed by Murphy Pipelines, and the challenges associated with the installation through an urban residential neighborhood.

The utilization of this technology with HDPE pipe allowed the owner to meet all design parameters and increase the flow capacity.

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