The Northern California Pipe User's Group
26th Annual Sharing Technologies Seminar

Concord, CA
February 22, 2018

www.norcalpug.com

HIGHLIGHTING INNOVATION AND SUSTAINABILITY BY RENEWING AC PIPELINES WITH CURED-IN-PLACE PIPE

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ABSTRACT: Like many water utilities, East Bay Municipal Utility District's (EBMUD) system of 4,200 miles of distribution and transmission pipelines is in need of renewal at an increasing rate to reduce the annual number of main breaks. In 2016, EBMUD embarked on an initiative to increase its yearly renewal rate from 10 miles to upwards of 40 miles and to make long-term recommendations focused on developing a cost-effective, efficient, and sustainable renewal program. This investment to replace pipelines is critical to maintaining system reliability for EBMUD's 1.4 million customers.

EBMUD maintains over 1,100 miles of asbestos cement (AC) pipelines with an average age of 50 years. AC pipes make up 30% of the distribution system and account for 16% of annual main breaks. In 2015 EBMUD and the Water Research Foundation (WRF) completed a study on the *Development of an Effective Management Strategy for Asbestos Cement Pipe* (WRF, 2015); one specific recommendation was to consider the use of structural rehabilitation as an alternative to open trench replacement.

This paper summarizes the selected projects, design criteria, construction processes, and lessons learned for the renewal of 2.5 miles of AC pipe using Cured-In-Place Pipe (CIPP). AC pipelines selected for renewal had a history of leaks and construction challenges, including pipes installed through city parks, below major freeways, and in areas with a high degree of underground utility congestion.

1. INTRODUCTION

In 2015, EBMUD began a pilot program to evaluate options for increasing its pipeline replacement rate as a means toward a better maintained distribution system. With approximately 4,200 miles of distribution and transmission pipe, including 1,100 miles of aging asbestos cement (AC) pipe, EBMUD is examining alternatives to open trench replacement as an effective management strategy to renew AC pipelines (WRF, 2015).

Four pilot projects, totaling 2.5 miles of AC pipeline, were selected for CIPP renewal. Projects were chosen in order of increasing difficulty and ranged from a relative straight run of pipe without any customer service connections, to a distribution pipe with many customer services on a busy street crowded with underground utilities. Details about each of the four projects are listed in Table 1. Pilot project findings also address maintenance, economic benefits, community impacts and environmental impacts related to EBMUD's sustainability goals.

Table 1. CIPP Pilot Projects

Attribute	Marina Park	Glenn	El Camino Corto	Upper Happy Valley
City	Richmond	San Pablo	Walnut Creek	Lafayette
Pipe Diameter	12-inch	12-inch	8-inch	12-inch
Pipe Type	AC/Steel	AC/Steel	AC	AC
Length	637 feet	1900 feet	4964 feet	5177 feet
Customer Services	0	0	69	82
Hydrants	0	0	8	13
Distribution Connections	2	5	10	14
Access Pits	3	7	13	30

2. TECHNICAL DISCUSSION

In 2015 EBMUD investigated CIPP for potable water main renewal. Staff reached out to liner manufacturers and water utilities that had conducted or considered pilots, attended conferences and trainings, and stayed informed on available literature and test results. Specific design criteria, installation techniques, and experience were considered in selecting which CIPP product to pilot.

CIPP Details and Specifications

CIPP lining installs a pipe within an existing (host) pipe. The liner adds service life to the host pipe, presumably with less disruption and cost as compared to open trench replacement. Many pipe liners are available today, with differing qualities and purpose. Some liners rely on the host pipe for their structural integrity, while others are fully structural, designed to withstand all internal and external loading with no help from the host pipe. Some liners fully adhere to the host pipe, while others are simply fit tight to the host pipe. Some liners are pulled into the host pipe while some are inverted. Liners cure by different methods as well, including ambient, heat (steam or water), and ultraviolet light.

EBMUD reviewed available CIPP liner alternatives with specific suitability criteria in mind:

1) NSF 61 certification – a must have, but the list of liners with this approval is surprisingly short
2) Class IV structural – with AC pipes failing structurally, it was imperative that the renewal strategy be structural
3) 3rd party tested – unbiased data on the performance of the liner and destructive laboratory testing
4) Manufacturing and installation maturity – a list of water utilities to interview on their experience during and since construction
5) Full adherence to host pipe – keeping maintenance simple and eliminating the need for end seals or special fittings
6) The ability to internally reinstate services – to minimize the trenching, including service reconnections.

Based on these criteria, EBMUD selected Aqua-Pipe for a CIPP pilot. In this paper, CIPP refers to the lining technology in general, and Aqua-Pipe refers specifically to Sanexen Environmental Services proprietary CIPP product. Aqua-Pipe is a woven textile jacket with an inside polymeric membrane for water tightness, that is injected with epoxy resin, pulled-in-place and cured with hot water. Technical Aqua-Pipe details are listed in Table 2.

Table 2. Aqua-Pipe Technical Details

Attribute	Detail
Available Sizes	6-inch to 24-inch typical (larger is available)
Installation Length	Up to 1,000 feet between access pits, typical 600 ft for 6-inch pipe
Structural Grade	Class IV
Maximum Bend	45 degrees
"C" Factor	> 120
Thickness	~ 0.2-inch (1/2-inch ID loss)
Design Method	Fully Deteriorated Pressure Pipe Condition, ASTM F1216, Appendix X1
Design Life	50 years or greater
Manufacturer's Warranty	1 year
Design Pressure	125 psi

Technology Background

CIPP technology was initially utilized for pipe renewal of sewers in Europe during the early 1970s. The technology made its way to residential applications and the United States in the later 1970s and 1980s, but remained primarily a solution for rehabilitating sewers. In the late 1990s, Aqua-Pipe was introduced as one of the first CIPP products specific to potable water mains. Aqua-Pipe was installed in Quebec for potable water main rehabilitation through the 1990s, and by the 2000s it was widely utilized in Toronto, Montreal, and Ottawa. The City of Montreal renewed half a million feet of water mains using Aqua-Pipe since 2009, investing over $175 million in contracts for turnkey water main renewal projects. Water utilities in the United States began renewing water pipelines with Aqua-Pipe in 2014. By 2017, over 3 million feet of Aqua-Pipe has been installed in North America.

In 2012, due to increasing interest but limited information on innovative pipeline renewal technologies available in the United States, the U. S. Environmental Protection Agency (EPA) evaluated the performance of a 2,000 foot CIPP installation in Cleveland Ohio (EPA, 2012). The demonstration was considered successful in meeting the utility owner's needs, while noting that there was room for improvement in the technology and methods. Notably, improvements to the camera inspection and robotic technology used in CIPP renewal would enhance pipe inspection practices, and the ability to reinstate services.

With CIPP products and installation methods being relatively new to potable water systems, specific standards, test methods, and training courses are not yet readily available. Most available standards and CIPP training courses are geared toward lining of gravity pipes, with little to no mention of potable water mains, let alone AC pipes. For contract specifications, there is little guidance aside from the anecdotes of small pilots conducted by other utilities, and the recommendations of the manufacturer/installer. Currently, CIPP technology is mostly applied to renewing cast iron mains rather than asbestos cement mains, therefore experience cleaning and lining asbestos cement mains is limited. EBMUD considered CIPP technology primarily for AC pipe rehabilitation, so it is important for the CIPP market to continue to mature in this area.

4. PROJECT SELECTION

The EBMUD CIPP pilot program aimed to select pipelines where open trench was not a preferred option. Each pilot project selected increases in complexity, allowing EBMUD staff to build skills and knowledge of the product and process through each project. Summaries of each pilot are included below, and site maps are included in Figure 2.

Pilot 1

This 1956 AC transmission pipeline is located in a popular waterfront city park with known buried archeological resources. The 12-inch main had broken four times (in 1997, 2000, 2014 and 2015). Because it is buried under 5.5 feet of cover, repairs required large and deep excavations that were disruptive to the public's enjoyment of the park. After the main break in 2015, the 640 foot long pipe was removed from service.

CIPP was selected for the first pilot project to help preserve the park assets and access during construction. The transmission capacity of this main needed to be maintained, but the main could be relocated if necessary. Since this pipe had no hydrants or services, no temporary main would be needed to maintain service to customers while the pilot was conducted. Being in a park, construction here would have low interference from cars or pedestrians.

Pilot 2
This 1954 AC and steel pipeline was the second alignment selected for the CIPP pilot. The AC portion of the 12-inch main had broken multiple times in the 1990s, and in some places is more than 8 feet deep. The steel portion recently broke at the east side of an Interstate-80 crossing. Too close to a sound wall for maintenance crews to locate and access for repair, the pipe was removed from service, limiting operational flexibility and rendering other freeway crossings more critical.

It was preferable to maintain the transmission capacity of this main for system redundancy, but if CIPP didn't work the main could be abandoned, leaving the remaining freeway crossings critical. Traditional replacement or repair methods for the freeway section would have been prohibitively expensive (the jack and bore section was estimated at $1620/foot). This pipe had no services or hydrants, so no temporary main was needed, but was located in a street that had multiple side connections requiring isolation and reconnection. Relatively low risk, this was selected as the second pilot project, adding some design and construction complexity not featured in the previous Marina Park pilot.

Pilot 3
This 1955-1959 AC distribution main had broken four times in 2015. Maintenance crews had difficulty locating the breaks and making repairs on this 8-inch main because the existing alignment was inherited from a legacy water company and not well documented, so each subsequent repair was going to be expensive.

The City of Walnut Creek had recently paved the street and placed it under a paving moratorium. Rather than wait for the paving moratorium to expire and do a traditional open-cut replacement, renewal by a trenchless method that would minimize the street cuts was considered the best option, and was selected as the third CIPP pilot. Unlike the previous two pilots, this project featured services and hydrants, and a temporary main would be needed to keep customers in service during renewal, adding design and construction complexity to the suite of CIPP pilots.

Pilot 4
This 1956 AC distribution main was located on a high traffic roadway. The 12-inch main had broken 29 times since the 1990s, and four times since 2015 (Figure 1). Maintenance crews had difficulty making repairs due to the size of the failures, depth of the pipe and traffic on the road, and large claims were filed against EBMUD in this affluent neighborhood.

This main was identified for replacement 15 years ago, and designs were completed, but construction was repeatedly put off because the City of Lafayette wouldn't allow for any road closures. In 2013 the designed alignment was used by the City of Lafayette for a storm sewer replacement, leaving no corridor for a new water main. The only feasible option was to replace the main in its existing location; leveraging the use of an innovative, trenchless technology this was selected for the fourth CIPP pilot. Like El Camino Corto, it has many existing services, hydrants and connections necessitating the use of the temporary main system, but is in a higher traffic area with more underground congestion.

Figure 1. Two main breaks on Pilot 4 (12-inch AC main) in 2016

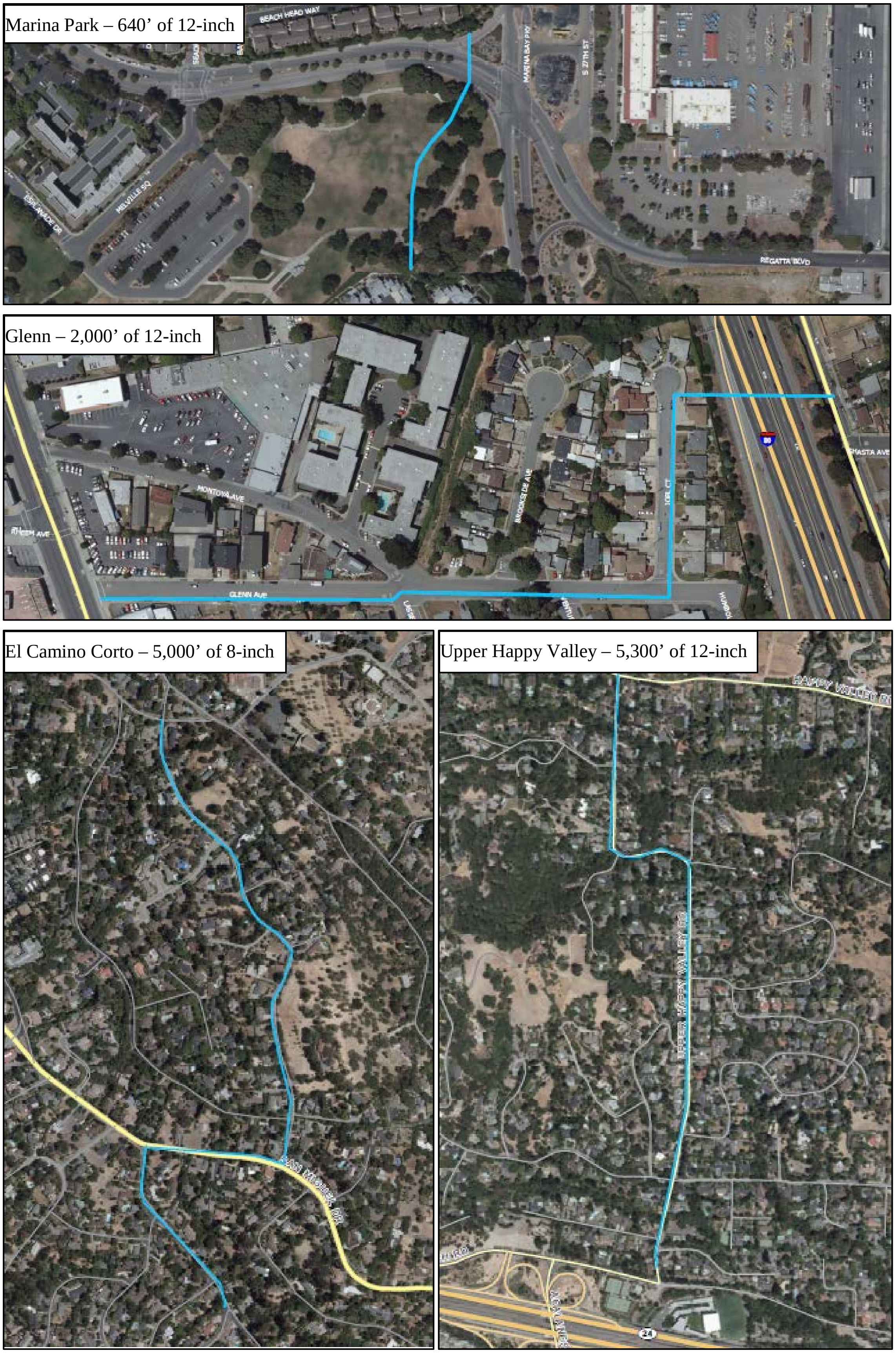

Figure 2. Pilot project site maps

5. DESIGN

With CIPP the alignment is fixed, but there is still plenty to design: the liner diameter and thickness; the location and dimension of access pits; and how the pipe should ultimately be reconnected, both in the pits and to the distribution system. The design must include research of potential pipeline obstructions, and locations for new hydrants and valves, including air valves and blow-offs. In addition to the pipe that is being lined, a temporary main to keep customers in service also requires design including sizing for hydraulic capacity, temporary hydrants, sample or flush points, and means of maintaining driveway access.

Liner Design

CIPP design starts with researching existing records. The as-builts and maintenance records for the host pipe are reviewed to gain a clear picture of all bends, tees, and valves or potential obstructions in the host pipe. Even with a thorough review of as-built records, unknowns will likely be discovered during construction: unmapped or abandoned offsets, tees, valves, blow offs, services, repairs, etc. This can lead to additional access pits, additional connections, and not insignificant additional costs. The simplest CIPP projects will be straight (both horizontal and vertical), with valves, appurtenances, and tees occurring at logical intervals for access pit spacing (usually 300-600 feet apart, depending on pipe diameter). Most lining technologies can line through 45 degree bends, but consecutive bends (such as in an offset return) are more challenging and should be discussed with the contractor or manufacturer.

During the design process, the host pipe should be uncovered in one or more locations and measured for internal diameter so the manufacturer can appropriately size the liner. At the same time, the outside diameter of the host pipe should be measured for planning the final connections and acquiring suitably sized fittings. While the project specification should require the manufacturer to measure the internal diameter of the pipe before fabricating the liner, it is the responsibility of the water utility owner to facilitate and ensure this happens.

The liner thickness is determined from the equations in ASTM F1216 Appendix X1, the typical scenario is a for a fully deteriorated pressure pipe, however the gravity pipe conditions must also be met (and usually dominate), to ensure the pipe is designed to accommodate external forces when the pipe is not pressurized. This calculation should be completed by the manufacturer and independently verified by the water utility owner. In these pilot projects the liner reduced the internal diameter of the pipe by approximately 0.5 inch. This is acceptable in most cases from a hydraulic capacity perspective, especially since the Hazen-Williams coefficient of the CIPP is usually higher than that of the host pipe. For AC pipe, the Hazen-Williams coefficient is similar to CIPP so the hydraulic capacity difference is negligible as long as a reduction in internal diameter is acceptable.

For Pilots 1 through 3, the manufacturer sized the liner based on an assumed “standard” internal diameter for the host pipe. Upon installation a longitudinal fold in the liner was observed, showing that the liner had fully expanded for a tight fit within the host pipe. Absence of any fold might indicate that the liner is not correctly sized (too small), and may not have fully adhered to the host pipe. The fold should be minimal, not significantly impacting hydraulics. In the first three pilots, the fold was larger than anticipated, but EBMUD was assured by the manufacturer that this was acceptable. For Pilot 4, the manufacturer sized the liner based on two internal diameter measurements that were provided by EBMUD. Upon installation of the liner it was immediately apparent that this method provided a better fit and smaller fold than the previous pilots. The designed thicknesses were 4.8 mm for 12-inch, and 3.7 mm for 8-inch.

Temporary Main

For any CIPP project, if the host pipe directly serves customers or hydrants, a temporary main is required during construction. For Pilots 3 and 4, a hydraulic analysis of customer demands (diurnal and seasonal patterns), fire flow and available water sources confirmed the temporary main system was sized to meet demands and maintain water quality. The temporary main system comprised of 4-inch restrained PVC and 2.5-inch rubber hose with ½-inch hoses for the service lines. Where the temporary main system crossed sidewalks, driveways, and intersections, ramps or trenches were required to protect the pipes and maintain safe access. Traffic-rated pre-formed ramps were used on flat driveways, while steep driveways required a custom built berm. The temporary mains were easy to install and functioned well throughout the pilots, though in the future ¾-inch or 1-inch service hoses should be used to improve flow to customers with larger irrigation demands. Figure 3 shows examples of the temporary main and ramp materials.

Figure 3. Temporary main materials and setup

EBMUD purchased all the temporary main materials needed for this pilot (rather than renting) so they are available for use in future trenchless applications, and for emergency preparedness. EBMUD pipeline and maintenance crews have been trained on how to install the system, so experienced staff is now able to deploy the system swiftly in a future emergency, and has practiced this in emergency operations exercises.

Contract Specifications

EBMUD developed new contract specifications for the CIPP pilot projects. The specifications detailed which elements of the work were to be completed by the contractor, versus by EBMUD; contractor qualifications; submittals; safety, environmental, and quality assurance testing requirements; design parameters; installation and inspection requirements; acceptance criteria; and training for EBMUD maintenance crews.

The contract was structured such that EBMUD and Sanexen collaborated throughout construction. EBMUD crews performed much of the work that is typical of pipeline construction (excavation, any work related to live water mains or services, disinfection, reconnections, and site restoration), while Sanexen, the manufacturer of the liner, completed the specialized cleaning, lining, and inspection work, with assistance from EBMUD crews for traffic and safety controls.

The first three projects in the pilot were constructed in succession, from May to August of 2016. The fourth and final pilot was completed in the spring/summer months of 2017. This break between pilots allowed EBMUD and Sanexen to discuss lessons learned from the first three pilots in adapting and finalizing the scope and schedule for the fourth project. In addition to improving plans for the final pilot project, EBMUD crews also worked on a major open trench pipe replacement project on neighborhood streets adjacent to the alignment of the CIPP project. This ensured EBMUD crews were available as needed to support Sanexen, but were also productive rather than on standby when the manufacturer didn’t need assistance.

6. CONSTRUCTION

Crews from the manufacturer mobilized from Canada and Colorado with large trucks and equipment (Figure 4). EBMUD dedicated one crew to support CIPP construction, plus additional resources as needed to ensure the project stayed on schedule.

Figure 4. Liner truck (left), winch truck (center), camera truck and boiler trailer (right)

Access Pit Preparation

Access pits were excavated to expose the host pipe for CIPP lining operations. Ideally, the host pipe was out of service so that excavation could be completed without worry of damaging or disturbing the host pipe. Access pits were approximately 6 feet wide by 12 feet long and excavated to a depth of one foot below the bottom of the host pipe. Rock was placed in the bottom of the pit to facilitate drainage and provide a stable work area. Protective shields were installed along the pit walls to provide a safe work environment. The host pipe was cut within 12 to 18 inches of ends of the pit to provide access to the inside of the host pipe.

Safety and Traffic Control

The day-to-day work area for CIPP is at least several hundred feet (the distance between access pits), and can be much greater than traditional open cut work spaces. As a result, careful coordination and planning was essential to develop functional traffic control plans, and additional flagging resources were required to cover the length of the work area and any intersections or driveways between active access pits.

For the first three pilots, permit restrictions were typical with lane closures limited to 7:00 am to 4:30 pm. On the fourth pilot, the encroachment permit from the City limited lane closures to 9:00 am-2:30 pm. Aside from being inefficient, these work hours were not feasible with CIPP lining operations, as the inspection, lining, and curing process for each liner section must happen in one day, uninterrupted. The process requires CIPP equipment (liner, boiler, winch, and camera trucks) to be parked adjacent to the access pit, and the process typically lasts longer than 6 hours. EBMUD presented the City with traffic control plans and a site-specific traffic study prepared by a consultant and requested a work hour extension. Without updating the permit, the City granted a temporary extension to 4:30 pm, to last as long as there were no complaints from residents. During the project, EBMUD and the manufacturer were able to keep traffic flowing through the work area, so the extended workhours remained in place for the duration of construction.

Cleaning

In CIPP for cast iron mains, the cleaning is aggressive to remove tuberculation and provide a reasonably clean surface for CIPP bonding. The same methods are too aggressive for AC pipe, and new cleaning methods had to be developed.

For Pilot 1, the host pipe was cleaned with high pressure water that scoured the inside surface of the pipe. The pressure of 5,000-6,000 psi was too high, and the slurry of cleaning water that was discharged contained a high concentration of asbestos fibers that had to be assessed by EBMUD's Environmental Health and Safety staff, contained, and appropriately disposed. In Pilot 2 all construction staff were trained on working around asbestos, pipe cleaning efforts were reduced to lower pressure washing (1,500-2,200 psi) and swabbing with a foam pig, filters were added to the sewer drains to collect and separate discharge solids. Due to discharge permit restrictions with the sanitary and storm sewer district that served Pilots 3 and 4, all discharge water was either hauled offsite, or collected and pre-treated, respectively (see Water Management section).

Inspections
The cleaned host pipe was inspected by CCTV after it was cleaned, and the inspection videos were submitted to EBMUD for review. The pipe was inspected a second time after all the services were patched, and a third time after the pipe was lined and services were reinstated. The inspection videos included a running footage measurement, and callouts for each service tap (address) and fittings along the host pipe (see Figures 5 and 7).

Service Patching
In all four pilot projects, the host pipe was thick-walled rough barrel AC, so the services did not protrude beyond the pipe wall. This required service patches, rather than the standard plugs. The robot could install multiple plugs on one trip into the pipe, but only one patch per trip, so the patching process was slower than expected. EBMUD didn't have records on the thickness of the pipe or whether the services protruded into the pipe, so this could only have been known once the pipe was taken out of service and inspected.

EBMUD researched service tap records and any services that were undersized, in poor condition, or a material that is no longer approved by EBMUD (i.e. polybutylene) were considered substandard and replaced by EBMUD, ideally prior to lining. Once the host pipe was inspected and all live services were positively identified, customer taps, 2-inches and under, were plugged or patched over. Any services found to be offset upon inspection (not lined up with the tap, Figure 5) were also considered substandard and replaced by EBMUD, usually after lining operations.

The patches or plugs were adhered to the inside of the host pipe by a technician using a camera and robot inside the pipe (Figure 5). The status and location (i.e., footage measurements on inspection videos) of all services were documented by both the manufacturer and EBMUD to ensure all services that needed to be reinstated, were in fact reinstated, and that older abandoned services were not.

Figure 5. Offset service (left), patched service (right)

Installation and Pressure Testing
The Aqua-Pipe liner was injected with resin, pulled into the host pipe, cured with hot water, and then pressure tested. The resin injection process happened within a refrigerated truck, with a carefully monitored process to maintain even and adequate resin distribution. The Aqua-Pipe liner was pulled from the lining truck into the host pipe, and to the next access pit by a winch truck. The winch truck had multiple breakdowns during Pilots 1 through 3 which caused delays. The boiler also had occasional malfunctions, which caused delays and slowed curing. Both of these delays caused late nights for EBMUD construction inspection staff. By Pilot 4, newer equipment was delivered to the jobsite, and these issues were resolved.

Over the course of the four pilots, 12,823 of the 12,940 feet of Aqua-Pipe installed was accepted; there were three rejected sections totaling 117 feet (Figure 6). The 12-foot rejection on Pilot 2 was a "donut" that formed due to the inside and outside sleeves of the liner being different lengths, a manufacturing flaw. The 100-foot rejection on Pilot 3 was caused by water management problems (see the Water Management section). The 5-foot rejection on Pilot 4 was due to the resin beginning to harden before the foam pig reached the exit pit, resulting in a solid blob of resin adjacent to an access pit. Each of these issues were removed and repaired by EBMUD crews, and reimbursed by the manufacturer.

Once the Aqua-Pipe was cured, each section (pit-to-pit) was pressure tested at 150 pounds per square inch. All pressure tests reported zero pressure loss over the two hour test.

Figure 6. Accepted CIPP, rejected CIPP on Pilot 2, Pilot 3, and Pilot 4 (left to right)

Service Reinstating

After pressure testing, services were reinstated by a technician using a robotic drill and a camera (Figure 7). For Pilots 3 and 4, 83 percent and 96 percent of services were reinstated robotically, respectively. Examples requiring excavation included services that were:

- Located behind the fold;
- Misdrilled; and
- Unable to be located.

Figure 7. Service reinstatement robot (left), accepted drill (center), misdrill (right)

Connections

Connections were constructed of PVC or steel, and attached to the Aqua-Pipe-lined AC pipe with flexible couplings (Figure 8). The thick-walled AC pipe had a very large outside diameter compared to steel or PVC of the same nominal diameter. Standard couplings did not have a wide enough range to fit all of the connections, so some reducing couplings were used, which were not in EBMUD's standard warehouse supply.

Figure 8. New valve and reconnect in access pit

Overall, it is best to minimize the number of access pits, so long as it doesn't impact the ability to install the CIPP. What were once aging AC mains with joints every thirteen feet, became jointless CIPP mains with connections every few hundred feet, considerably reducing potential weak points. The pits identified in the design phase were unchanged in construction for Pilots 1 through 3, but Pilot 4 required five additional pits (and connections) to accommodate unknown offsets that were discovered during the initial inspection. At 30 pits within a mile of pipe, Pilot 4 didn't exactly feel "trenchless," though the paving restoration and excavated and backfilled soil were still considerably less than open trench.

Disinfection and Water Quality

Once the connections were complete, the pipe was disinfected and tested per standard EBMUD practices. Upon passing disinfection the newly lined mains were placed into service so that customers could be reconnected to the main and removed from the temporary system as soon as possible.

To confirm water quality remains in compliance with water quality standards, EBMUD will collect water quality samples from locations where water has maximum contact time with the CIPP liner, as well as control samples from unlined sections of main near each of the pilots, and analyze these samples for VOCs. An ongoing sampling protocol (i.e., annual for five years) will inform EBMUD of unanticipated liner degradation or chemical breakdown leading to contaminants leaching to the water.

EBMUD installed an access point at the north extent of Pilot 1 to simplify future physical inspection of the CIPP lined pipe. EBMUD will isolate Pilot 1 in five years (2021) to physically inspect the condition of the liner and bonding adhesion.

Water Management

The CIPP process required a comprehensive water management plan. Between draining, cleaning (which contained asbestos fibers due to the AC pipe), curing, pressure testing, flushing and disinfection, approximately six pipe volumes were discharged either to the storm or sanitary sewer.

For Pilots 1 and 2, potable water (draining, pressure testing, flushing water) was dechlorinated and discharged to the storm drain. Any discharge water that contained solids (cleaning water) was filtered before being released. The remaining water (superchlorinated or used during the curing process) was dechlorinated and discharged to the sanitary sewer.

The storm and sanitary sewer district that served the area of Pilots 3 and 4 prohibited EBMUD from discharging any "process" water to the storm or sanitary sewer, this included cleaning, curing, and pressure testing water. In Pilot 3 all "process" water was hauled offsite to EBMUD's Main Wastewater Treatment Plant twenty miles away in Oakland, which added truck trips, complicated scheduling, and caused delays. The manufacturer attributed the 100-foot failure (delamination) to non-standard operations due to discharge water collection requirements. On the section that failed, the manufacturer had pumped curing water directly from the pipe to the water truck (the discharge permit prohibited curing water being released into the pit and then pumped), creating suction inside the pipe which pulled the inner layer of the liner away from pipe wall. For Pilot 4, all the water was collected in tanks, pre-treated on site, tested periodically by EBMUD and the sewer district, and then discharged to the sanitary sewer; this made the day-to-day work less complex, but was considerably more expensive ($15k for trucking offsite, versus $250k for onsite treatment).

Hazard Resiliency

EBMUD's entire service area is seismically active, split by the Hayward Fault and the Calaveras Fault, and fifteen miles east of the San Andreas Fault. The CIPP pilot projects range from 1,500 feet to five miles in distance from either the Hayward or Calaveras.

Laboratory research of various pipeline materials suggest the hazard resiliency of a pipeline can be improved and/or achieved by using a rugged, ductile material with restrained/welded/fused joints that allow for at least 1% strain (Ballantyne, 2014). Ring fracture tests conducted by Louisiana Tech University found that 70-year old brittle cast iron mains lined with Aqua-Pipe sustained internal pressure at locations of extreme angular deflection, well after the host pipe cracked (Louisiana Tech, 2012). CIPP liners also performed well in shake table seismic tests (EPA, 2014), improving the ductility of old brittle pipes and also effectively restraining and welding the joints. Seismic testing of CIPP has so far only been conducted on new ductile iron pipe, further testing of old ductile iron, asbestos cement, or a reasonable proxy for asbestos cement pipe would be informative. The extent of the improved strength and ductility of CIPP lined systems will be further reviewed by Cornell's Geotechnical Lifelines Large Scale Testing Facility in the next 1-2 years, providing further guidance on the hazard resiliency of CIPP-lined pipe.

7. MAINTENANCE

After construction, the CIPP lined pipe is part of the overall pipeline inventory, and will eventually require maintenance crews to tap, connect, or make repairs. Maintenance crews assisted at various points of construction in each of the pilots, giving them exposure to both CIPP and the temporary main system.

Repairs and Tapping

Repairing the CIPP-lined pipe will be consistent with traditional pipe repair methods, using repair clamps, flexible couplings, and service clamps. While the CIPP is fully structural, it is not meant to be clamped directly. The host pipe, which acts as a mating surface for repair clamps, needs to retain some structural integrity throughout the lifespan of the CIPP in order to perform long term maintenance.

For any future taps, wet tapping is limited to a maximum of 2-inch diameter and can be performed with standard equipment; however the typical bit used for AC taps isn't recommended. A shell cutter, with carbide teeth, is the appropriate bit for tapping into CIPP-lined AC pipe. EBMUD performed 4-inch and 6-inch wet taps on CIPP-lined AC pipe with the manufacturer's supervision. While these taps were successful, wet taps greater than 2-inch are not recommended (or warranted), large taps require a tee to be cut into the line, thus necessitating a complete shutdown to customers. Cutting into the CIPP and host pipe can be performed easily with use of a guillotine saw.

During the pilot project, a rejected section of CIPP from Pilot 2 was used as a training opportunity, simulating a failure in order to evaluate the feasibility of repairs to CIPP- lined AC pipe. Representatives from the manufacturer provided two days of training to EBMUD maintenance crews where they performed tapping, main repairs, and the use of leak detection equipment. The exercise was recorded and a training video was developed for future reference and training for EBMUD crews.

8. METRICS AND PERFORMANCE INDICATORS

EBMUD strives to reduce costs and increase productivity. Improving processes requires first controlling processes, and to do that we have to understand and measure, and create benchmarks. In evaluating the CIPP pilots, staff evaluated the pilot project metrics, including costs, productivity, and duration relative to community impacts. Data is gathered from various sources, including the District's Financial Information System, final design and as-built drawings, the Electronic Timesheet System, and the Materials Management Information System.

Costs

All costs are presented as direct costs, i.e. not including department or District overhead. Entire costs paid to Sanexen are included and allocated to each Pilot. In analyzing costs for pipeline project and conducting comparisons between projects, staff divides costs into four main categories, as shown in Table 3 below: Construction; Construction Support; Project Support and Documentation; and Paving. The vast majority of projects included in calculating the FY17 Cost per Foot are traditional open-trench renewals. The pilot projects were selected because they presented unique challenges to open-trench replacement, while the FY17 Cost per Foot is included for reference; a comparison versus the estimated cost of open-trench for the pilots is presented later in this section.

Table 3. Cost Model

Project Phase	FY17 Cost per Foot	FY17 Percent of Costs	Cost per Foot for CIPP Pilots	Percent of Costs for CIPP Pilots
Construction	$350	76%	$502	87%
Construction Labor	$147	32%	$163	28%
Construction Materials, Contracts, and Equipment	$203	44%	$339	59%
Construction Support	$20	4%	$25	4%
Project Support and Documentation	$33	7%	$14	2%
Paving and Other	$59	13%	$33	6%
Total	**$462**	**100%**	**$574**	**100%**

Construction includes all the work of construction crews in the field as well as their office support and management. Construction Support includes the work of those work units that support field work, including construction inspection, system water quality, regulatory compliance, and geotechnical engineering. Project Support and Documentation includes all work units who contribute to the selection, planning and design of the project as well as records management and mapping.

As expected, by doing an in-situ replacement, rather than open-cut replacement, with only access pits to restore, paving costs were reduced. However, they were not reduced as much as anticipated, as re-paving the distributed access pits was not as efficient as paving continuous street surfaces.

The costs of each phase for each of the four CIPP pilots is shown in Table 4 below. Because much of the labor of renewing these AC pipes was born by Sanexen rather than EBMUD construction crews, costs shifted from Construction Labor to Construction Contracts as compared to typical pipeline renewal projects.

Table 4. Costs per Foot (Direct Costs)

Project Phase	Marina Park	Glenn	El Camino Corto	Upper Happy Valley
Construction	$483	$416	$382	$650
Construction Labor	$171	$140	$110	$222
Construction Materials, Contracts, and Equipment	$312	$276	$273	$428
Construction Support	$42	$29	$22	$25
Project Support and Documentation	$34	$10	$9	$18
Paving and Other	$11	$31	$25	$43
Total	**$571**	**$485**	**$438**	**$737**

The temporary main system discussed above was purchased outright for the El Camino Corto project, but was used for Upper Happy Valley as well and is now an EBMUD asset that can be used for other project or emergency operations. This system added approximately $50/foot to the El Camino Corto costs.

Costs for Upper Happy Valley are probably considerably higher than was actually spent. Because this job was constructed in conjunction with an 11,595 foot open-trench renewal on adjoining streets, construction crews were working on both jobs simultaneously, charges into the Electronic Timesheet System were potentially muddled, and all the costs of final connections between the two projects were charged to Upper Happy Valley. The apparent costs for the adjacent open-trench replacement were 85% of what might have been expected, which equates to $172/foot that may have been incorrectly charged to Upper Happy Valley. Additionally, the water management (collecting and treating discharge water), and traffic control were made a responsibility of Sanexen on Pilot 4, and added approximately $48/foot and $52/foot to the contract, respectively.

The cost savings for CIPP renewal as compared to open trench replacement can range from 15-30% (WRF, 2015). The costs of all four CIPP pilot projects were between 10% to 30% less than EBMUD's estimate for constructing these pilots by open trench (Figure 9). Open trench construction on Pilot 1 would have required hiring an archeological consultant (estimated at $100,000), as well as park restoration and a year of maintenance (estimated at $30,000). Pilot 2 would have required jack-and-bore under the freeway estimated at the cost of nearly half a million dollars for a 300-foot section. Pilot 3 is most comparable to open trench, as the main driver for CIPP was a paving moratorium rather than a difficult construction issue, but it is assumed that at least two more main breaks would have required repair before the paving moratorium expired. And Pilot 4 would have required a temporary main even for open-trench replacement ($250,000), plus excavating and disposing of the existing AC pipe in order to put a new pipe in its place (estimated at $100,000).

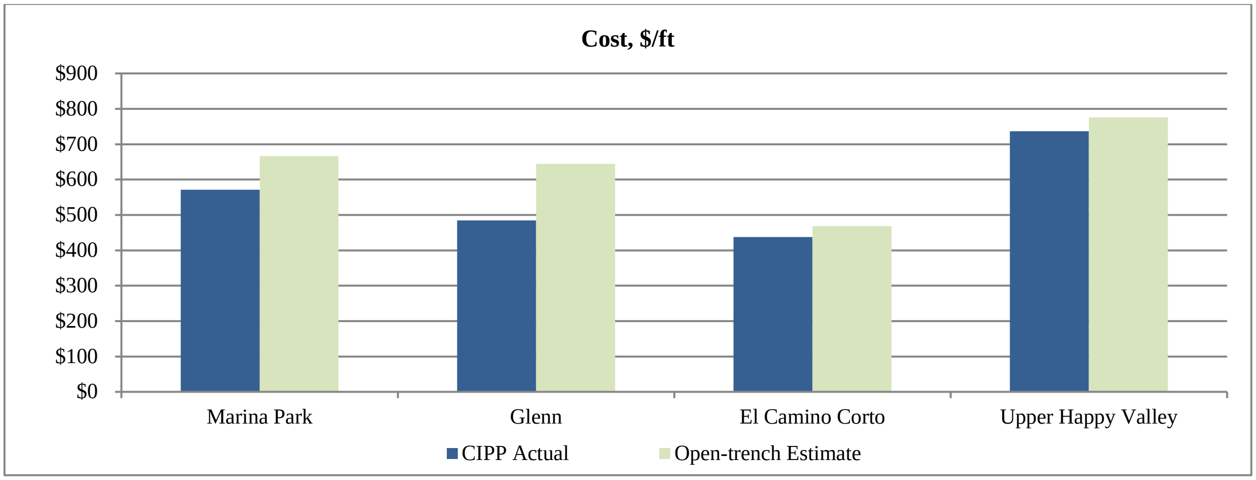

Figure 9. Cost of CIPP versus estimate of open-trench replacement

Community Impacts

EBMUD endeavors to create as minimal disturbance to our customers as possible when doing pipeline replacement work. Data is gathered on pipeline projects for four 'bookmarks'. The inner two (construction duration) bracket the time it takes to do mainline pipe construction, from breaking ground through pressure testing. Outside of this are two additional brackets (neighborhood presence) that bracket the time that EBMUD has a presence in the neighborhood, including posting signs, staging materials, and pre-construction work through completion of temporary paving and cleanup. Currently, final street restoration is outside of these dates.

Neighborhood Presence	Construction Duration		Neighborhood Presence
Post signs →	Break ground →	Pressure test →	Cleanup

While these performance indicators are a relatively new measurement for EBMUD and typical benchmarks have not been established, these values (Figure 10), especially on the last two pilots, are considered reasonable impacts to the community.

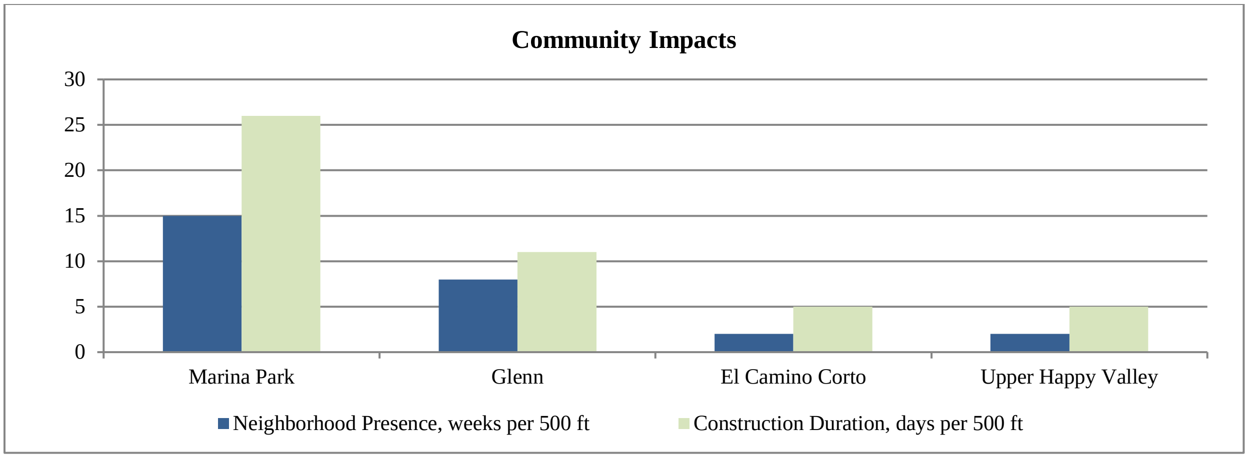

Figure 10. CIPP community impacts

The construction duration and neighborhood presence for Marina Park and Glenn were likely similar to open trench replacement, but EBMUD estimates neighborhood presence at El Camino Corto would have been 8 months, and Upper Happy Valley more than a year by open trench, compared to approximately 4 months and 5 months respectively by CIPP.

CIPP renewal of distribution mains can be faster than open trench replacement, but whether that translates to reduced community impact is debatable. Customers aren't necessarily aware that the work is completed faster than it could have been by another method, so their perception is still that there is a construction impact. In open trench replacement, the work is slower, but it's spread out evenly over the length of the project. With CIPP renewal, aboveground temporary pipes might line both sides of the street for the duration of the project, a daily reminder to residents that construction is ongoing even if construction isn't active in front of their home. With work areas limited to access pits, fewer residents have construction directly in front of their homes or businesses, so fewer residents experience the noise and dust associated with pipeline construction. However, the residents who live adjacent to the access pits experience the majority of the impacts, and for a longer duration. CIPP crews will work near each pit during the course of a CIPP project (excavating and shoring, draining, cleaning, inspecting, plugging services, lining, curing, pressure testing, reinstating, and finally reconnecting and backfilling), whereas an open trench crew will pass by any given home or business in a day.

Environmental Impacts
There are significant environmental benefits to using CIPP to renew aging water mains. Lining an aging water main will reduce or eliminate the leaks on that pipe, improving the efficiency of the water system and reducing waste of water – which is both an expensive commodity, and highly valuable in drought stricken areas. The reduced excavation footprint means less soil, asphalt, and concrete hauling, equating to a reduction in fossil fuels consumption, emissions released, and waste requiring landfill or recycling. A 2011 evaluation by Sanexen estimates that CIPP offers an 84 percent reduction in greenhouse gases compared to open-cut replacement methods, with the biggest reduction happening in material production.

Unlike all the moving parts of open trench construction, CIPP equipment is mostly stationary throughout the day. This, along with the reduced excavation footprint, leads to significantly less construction traffic in the neighborhood over the duration of the project (Figure 11).

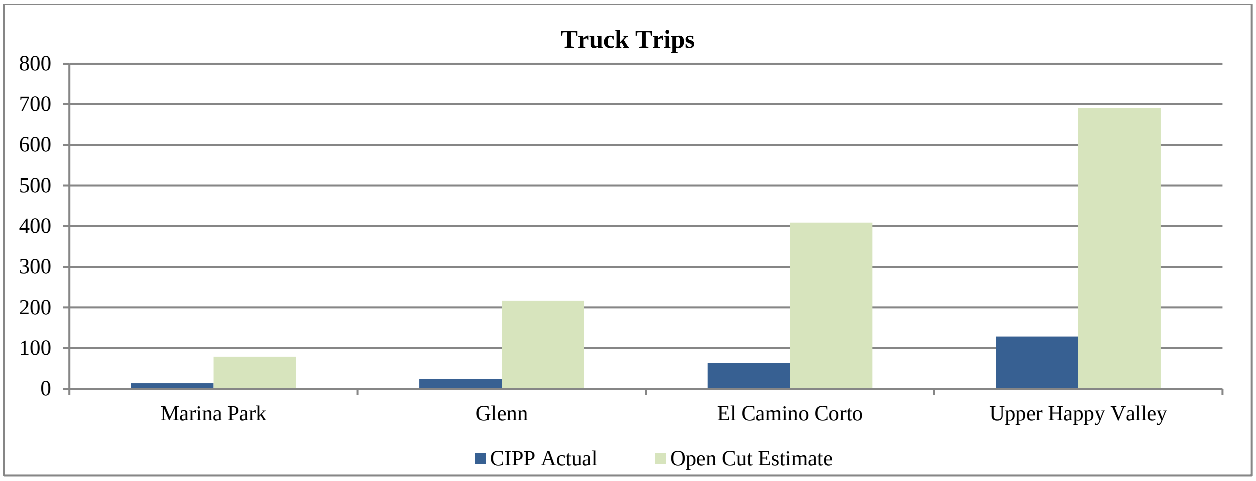

Figure 11. Truck trips compared to open trench

9. CONCLUSION

EBMUD's CIPP pilot was successful in a number of areas. Each of the four projects had challenges during construction, but issues were resolved and valuable lessons were learned. EBMUD engineers researched available trenchless methods and selected Sanexen's Aqua-Pipe as a CIPP product that met all required design, construction, and maintenance criteria. Rather than a typical relationship with a hired contractor, EBMUD and Sanexen worked as a team on finalizing designs and completing the CIPP work. This innovative working relationship enabled the team to develop solutions collaboratively throughout the course of each project. EBMUD crews took the lead on installing the aboveground temporary main, building ramps at each driveway, and excavating and shoring access pits. Sanexen provided expertise on how to set up the temporary main, what materials to use, and advice on looping and flushing the temporary system for improved water quality. EBMUD and Sanexen were trained together on working with AC pipe, and collaborated to develop solutions to unique water disposal challenges. Sanexen performed video inspections of the pipe (showing past breaks and likely future breaks), pressure washed the pipe (while refining the appropriate level of pressure), patched or plugged 151 services inside the pipe, lined the pipe (in 49 sections), completed pressure testing for each section of new liner, reinstated the services internally using a robotic drill, and completed final video inspections. The total number of 53 access pits equated to approximately 700 linear feet of roadway, rather than 12,678 feet by open trench, a 95% reduction in trenching, and also a 95% success rate with internally reinstating services. While the final project duration was 10 months rather than the anticipated 7 months, this was still a monumental improvement on the estimated 24 months needed for open trench construction of the pilot jobs.

EBMUD's pilot revealed that CIPP is a viable alternative to open-trench pipeline replacement with site-specific conditions. As with any pipe renewal process, there are advantages and challenges to CIPP. In potable water applications the technology is still relatively new, and as it continues to mature CIPP will likely become a more attractive pipeline renewal option. The breakdown below summarizes advantages for using CIPP and areas for improvement for both the manufacturer and EBMUD.

CIPP Advantages

- Can be used where open trench is not a feasible alternative: under freeways, through parks, under creeks
- Adds seismic resiliency to aging mains
- Approximately 85 percent reduction in truck trips and greenhouse gases compared to open trench
- Approximately 20 percent faster than open trench alternative, and anticipate this improving with more experience.

Areas for Improvement by Manufacturer

- Robotics and camera inspection – the existing tools are simple and prone to mistake or failure, manufacturers should invest in improving the technology (smaller equipment, improved imagery, improved location tracking), or partnering with technology firms who specialize in these fields.
- Experience with AC Pipe – additional testing should be conducted on CIPP-lined AC pipe to confirm long term structural properties and the improved hazard resiliency that CIPP adds to the AC main. Studies confirming the bonding adhesion to a cast iron host pipe has been conducted (Louisiana Tech, 2014); this should also be conducted for AC pipe.
- Consistent ability to install CIPP through consecutive 45-degree bends – offset returns are a common occurrence in potable water pipelines, and ability to line through them should be consistent.

Areas for Improvement by EBMUD

- Management of excess resin within pits – excess resin gathers in the access pits during the lining process, and had to be broken and removed prior to connections, backfill, and compaction. Excess resin should be captured and removed from the pit; this will be included in future contract specifications.
- CIPP standards and trainings specific to potable water – as the use of CIPP for potable water main rehabilitation grows, water utilities should collaborate to encourage manufacturers and installers to improve the relevant standards, training, testing methods, and inspection/installation methods.
- Water management – continue to work with local agencies to improve permit and discharge requirements related to potable water CIPP. In areas where construction water cannot be discharged to the sewer, factor in the added cost and effort of water management when determining if CIPP is a reasonable alternative.
- Optimize resources – construction of the pilot projects was a learning opportunity for EBMUD, with many staff given the opportunity to experience the CIPP process. For future projects, EBMUD will refine the staffing level necessary to support the manufacturer during construction.

In the coming years, EBMUD will continue to monitor the pilot installations. Based on the results of the pilot monitoring, and improvements in CIPP technologies, a broader implementation plan may be developed. The current recommendation for EBMUD is to use CIPP to renew pipelines in areas where open trench construction options are limited or cost prohibitive, and to allow CIPP to be bid competitively against open trench when appropriate for contractor installed projects.

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