Water Main Rehabilitation Alternatives

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The city of Fort Lauderdale's water distribution system includes piping dating back to the 1940s. Most older piping is cast iron with leadite or lead joints. Some pipelines are in poor condition and the entire line may need to be replaced. Others are in reasonably good condition, but valve function is questionable and the joints are weak and prone to separating or developing leaks if disturbed. Many of the major mains that will require rehabilitation are located in major thoroughfares or areas that are difficult to excavate for other reasons.

For some of these pipelines, the most effective approach to rehabilitation and repair will be excavation and replacement. For others, a trenchless rehabilitation or replacement approach may be a feasible alternative. Rehabilitation alternatives were evaluated and recommendations were made for the following four water main projects:

- *Pipeline 1*—Approximately 120 linear feet (lf) of 10-inch main along Las Olas Boulevard, including an aerial crossing supported beneath a heavily traveled traffic bridge over a tidal canal. The cast-iron pipeline has been repaired multiple times with clamps and is in poor condition overall. Alternatives evaluated were rehabilitation, replacement, and alternate routes.
- *Pipeline 2*—Approximately 3,700 lf of 16-inch main underlying a heavily traveled traffic route along North Andrews Avenue near the city center. The pipeline is cast iron in reasonably good condition, but the poured joints and service-connection goosenecks are in poor condition and have caused multiple leaks. Alternatives evaluated were rehabilitation, replacement, and upsizing the line to an 18-inch or 24-inch diameter main.
- *Pipeline 3*—Approximately 4,300 lf of 4-inch main underlying a moderately busy traffic route along South Andrews Avenue near the city center. This cast-iron line is in poor overall condition and has been repaired multiple times in the past; moreover, the line requires upsizing to 8 inches, and therefore only alternatives capable of installing increased capacity were considered.
- *Pipeline 4*—Approximately 5,900 lf of 12-inch and 3,200 lf of 16-inch main underlying a very busy roadway, Broward Boulevard, at the city center. The cast-iron pipeline is in reasonably good condition, but the poured joints and service-connection goosenecks are in poor condition and have caused multiple leaks. Alternatives evaluated were rehabilitation, replacing the line with the same size, and upgrading the 16-inch segment to 24 inches and upgrading the 12-inch segment to 18 inches.

Pipeline Condition Assessment

Condition assessment was based on interviews conducted with senior operations staff from the city concerning operations requirements and the repair history of the pipelines, and also on site visits to assess site-specific factors that could affect the selection of renewal/replacement technologies. Key considerations evaluated during the process are:

- Pipe material, internal corrosion and tuberculation, joint failure, and external corrosion.
- Operational factors, including hydraulic limitations or water quality.
- Condition of the pipeline foundation and depth of the pipeline and water table.
- Hydraulic and operating pressure requirements.
- Number and type of fittings, including branch and service line connections, valves, fire hydrants, and repair sleeves.
- Length of pipeline runs that can be rehabilitated without intermediate excavations.
- Length of time the main can be taken out of service, if allowable, and the level of disruption involved in providing temporary service if needed.
- Site-specific factors, including the nature of potential conflicts from other utilities.
- Surface and traffic conditions over the stretch of pipeline to be rehabilitated.

The city water atlas was used during field visits to verify locations of valves, hydrants, services, and branch connections. Because of limited available information concerning locations of other utilities, limited inquiries on this topic were made through Sunshine State One Call and directly with identified utility providers. The limited utility conflict investigation identified a variety of probable utility conflicts that would require definitive investigation in the design phase.

Increasing Use of Trenchless Methods for Water Main Repairs

The American Water Works Association (AWWA) published a report in May 2001 entitled *Dawn of the Replacement Era – Reinvesting in Drinking Water Infrastructure* (AWWA, 2001). This publication addressed the nation's water infrastructure condition and the need to begin the rehabilitation and replacement of many of the older piping systems in the ground.

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The study concluded that by the year 2030, the average utility in the study will have to spend nearly four times more on pipe replacement than it spends today, that needs would be driven more by the aging of buried infrastructure rather than by lack of maintenance or poor management, and that infrastructure replacement would be most critical in inner-city cores where piping systems are the oldest.

Older inner-city areas are also the most densely developed areas and the most sensitive areas in which to perform construction work. The subsurface may include numerous existing utilities; abandoned pipes, rail and trolley tracks; multiple layers of paving; old foundations; piers; and other obstacles not shown on any plans or maps. On the surface, work may be complicated by narrow alleys, multiple buildings, traffic, and public activity. For these and other reasons, utilities are increasingly turning to trenchless methods for this work.

Trenchless Technologies For Rehabilitation

Trenchless technologies for water main rehabilitation include installation of a manufactured liner pipe within the host main and *in-situ* spray application of a liner material.

Sliplining

Sliplining involves removing a portion of the existing main for access, then pulling a new pipe into the existing main. While several types of thermoplastic pipes have been used, HDPE is the most common. One drawback to sliplining is the loss of internal diameter and resulting loss of carrying capacity. While a reduced friction factor may help compensate, hydraulic requirements must be considered carefully before selecting sliplining, which is generally better suited for larger-diameter mains.

Another drawback is the inability to negotiate elbows. All valves, tees, and elbows must be exposed in advance and later reinstated on the new main, frequently requiring the installation of new valves if the older valves are not compatible. Also, service connections must be exposed to make the connection to the new liner pipe.

Deformed/Reformed Systems

A modified version of sliplining involves deformation of the liner pipe to make it easier to pull into the old main. The liner is then reformed within the main to assume its original round shape.

Fold-and-form systems can use either PVC pipe or HDPE pipe, with HDPE pipe being the most common for lining of water mains. The original pipe is extruded round at the factory and is then folded, usually into either a "C" or "U" shape, before being rolled on a reel for transport to the work site.

Once at the site, the end of the folded liner pipe is attached to a cable that has been floated through the section of host main to be lined. Typically, the host main will be exposed at convenient intervals, usually at valves, tees, or elbows. The folded liner pipe is then pulled through the old main; reformed by a variety of methods, including pulling a proving plug through the liner or by hot water or steam pressure; and then allowed to relax for a period of time to ease residual stresses within the pipe wall caused by the installation. The fittings and service connections are then reinstated.

Fold-and-form systems are available in sizes up to 15 inches in diameter, although most applications are for the smaller diameters, generally up to 8 inches.

The so-called ***tight-fit systems***, including rolldown and swage lining systems, were originally developed to rehabilitate gas mains. These systems use HDPE pipe that has been brought to the site and butt-fused into the lengths needed. The pipe is then pulled through a set of reducing dies or rollers that compress the HDPE pipe to a slightly smaller diameter. The reduced pipe is then pulled into the host water main and expanded to fit tightly within the host pipe.

Cured-In-Place Systems

The most commonly used cured-in-place (CIP) lining systems employ either a nonwoven felt bag or a woven polyester fiber hose, impregnated with either an epoxy or vinyl ester thermosetting resin, with an impermeable membrane on one side of the bag or tube.

The impregnated liner is inverted into the host main using cold water. Thorough cleaning of the host pipe before insertion of the liner is important. The inversion process results in the resin adhering to the walls of the host pipe and the impermeable membrane is on the inside of the new pipe. Once in place, the resin is cured, typically using hot water or steam.

The resin can be designed for full structural, semi-structural, or non-structural capabilities. Resins for potable-water applications must meet National Sanitation Foundation and local health authority approvals. The fabric material can be factory-tailored to suit the diameter of the host pipe. CIP liners can negotiate 90-degree bends within the host pipe.

The ***Woven Hose System*** is used in water mains where the structural integrity of the host pipe is compromised by breaks, external corrosion, faulty joints, pinholes, or internal corrosion. These liners can provide either full structural integrity or semi-structural integrity as needed, depending on the condition of the host pipe.

The ***Felt-Based Liner System*** is made of non-woven polyester felt, coated on one face with a layer of elastomer. The felt-based liner can include reinforced fibers to provide full or semi-structural integrity. The resin plays a large role in the structural integrity of the new liner.

The ***Membrane System*** is inserted into the host pipe with an elastomeric membrane impregnated with resin. This membrane is very thin and was initially designed for low-pressure gas main rehabilitation. A membrane system can bridge very small pinholes and joint gaps, but is mainly suitable for non-structural water main rehabilitation and offers internal corrosion protection.

Spray Applied Lining Systems

The most commonly used method for rehabilitating water mains has been ***spray-applied cement mortar lining***, although recently spray systems using an ***epoxy resin*** are presenting a competitive alternative. Both systems employ a rotating spray nozzle mounted on a skid or tractor and centered within the pipeline. The apparatus is pulled at a set rate through the pipe as the nozzle rotates, applying a coating of the liner material on the walls of the pipe.

As with the manufactured pipe liner systems, the host pipe must be exposed at intervals, typically at valves, tees, and elbows. A cable and the product supply hoses are passed through the exposed section of main and connected to the spray nozzle skid or tractor. A CCTV camera should be included in the equipment train so the operator can monitor progress and check for irregularities or malfunctions. Both types of liner must be kept dry while they set up.

When cement mortar is applied to the wall of an iron pipe, oxidation of the pipe wall ceases. Deterioration of the pipe wall ceases because, as the water passes through the porous cement mortar, it becomes alkaline and a chemical inhibitor against oxidation forms.

Lining a water main with cement mortar reduces internal deterioration of the main and eliminates or reduces the need to flush the main due to red water concerns. With larger mains that allow the necessary access, a semi-structural capability can be obtained by installing a wire mesh.

The application of the cement mortar requires a completely cleaned and dewatered pipe. All line valves must have their bonnets removed to clean the cement mortar from the valve interior.

Most cement mortar lining equipment can accommodate bends up to 45 degrees, depending on the main diameter. After mortar application, service lines of 2 inches or less must be cleared by blowing compressed air or letting water run back through the service line. Service lines greater than 2 inches in diameter generally do not get plugged if proper techniques are used. To cure the mortar, the ends of the pipe section are capped and left to cure for 12 to 24 hours.

Lining a water main with epoxy resin is typically a non-structural rehabilitation method, although new, semi-structural methods are under development. The initial process of preparing the water main is similar to the cement mortar lining technique in that a completely clean pipe is required, free of any debris or water. Epoxy is a dielectric insulator that stops the flow of negative ions off the iron surface and into the water; therefore, corrosion can still occur if the epoxy does not provide electrical insulation because of voids or pinholes in the coating.

The epoxy lining process involves the application of a very thin layer (1 mm) of resin and hardener to the pipe wall. Computerized machinery with heating devices is employed to achieve the appropriate mixture and temperature of resin and hardener that is critical for durability and cohesiveness.

After lining, the ends of the water main are capped and the resin is allowed to cure. Water service connections to the newly relined water main do not have to be back-flushed with water or blown with air, as with cement mortar lining. After the curing process is completed (normally 16 hours), the pipe should be inspected visually or by closed-circuit television, after which the water main is flushed and disinfected before being put back into service.

Internal Joint Seals

An internal joint seal makes the inside surfaces of leaking pipe joints watertight. The pipe joints must be cleared of debris and dust and the area on either side of the joint prepared, after which the seal is positioned to span the gap and kept in place by stainless steel retaining bands. The seal's flexibility allows a bottle-tight seal around the entire pipe joint, while its low profile and graded edge permit water to flow without creating turbulence.

Internal joint seals are made of ethylene propylene diene monomer (EPDM) synthetic rubber. At the time of this study, the technique had generally been applied only to larger pipes that allowed worker access, but recent robotic methods are extending this

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technology to smaller diameters.

Technologies for Replacement

Alternative methods for the replacement of water mains include open cut, pipe bursting, horizontal directional drilling, and microtunneling. All but the first are considered trenchless.

Open Cut

The most common method is the conventional open-cut excavation method for constructing a new main in a new trench, usually parallel to the old main. Less frequently, the old main can be dug up and removed and a new pipe installed in the same trench. Most municipalities have long experience and good design and construction specifications for these types of projects.

Pipe Bursting

The process of pipe bursting employs a specially designed bursting head, larger than the old pipe, which cracks or bursts the old pipe as it is pulled through and pushes the pieces of the old pipe outward into the surrounding soil. The new pipe is attached to the rear of the bursting head and is pulled into the space left by the broken old main.

It is possible to upsize substantially greater than the diameter of the existing pipe, but this depends on soil conditions, the proximity of other existing structures, and the depth of cover. The pulling force of the bursting unit must be maintained at a value less than the tensile strength of the replacement pipe to avoid overstressing the new pipe. The replacement pipe must be installed in one continuous length; therefore, butt-fused PE pipe is used in most cases. Bursting tools include the static burster, pneumatic burster, and hydraulic burster.

- The ***static burster*** consists of a cone-shaped or bullet-shaped solid tool which bursts the old pipe through the power imparted by the pulling winch and the sloping face of the tool. An advanced form, commonly used for steel and ductile iron pipe, includes cutting disks and a cutting edge to score the inside of the pipe and make it easier to split.
- ***Pneumatic bursting*** tools consist of a bursting head followed by a hollow section that contains an air-driven hammer. The hammer impacts on the bursting head, driving it forward and imparting bursting pressure on the old pipe. As with the static tool, the pneumatic tool is pulled through the pipe with a winch and cable to provide additional bursting pressure and help keep the tool on track within the existing pipe.
- ***Hydraulic bursters*** have a bursting head fitted with leaves that expand outward using hydraulic pressure, bursting the pipe and pushing the pieces into the surrounding soil.

All bursting systems require openings in the existing pipe long enough to accommodate the bursting tool and to provide space for new pipe to be fed into the main. All valves, fittings, and service connections must be removed in advance to avoid damage. Any repair clamps on the existing pipe should also be identified and may require advance removal.

An important consideration, especially with the pneumatic tool, is the impact on other structures or utilities. The bursting tool will create a pressure zone, the size of which will depend on the type of soil, the size of the host pipe, and the degree of upsizing for the new pipe. There may also be vibration impacts.

For most operations, the potential for damage to utilities will become significant only at very close ranges. In the case of a utility crossing, the damage can be prevented by exposing the crossing and removing the soil between the utilities. For close parallel utilities, open cutting may be needed if the existing main is to be upsized.

Horizontal Directional Drilling

Horizontal directional drilling (HDD) consists of several installation stages. First, a pilot bore is made with a suitable-sized drilling rig. The bore is steered to create an initial hole at the required line and grade. Successive reamers are then pulled back to enlarge the bore diameter to the desired size. During the last stage of reaming, the service pipe is pulled back into the bore.

This method is frequently employed when an open-cut excavation is unsuitable, such as at a railway crossing. Most water mains installed by this method are continuously welded PE pipe, although steel, ductile iron, and PVC have also been used. Since HDPE pipe is subject to contraction and expansion, restraint mechanisms should be considered in the design stage.

Micro-Tunneling

While micro-tunneling is normally used for very deep, usually new installations, applications have included rerouting existing water mains. Micro-tunneling uses a remotely controlled boring machine combined with the pipe jacking technique to install pipelines. Experts should be engaged for any application of this technology. Like horizontal drilling and pipe bursting techniques, there is limited quality control of pipe bedding and side fill support.

While microtunneling is technically feasible for replacement, it was not considered for the pipelines discussed in this article because of the specialized nature of microtunneling applications.

Design Considerations

The decision on which rehabilitation measure to use depends primarily on hydraulic adequacy, structural conditions, and surface conditions.

- Hydraulic adequacy refers to the capacity of the existing pipe to accommodate present or future flow requirements. A pipe that is undersized must be upsized or paralleled, indicating the use of either open-cut methods, pipe bursting, or HDD.
- Structural condition assessment will ideally include field data from test coupons, flow tests, or other field inspections which can identify problem pipe segments prior to failure. Other indicators may be a history of main breaks or customer complaints of low flow volumes, low pressures, colored water outbreaks, or taste and odor problems. A cast-iron main that is structurally sound and hydraulically adequate but has contributed to colored water complaints can be lined using a non-structural liner, but if the main is in poor physical condition, a structural liner or replacement method is warranted.
- Surface conditions may influence a decision to use a trenchless method. Where the main is easily accessible and away from the public, such as in an easement or on the shoulder of a road, conventional open cut will generally be preferred. In congested urban areas or sensitive environmental areas such as wetlands, trenchless methods may be preferred.

Table 1 provides general guidance concerning the suitability of the alternative technologies to address a typical range of water main problems.

It is important to note that these "trenchless" technologies are not "no-dig" technologies. Each method requires excavating pits for access to the main. Sliplining and pipe bursting generally require larger pits to provide enough space for inserting the new liner pipe. These pits may be on the order of 4 feet wide by 15 to 20 feet long, depending on the methods and materials used. Spray-applied lining systems and cured-in-place lining systems will require smaller pits for equipment access and retrieval, generally on the order of 4 feet wide by 6 to 10 feet long.

All methods will require pits for access to valves, elbows, tees, and service connections. Generally, these pits need be no larger than necessary to gain access to the fitting and can usually be limited to about 4 feet square (pit dimensions assume mains have been installed at the minimum required depths). Cost estimates, therefore, must include the number, size and location of access pits as well as surface restoration.

Other critical items to consider in technology selection include the size of the contract, local availability of the technology, possible impacts of the water main material to be used (potential expansion/contraction

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issues), and the density of water services on the water main.

With larger contracts, more options will be available for various technologies, since mobilization costs may be high for specialized equipment and personnel. Moreover, some regions may have little local presence of some of the newer technologies. This factor is linked to the contract size, since a larger contract may attract companies from other regions.

The quantity and density of water services, valves, and branch piping connected to the water main may play a large role in selecting alternative technologies, since these fittings will require excavation for preparation and reinstatement. If such fittings are numerous, then open-cut replacement is likely the most economical solution.

Another important consideration is whether the utility will provide temporary bypass piping to maintain water service during performance of the work. This can be time-consuming and expensive, and it can be a significant differentiator among alternative approaches.

Cost-related guidelines reflect only the actual construction work and do not include other community concerns. Using a different technology at a higher construction cost than the open-cut method may be in the best interests of the community when issues such as traffic, impacts on commercial and industrial customers, and environmental and safety concerns are considered.

Table 1: Suitability of the Technologies

Water Main Problem	Potentially Suitable Technologies
Tuberculation in structurally sound pipe, causing poor water quality and flow restriction	Spray lining, CIP lining, deformed/reformed lining
Joint failure and/or localized corrosion causing leakage	CIP lining, joint seals
Extensive corrosion or graphitization, with loss of structural strength causing breaks and leaks	CIP lining, deformed/reformed lining, sliplining, pipe bursting, HDD, open cut
Pipe diameter too small, causing flow restriction	Pipe bursting, HDD, open cut

Alternative Evaluation & Recommendations

Based on specific pipeline conditions, advantages and disadvantages of the various technologies, and design considerations, alternatives were evaluated and recommended for rehabilitation or replacement of each pipeline. Cost estimates were developed to compare feasible alternatives.

Pipeline 1 – 120 lf of 10-inch main including an aerial canal crossing

Required evaluation scenarios for this project include rehabilitation, replacement, and replacement using an alternate route. Upsizing was not identified as a necessary consideration.

Given the poor overall condition, technically feasible alternatives for rehabilitation were limited to installation of a structural liner. Neither spray lining nor joint seals would provide the required structural strength, and the pipe diameter is too small to allow access for joint seal installation.

Because of the apparent presence of 45-degree bends in the line and considerations related to the reduction of hydraulic capacity, sliplining did not appear viable. Pipe bursting would be considered only for the replacement of buried pipe and therefore would not apply to this project because the majority of the pipe is an aerial crossing.

For pipe replacement using the same or an alternate route, issues related to the bridge foundation, concrete encasement of portions of the pipe, and limited right-of-way access on the approach to the bridge could present challenges, depending on the extent of pipe replaced. The aerial crossing portion by itself could be replaced as a viable option without undue difficulty.

Based on the absence of services or branch connections on the section of pipe to be addressed, HDD could be used to install an underground canal crossing, although the cost of this alternative could not be accurately estimated without as-built drawings showing the depth and location of the bridge foundation and associated pilings.

The recommended alternative for this project was to install approximately 120 linear feet (lf) of structural liner. The Thermopipe® lining system from Insituform, or an approved equal, would be suitable for this purpose.

Thermopipe® is a polyester-reinforced polyethylene lining system designed for use in water mains and other pressurized systems. The product is approved pursuant to ANSI/NSF (American National Standards Institute/National Sanitation Foundation) Standard 61, a standard developed to assure that products are safe for use in public drinking-water systems. It has a long-term, independent internal pressure rating of up to 230 psi and can navigate most bends (Thermopipe® is available in sizes only up to 8 inches, but reportedly will be available in 10-inch size within approximately one year.

Access pits would need to be excavated on either side of the bridge. The exterior of the aerial crossing pipe would also be cleaned and painted as part of this work. To minimize disruption, work would be planned for the summer months when traffic and local population reach annual lows.

Pipeline 2 – 3,700 lf of 16-inch main underlying a heavily traveled traffic route

Required evaluation scenarios for this project include rehabilitation, replacement, and upsizing the line to an 18- or 24-inch diameter main.

Given the poor joint condition, technically feasible alternatives for rehabilitation are limited to installation of a semi-structural or structural liner, sliplining, or external joint repair clamps. Spray lining and joint seals could not be considered for the same reasons applicable to Pipeline 1. Concerns about hydraulic capacity reduction also rule out sliplining.

Pipe bursting could be viable for replacement or upsizing, but the reported presence of repair clamps at unknown locations could present serious impediments to progress of the bursting head. Moreover, based on the relatively shallow line depth and likelihood of well-compacted soil, the roadway could be susceptible to heaving from the bursting process, especially if accompanied by an upsizing of the pipe. Measures would also be needed to guard against damage to adjacent utilities from the bursting process.

HDD may be technically feasible for installing a new main of the same size or larger, but the ability to stay on grade and manage drilling fluid at such a shallow depth presents concerns. With this technology, the possibility of hitting another utility is always a major concern and adds significantly to the cost in proportion to the contractor's perceived level of risk. HDD was considered to have greater applicability for a portion of this project, as noted later in this article.

The recommended alternative for this project was to install a 24-inch line using open-cut methods. Portions of the work would be conducted at night to minimize traffic disruptions. HDD could be considered

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for that portion of the line crossing the largest intersection, but since this crossing would be made at substantial depth to avoid other utilities, a hydraulic evaluation would be needed concerning the importance of re-establishing the branch connections and associated valves within the intersection.

Several factors place the open-cut method at an advantage for this project. The line is reportedly shallow, and installing an upsized line using this method adds relatively little in cost and essentially no additional risk. Regulators are familiar with this approach, making the permitting process potentially easier than might be the case with a less-familiar trenchless technology. The strong availability of local contractors for this method, moreover, should help the city obtain competitive pricing for such a project.

Another major advantage of this method over most trenchless methods would be the opportunity to complete the work without the time-consuming, expensive task of providing temporary water service to affected customers. The new line could be built in parallel, and only brief losses of service would be experienced–perhaps a one-night shift for cutting in each section of line and, on a subsequent occasion, a few hours of service when services are switched over to the new line. Any option that entailed internal work on the existing line (bursting or lining, for example) would result in a much longer loss of service than could be reasonably tolerated by the city's customers without temporary water supply.

Another factor that encourages open cut on this line is the high total number of branch connections, services, hydrants, and valves, each of which would require excavation for reinstatement. The primary advantage of trenchless methods is, of course, the avoidance of digging, and on a long stretch of line with few or no fittings, this advantage can translate into both monetary savings and greatly reduced disruption. On the subject line, however, so much digging would be required for reinstatement–often within intersections at the point of greatest impact to traffic–that the potential advantage of a trenchless approach could not be realized.

It was recommended that this work be done, if possible, in coordination with the county's repaving schedule and reported plans to redevelop properties along this pipeline. The possibility of a joint partnership agreement with the county would also be explored.

<u>Pipeline 3 – 4,300 lf of 4-inch main underlying a moderately busy traffic route</u>

Given the fact that this line requires upsizing, rehabilitation approaches did not apply. Pipe bursting and HDD were considered but not recommended for the same reasons given for Pipeline 2.

The recommended alternative for this project was to install an 8-inch line using open-cut methods. The factors placing open cut at an advantage for this project were the same as those described for Pipeline 2. Also, for Pipeline 3 the road is wide and traffic volume is moderate, so the prospect of lane closures is more acceptable. Excavation of some intersections during off-hours with appropriate traffic detours was recommended.

As with Pipeline 2, it was recommended that attempts be made to coordinate this work with the county's repaving schedule and reported plans to redevelop properties along this pipeline. The possibility of a joint partnership agreement with the county would also be explored.

<u>Pipeline 4 – 9,100 lf of main (12-inch and 16-inch) underlying a very busy roadway</u>

Required evaluation scenarios for this project include rehabilitation, replacement, and upsizing of the 16-inch segment to 24 inches and the 12-inch segment to 18 inches. Technically feasible alternatives for rehabilitation and replacement were the same as those outlined for Pipeline 2 and were decided against for the same reasons.

The long-term recommendation for this project was to install an upsized line using open-cut methods. The factors placing open cut at an advantage for this project were the same as those described for Pipeline 2, with the added emphasis that blocks are relatively short and branch connections exist at nearly every intersection, a circumstance that would require extensive excavation in intersections even if trenchless methods were used. HDD or jack and bore methods would be needed, however, for a portion of the line underneath railroad tracks. Portions of the work would be conducted at night to minimize traffic disruptions.

The short-term recommendation was to take no action. The road surface is relatively new, and traffic is extremely heavy. The Florida Department of Transportation has stated that a five-year moratorium exists on non-emergency work that would require cutting into the road surface. Any emergency repairs would be addressed as required, but otherwise, work would be postponed until it could be performed in conjunction with another significant infrastructure effort affecting that stretch of road.

It was seen as possible, given the generally good condition of the main as evidenced by a pipe coupon obtained from a tap of the pipeline, that the pipe itself could last a good deal longer, and that the joints, although susceptible to separating and developing leaks if disturbed, would cease to develop many problems since nearby construction work has been completed and the sources of disturbance have been greatly reduced.

The pipe coupon was collected in December 2003 and exhibited an average thickness of 13.91 mm, or about 0.55 inches. While the original thickness and pressure class of the pipe was not known, a Class B (86 pounds pressure) cast-iron pipe today would be manufactured with a wall thickness of 0.70 inches.

Conclusions

For three of the four pipelines that were evaluated, despite the technical feasibility of several trenchless methods, open-cut methods were recommended for two primary reasons. First, trenchless methods still require that numerous fittings for branch connections, services, hydrants, and valves on the lines be excavated for preparation and reinstatement, often in major intersections where the greatest traffic impacts would occur. Second, the open-cut method would allow the new line to be built in parallel and brought into service quickly, with only minor service interruptions to customers. This would avoid the costly and time-consuming necessity of providing temporary water supply, an advantage not offered by trenchless alternatives.

For the fourth pipeline, trenchless installation of a structural liner was recommended. In this case the major difference was that the stretch of pipeline requiring rehabilitation had no services or other fittings requiring excavation and could be valved off at each end during the rehabilitation without adversely impacting any customers.

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