Appendix C. Transmission Main Condition Assessment

BLACK & VEATCH CORPORATION
Lincoln Water System — **B&V Project Number 401472**
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Transmission Main Condition Assessment

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Condition Assessment of Water Transmission Mains

The goal of a condition assessment is to gather information using non-destructive testing methods to evaluate the current condition of the pipe. The results of the inspection are analyzed and evaluated to determine if repair or rehabilitation is needed and cost effective. The key to condition assessment is in the understanding and implementation of the inspection technologies used to gather the information needed. The EPA defines condition assessment as "The collection of data and information through direct and/or indirect methods, followed by analysis of the data and information, to make a determination of the current and/or future structural, water quality, and hydraulic status of the pipeline" (EPA/600/X-09/003 April 2007). The primary emphasis in this project is structural condition assessment, as opposed to hydraulic or water quality condition assessment.

The critical transmission mains for providing water service to the City of Lincoln are the three transmission mains that provide water from the Ashland Treatment Plant near the Platte River to the City of Lincoln located approximately 19 miles away. We will examine the condition assessment approach for each of these four pipelines based upon material, age, and criticality to operations:

- 36-inch Cast Iron Transmission Main
- 48-inch Prestressed Concrete Cylinder Pipe (PCCP) Transmission Main
- 48-inch/54-inch PCCP from Northeast Pump Station to Vine Street Pumping
- 54-inch Welded Steel Transmission Main

Understanding how a given pipe material fails is critical to being able to assess the condition based on the data collected from the inspection. The major factors, shown in Figure C-1, include:

- Manufacturing defects
- Improper design/construction
- Pressure (operating and surges)
- Temperature changes
- External loads
- Internal and external corrosion
- Third party damage

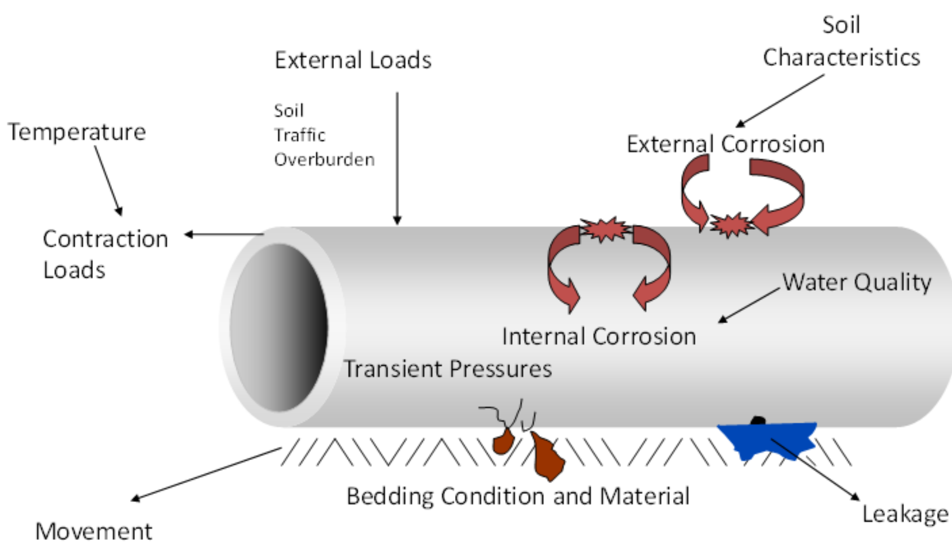

Figure C-1 Factors Affecting Pipe Failure

The decision to rehabilitate or replace a pipeline should be based upon how the pipeline meets the level of service expected. The failure of a pipeline is described as the pipe not being able to provide this level of service. A pipeline with redundancy and which is not critical for providing flows could have a level of service that a leak once a year is acceptable. Other pipelines that provide a majority of the required flows have a higher level of service and any leaks would create an impact on customer service. When evaluating pipelines, it is necessary to consider that similar pipe in different operating conditions will not fail at the same time. The facts show that not all pipe installed in the same year fail at the same time. The deterioration of a pipe is not necessarily a function of the age of the material but rather the cumulative effect of the external and internal forces acting on it.

36-inch Cast Iron Transmission Main

This pipeline is assumed to be cast iron and was installed in the mid-1930's when the Ashland WTP was built. The pipeline runs about 20 miles from the Ashland WTP to the 51st Street Pumping Station and then about 5 miles through the City to the "A" Street Pumping Station for a total length of about 25 miles. In a previous study it was determined the pipe is AWWA standard 1927 Class "C" pipe with a 1.36" wall thickness. The grade of iron used could either be 18/40 or 21/45.

The first cast iron pipe manufacturing process in the 1900's consisted of pouring molten iron into a sand mold, which stood on end in a pit in the ground. The pipe manufactured by this method is referred today as "pit" cast iron pipe. Due to potential for inconsistencies in the pipe wall thickness the pipe was designed with a wall thickness that was much greater than required for the anticipated loadings that the pipe would be subjected to. The pipe was installed using a rope and lead that was heated, poured into the joint and allowed to cool. This pipe normally did not have internal or external coatings but because of the wall thickness continues to be in service throughout the country.

The process was improved in the 1920's when the use of centrifugally casting pipe in a sand mold was introduced. The pipe manufactured with this process is referred to as "spun" or "centrifugal cast iron pipe. The centrifugal forces that are induced on the iron result in an increase in the tensile strength. The higher strength and lack of inconsistencies in the wall thickness resulted in thinner wall thickness than the pit cast pipe. Interior lining of the pipe with cement to prevent corrosion was available in the 1920's but did not become widely accepted until late in the 1930's. The improved tensile strength and reduction in wall thickness coupled with the lack of corrosion protection resulted in this pipe not having the long service life as the "pit" cast iron pipe.

Also, in the 1920's a plasticized sulfur cement compound, known as "leadite" was developed as an alternative to lead for sealing the pipe joints in construction. The use of leadite to seal the joints has proven to be inferior to lead and affects the service life of the joints and therefore the pipeline. The leadite has a different thermal expansion than cast iron and results in additional internal stresses that can lead to longitudinal splits in the pipe bell. Also, the sulfur can facilitate pitting corrosion resulting in circumferential breaks on the spigot end of the pipe. EPA has reported the failure rate in the industry for leadite joint pipe is significantly higher than for lead joint pipe even though the pipe may not be as old.

The metallurgical make up of cast iron is susceptible to a "graphitic" corrosion where an electrochemical reaction occurs between the cathodic graphite component (flakes) and the anodic iron matrix causing a metal loss.

In locations where the 36-inch Transmission Main has recently been exposed, it is our understanding that any leakage is occurring at the joints. This could be an indicator that leadite joints were used for construction and it would be consistent with that time period. The reported observations of the pipe at the leaks indicate the pipe wall is in good condition.

Inspection Plan for 36-inch Cast Iron Transmission Main

The implementation of an inspection plan allows the City of Lincoln to develop a realistic infrastructure management plan based on actual data. With accurate data, utility managers can make informed decisions on pipe replacement or repair instead of relying on guesswork. By identifying and phasing these activities, condition assessments frequently result in significant capital savings to utilities that would otherwise have replaced an entire pipeline.

A phased approach for data collection allows utilities to begin with the basic information and then select the next step based upon the results of the first. The cost of condition assessment increases with the amount of data collected, but increased data provides potentially more guidance for decisions about rehabilitation or replacement.

The proposed plan for the 36-inch Transmission Main is based upon the historical information regarding the leaks at the joints and the reported good condition of the pipe.

- Although inspection of the entire 36-inch may eliminate concerns about totality of the system, the most critical segment with respect to reliability/redundancy is the segment from 51st Street to the A Street Pumping Station. Therefore, to keep cost in check, we would recommend only this segment at this time.
- Based upon the leak detection additional testing may be required.
- If the initial inspection, and subsequent additional testing, yield concerning results, the City should then consider inspection of the 20-mile segment between Ashland and 51st Street Pumping Station.

The typical failure of cast iron with leadite joints is leaks at the joints and leaks typically occur before breaks or splits in the pipe. The recommended method for leak detection would be an in-line free swimming tool capable of detecting and locating small leaks. The purpose of the leak detection would be to determine if there are undetected leaks along the alignment indicating the current condition of the pipe.

The number, location and size of the leaks would be evaluated to determine the recommended next steps. If there are multiple leaks detected, the recommendation would likely be that the pipeline has failed, and rehabilitation is recommended. If no leaks are detected the results indicate the pipeline has a remaining service life, and because the pipeline is critical to operations, additional testing only is recommended in the future.

The potential to rehabilitate or replace this segment of the pipeline would be evaluated based upon the risk associated with failure. The need for soil corrosion potential analyses or examination of the external pipe condition is currently not recommended based on the wall thickness of the cast iron and the reported good condition. During any future repair of leaks the pipe should be examined for pitting and the next step re-evaluated.

There are three in-line leak detection systems currently available:

- Pure Technologies (SmartBall),
- Hydromax (Nautilus)
- PICA (RECON+). The PICA (RECON+) system does not have a tracking system to locate the tool along the alignment, so we would not recommend it for this inspection.

The details for an inspection with these tools should be prepared prior to the work being conducted and an inspection plan developed. The inspection plan would identify access and retrieval locations, tracking sites along the alignment, and other details required for a successful inspection.

Pure Technology SmartBall®

The SmartBall technology has been used in the United States for over 10 years and there are several case studies showing the advantages and disadvantages of this tool. The improved tracking of the tool with sensors spaced about 2,000 feet apart has reduced the potential to "lose" the ball during the inspection. The SmartBall has an inner core with the sensors protected by a foam outer layer as shown in Figure C-2. The sensor can detect very small leaks and air pockets since it is inside the pipe.

The SmartBall is inserted through a 4-inch tap and retrieved with a net that is inserted in the pipeline. The battery life is an estimated 15 hours and provides approximately 15 miles of inspection per insertion. The recommended segment of the 36-inch Transmission Main could be inspected with one insertion and retrieval.

Figure C-2 SmartBall Components

The preliminary cost for conducting a leak detection by Pure Technologies (received November 2019) on the proposed 5-mile segment of the 36-inch Transmission Main is described in Table C-1. The estimated cost includes a 20 percent contingency and 20 percent engineering and administrative costs. The construction estimated cost includes the cost to install a 4-inch tap for insertion and retrieval ($15,000 each) and 15 sensor locations ($1,000 each) along the alignment.

Table C-1 Estimated Cost for SmartBall Leak Detection - 51st Street to "A" Street

Description	Units	Unit Cost	Total Cost
Site visit, planning, data review	Each	$10,000	$10,000
Mobilization of Equipment	Each	$16,250	$16,250
Leak detection inspection	5 miles	$16,538	$82,690
Report of Results	Each	$10,500	$10,500
Total Estimated Inspection Cost			$119,440
Contingency	20%	$23,888	$23,888
Engineering & Administrative	20%	$28,665	$28,665
Construction Estimated Cost	2 Taps and 15 Sensors	$45,000	$45,000
Total Estimated Cost			**$216,993**

Hydromax Nautilus

The Nautilus system is new to the United States and has been available for less than 5 years. The technology was developed in Spain and is similar to the Smart Ball. Nautilus is an in-line, free swimming leak and air pocket detection tool for larger diameter distribution and transmission mains. The Nautilus is different from the Smart Ball because it is neutrally buoyant and floats instead of rolling along the bottom.

The Nautilus is inserted and retrieved through a 4-inch or larger tap. The system is tracked using synchronizers and detectors attached to the pipeline along the alignment about every 2,000 feet as shown in Figure C-5. The detectors and synchronizers track the system but are also used to help determine the location of any leaks identified by the Nautilus.

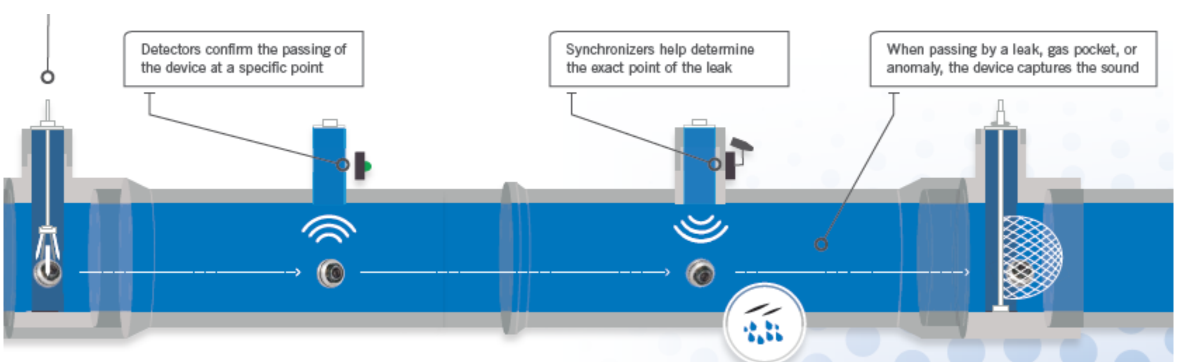

Figure C-5 Nautilus Inspection Layout

The preliminary cost for conducting a leak detection by Hydromax (received November 2019) on the proposed segment of the 36-inch Transmission Main is described in Table C-2. The estimated cost includes a 20 percent contingency and 20 percent engineering and administrative costs. The construction estimated cost includes the cost to install a 4-inch tap for insertion and retrieval ($15,000 each) and 15 sensor locations ($1,000 each) along the alignment.

Table C-2 Estimated Cost for Nautilus Leak Detection - 51st Street to "A" Street

Description	Units	Unit Cost	Total Cost
Site visit, planning, data review	Each	$0	$0
Mobilization of Equipment	Each	$11,000	$11,000
Leak detection inspection	5 miles	$7,125	$35,625
Report of Results	Each	$0	$0
Total Estimated Inspection Cost			$46,625
Contingency	20%	$9,325	$9,325
Engineering & Administrative	20%	$11,190	$11,190
Construction Estimated Cost	2 Taps and 15 Sensors	$45,000	$45,000
Total Estimated Cost			**$112,140**

PCCP Transmission Mains

There are two PCCP transmission mains included in this evaluation. The first is the 48-inch pipeline that was installed in about 1950 that starts out as ductile iron leaving the Ashland Water Treatment Plant but transitions to PCCP within the first mile. The pipeline runs about 16 miles from the WTP to the Northeast Pump Station. The second pipeline to be evaluated was installed in the 1970's and is 48-inch and 54-inch and runs about 5 miles from the Northeast Pumping Station to Vine Street Pumping Station.

PCCP is a common material for water transmission mains and has been used since the 1940's. PCCP was introduced during World War II to minimize the use of steel and by the 1960's was used throughout the United States and Canada. The manufacturing standards for PCCP were modified from 1964 to 1992 to allow for the use of thinner, high strength prestressing wires which is susceptible to failure from hydrogen embrittlement.

PCCP consists of a concrete core cast inside a steel cylinder that serves as a watertight membrane. High-tensile strength steel wire is wrapped directly on the steel cylinder, providing the strength to support the internal loads from the pipe operation. Wires are embedded in a cement mortar to protect the wire from corrosion. A cross section of PCCP identifying the components is shown in Figure C-6. The pipe design effectively utilizes the compressive strength of concrete and the high-tensile strength of steel in the wires. Manufacture of PCCP is covered by American Water Works Association (AWWA) standard C301 and the design is covered in AWWA C304.

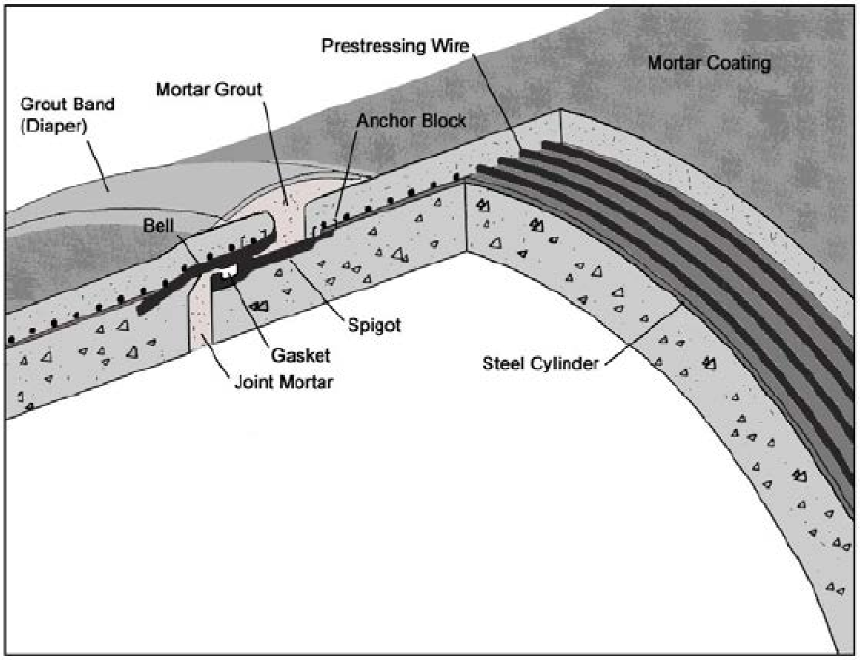

Figure C-6 PCCP Components

There are many reasons why PCCP can fail, but the most common are circumferential and longitudinal cracking of the mortar. Failure In the circumferential mode is typically in the form of prestress loss in the core caused by wire breaks. This is the most common failure mode of PCCP. That this failure mode is significant is supported by the fact that prestressing wires are known to be the primary structural component of PCCP, and breakage of the prestressing wires can result in sudden failure of the pipe. When wires break, the loads are transferred to the concrete core causing them to crack and exposing the steel cylinder to soil and ground water. Eventually, the steel cylinder corrodes and fails. Wire breaks can be caused by corrosion or hydrogen embrittlement. Causes of this failure mode may be related to design, manufacturer, installation, operation, or aggressive environment.

The failure process of hydrogen embrittlement is when elemental hydrogen diffuses into the steel causing it to become brittle and fail at a tensile stress below the normal yield stress of steel. The prestressed concrete pipe is made using wire with residual stress. When the cement coating breaks down or cracks, water and the accompanying hydrogen comes into contact with the wires. Over time, as the hydrogen affects the steel in the wires, they become brittle and break. Hydrogen embrittlement can also be caused by stray currents or over use of cathodic protection currents.

Design and manufacturing standards for PCCP have changed over time. One time period in particular has been associated with higher damage rates due to deficient wire and/or coating standards. In the period 1964 to 1992, the prevailing standard allowed the use of Class IV wire, which had no maximum tensile strength limit. During the manufacturing process, this wire was sometimes over-heated during drawing, leading to dynamic strain aging. This process resulted in less ductility and increased susceptibility to damage from hydrogen embrittlement. Also, during this same time frame, porous or thin mortar coating was applied over the prestressing wires. Low moisture in the mix increased permeability, allowing the coating to absorb chlorine ions exposing the steel to a corrosive environment.

In the longitudinal mode, PCCP may fail as a result of pipe movement caused by differential settlement, inadequate hydraulic thrust restraint, Poisson's effect of pressure, thermal loads, nearby blast or vibration loads, or seismic loads. The failure process may involve opening of joints or cracking of the concrete core or tearing of the steel cylinder with or without corrosion, and failure with or without prior leakage (AWWA M77, 2019).

Inspection Plan for 48-inch PCCP from Ashland WTP

There have not been any reported leaks or failures on the 48-inch Transmission Main from the Ashland WTP to Northeast Pumping Station. This may be an indication that the soil is not corrosive to the concrete pipe and conducting a field survey to collect soil data would likely not provide useful data. The gold standard for inspection of the PCCP would be to utilize electromagnetic (EM) technology mounted on a robot crawler to assess the condition of the main. However, that would be cost prohibitive for 16 miles of main when considering the main has not shown indications of degradation. Therefore, the recommended inspection plan is to evaluate the condition of the pipeline with an internal leak detection using the SmartBall or Nautilus technology.

The need for additional testing for broken prestressing wires will be evaluated based upon the number of leaks and the location of the leaks. Multiple leaks would be an indication that the pipe is deteriorating, and these areas could be further analyzed by EM or visual inspection. If any leaks are deemed significant, they should be repaired which would provide a good opportunity for additional inspection of the main, either with manned entry or with the electromagnetic inspection for broken wires.

The preliminary cost for conducting a leak detection by Pure Technologies on the 16 miles of 48-inch PCCP Transmission Main is described in Table C-3. The estimated cost includes a 20 percent contingency and 20 percent engineering and administrative costs. The construction estimated cost includes the cost to install 4-inch taps ($30,000 each) for insertion and retrieval and 40 sensor locations ($1,000 each) along the alignment.

Table C-3 Estimated Cost for SmartBall Leak Detection - Ashland to Northeast

Description	Units	Unit Cost	Total Cost
Site visit, planning, data review	Each	$10,000	$10,000
Mobilization of Equipment	Each	$16,250	$16,250
Leak detection inspection	5 miles	$16,538	$82,690
	Next 10 miles	$12,075	$120,750
	Over 15 miles (1 mile)	$7,350	$7,350
Report of Results	Each	$10,500	$10,500
Total Estimated Inspection Cost			$247,540
Contingency	20%	$56,858	$49,508
Engineering & Administrative	20%	$59,409	$59,409
Construction Estimated Cost	2 Taps and 40 Sensors	$100,000	$100,000
Total Estimated Cost			**$456,457**

The preliminary cost for conducting a leak detection by Hydromax on the 16 miles of 48-inch PCCP Transmission Main is described in Table C-4. The estimated cost includes a 20 percent contingency and 20 percent engineering and administrative costs. The construction estimated cost includes the cost to install 4-inch taps ($30,000 each) for insertion and retrieval and 40 sensor locations ($1,000 each) along the alignment.

Table C-4 Estimated Cost for Nautilus Leak Detection - Ashland to Northeast

Description	Units	Unit Cost	Total Cost
Site visit, planning, data review	Each	$0	$0
Mobilization of Equipment	Each	$11,000	$11,000
Leak detection inspection	16 miles	$6,431	$102,896
Report of Results	Each	$0	$0
Total Estimated Inspection Cost			$113,896
Contingency	20%	$22,779	$22,779
Engineering & Administrative	20%	$27,335	$27,335
Construction Estimated Cost	2 Taps and 40 Sensors	$100,000	$100,000
Total Estimated Cost			**$264,010**

Inspection Plan for 48-inch/54-inch PCCP from Northeast Pumping Station to Vine Street Pumping Station

There has not been any reported leaks or failures on the 5 miles of 48"/54" Transmission Main from the Northeast Pumping Station to Vine Street Pumping Station. This pipeline was constructed during the time period (early 1970's) that the standards for PCCP had been modified. In addition, this pipeline is one of the most critical in the Lincoln distribution system for providing water service to customers. Therefore, due to the criticality and comparatively shorter length, the recommended inspection plan for this PCCP pipeline is to conduct EM inspection on a majority of the pipeline.

Pure Technologies is currently the only contractor with the patent for the EM technology to inspect PCCP. Pure has two platforms for inspection of PCCP pipe for wire breaks: free-swimming or robotic crawler platform. The free-swimming platform does not require the pipe to be out of service and can be inserted through a 12" tap and retrieved with a net inserted into the pipe. The crawler platform requires the pipe be out of service and an 18" tap for insertion. The crawler is tethered so it can go about 4,000 feet in either direction and provides CCTV during the inspection. The crawler platform is recommended for this inspection. The proposed inspection will collect data on about 16,000 feet through two insertions. The data obtained from this inspection will be used to determine if additional testing is required.

The preliminary cost estimate for conducting this EM crawler inspection by Pure Technologies (provided November 2019) on the 48-inch/54-inch PCCP Transmission Main is described in Table C-5. The estimated cost includes a 20 percent contingency and 20 percent engineering and administrative costs. The construction estimate includes the cost to install two 18-inch taps ($40,000 each) for insertion of the crawler.

Table C-5 Estimated Cost for EM Inspection of PCCP - Northeast to Vine

Description	Units	Unit Cost	Total Cost
Site visit, planning, data review	Each	$25,000	$25,000
Mobilization of Equipment	Each	$27,000	$27,000
EM inspection	16,000 feet	$10.45/ft	$167,200
Report of Results	Each	$15,000	$15,000
Total Estimated Inspection Cost			$234,200
Contingency	20%	$46,840	$46,840
Engineering & Administrative	20%	$56,208	$56,208
Construction Estimated Cost	2 Taps	$80,000	$80,000
Total Estimated Cost			**$417,248**

54-inch Welded Steel Pipe

This 54-inch transmission pipeline was constructed in two phases in the 1993 time frame under contracts FWC.2TM and FWC.3TM. Project 2TM was steel pipe installed by Garney and the pipe manufacturer was Thompson Pipe. There are two classes of pipe, Class 1 with 0.320" wall thickness, and Class 2 with 0.560" thickness. Project 3TM was steel pipe constructed by a contractor called Kenko and the pipe was manufactured by Thompson Pipe. Based on information available, the project used two pipe classes and thicknesses, 0.320" and 0.450". These pipelines were constructed with both rubber gasket, and welded joints in restraint areas, and polyethylene tape wrap coating. These two contracts of 54-inch pipeline from Ashland WTP to Greenwood (interconnect) total approximately 7.6 miles long.

Inspection Plan for Steel

The recommended inspection plan for this pipeline is:

- Inspection of the cathodic protection system to determine the condition of the anodes and if they need to be replaced.
- An in-house pressure test on the segment.
- If the pressure test indicates a leak may be present, then a leak detection technology could be employed to locate the leaks.

References

"Deteriorating Buried Infrastructure Management Challenges and Strategies", EPA, May 2002

EPA/600/X-09/003 – "Innovation and Research for Water Infrastructure for the 21st Century", April 2007

AWWA Manual M77 – "Condition Assessment of Water Mains", 2019