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City of San Diego
Programmatic Water Transmission Pipelines Condition Assessment Project

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ABSTRACT: The City of San Diego set out to perform proactive condition assessments on 35 of its oldest and largest-diameter water transmission mains with the goals of improving system reliability and reducing future operation, maintenance, and replacement costs. The project comprised both raw and potable water pipelines installed in the 1940s and 1950s, predominately 36- to 46-inch in diameter, and constructed mainly of three different pipe materials – cement mortar lined & coated steel pipe, reinforced concrete steel cylinder pipe, and steel cylinder rod wrapped pipe – totaling 136 miles.

Black & Veatch (B&V) developed a work flow process for conducting the assessments with each step of the process building on the results and findings from the previous step. While keeping the majority of the pipelines in service, B&V conducted internal and external assessments of each pipeline alignment, along with assessments of over 200 valves and appurtenances on the potable water pipelines. B&V used results to develop a risk model and program of short- and long-term projects.

Project success was attributable to coordination with multiple groups, including the City, general contractor, technology vendors, and subconsultants. Continued involvement by all groups achieved the City's goals for the project and helped avert costly pipeline failures.

1.0 INTRODUCTION

The City of San Diego (City) retained Black & Veatch to perform condition assessments and risk analysis on 35 of the City's oldest and largest-diameter water transmission mains. The City pursued proactive condition assessments of its major water transmission mains with the goals of improving system reliability and reducing future operation, maintenance, and replacement costs. The City's main drivers were failure prevention and risk management of the selected 136 miles of pipeline.

The transmission pipelines shown in Figure 1 have been in service for 40 or more years and vary in size from 20-inch to 54-inch in diameter. Pipeline materials are primarily reinforced concrete steel cylinder (RCSC) pipe, steel cylinder rod wrapped (SCRW) pipe, and cement mortar lined and coated steel (CML&C) pipe. Of the 34 pipelines, three convey raw water and 31 convey potable water.

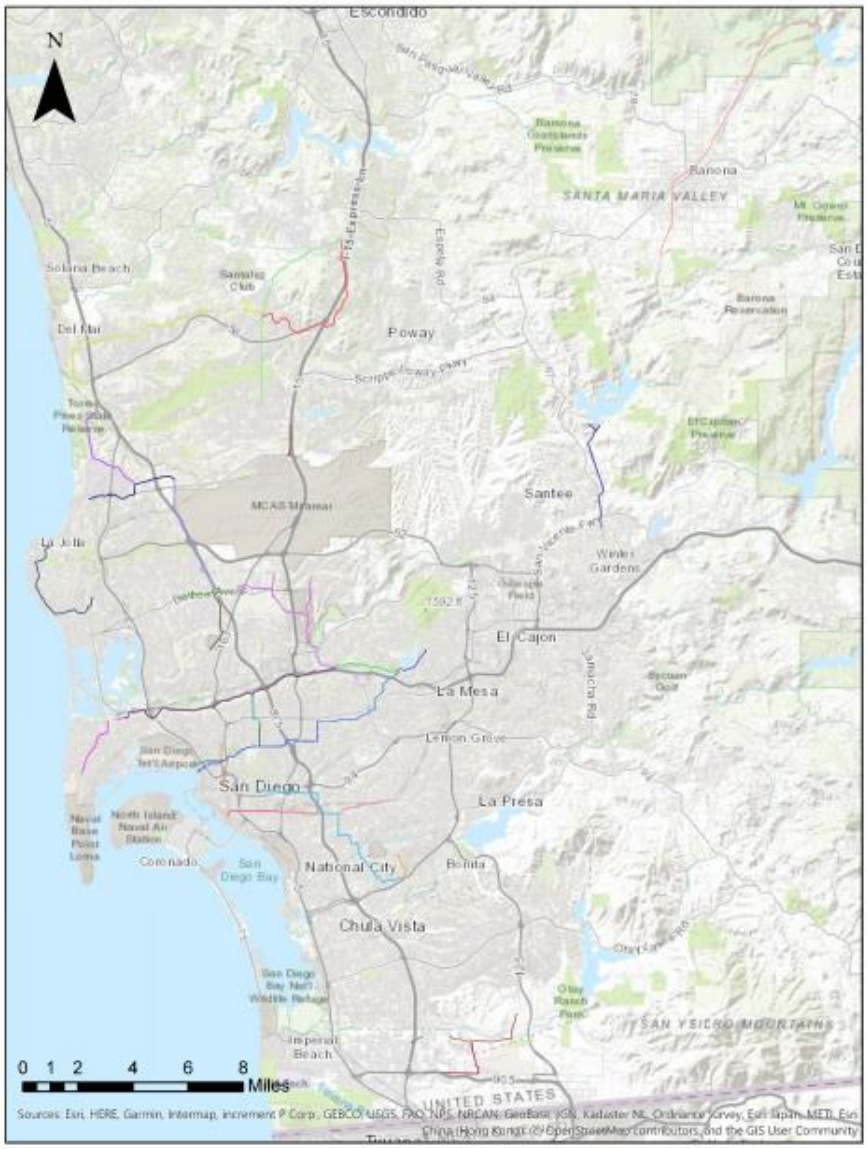

Figure 1. Map of assessed pipelines

2.0 PROJECT APPROACH

The goals and objectives of the pipeline condition assessments were as follows.

- Determine the current condition of each pipeline based on review of existing records and field investigations.
- Estimate the remaining useful service life by applying a risk-based assessment of pipeline condition.
- Identify and prioritize pipeline segments for needed maintenance, rehabilitation, repair, and follow up monitoring actions.
- Develop planning-level action plans and cost estimates for recommended improvements.
- Perform inspections as safely as possible.
- Minimize operational impact due to inspection activities.

These objectives were accomplished by:

1) Identifying and locating potential defect areas and other conditions that present a risk of water supply service interruption.
2) Evaluating and documenting pipe structural integrity, liner integrity, and other deficiencies that may affect the serviceability and reliability of the pipeline.
3) Engaging the City. The intricate nature of the Project pipelines required cooperation and assistance from the City, as well as feedback on which pipelines should be prioritized. The City provided a wealth of existing information, including GIS files, asset locations, and assisted with flow control for some inspections.
4) All involved parties followed the established safety protocol, including wearing appropriate personal protective equipment, performing manned entry inspections only when safe to do so, and signing on to the relevant lock-out/tag-out.
5) Remaining flexible during inspection activities with regard to conditions encountered in the field and proposed changes to inspection methods.

Black & Veatch developed a six-step work flow process for conducting the assessments with each step of the process building on the results and findings from the previous step, as shown in Figure 2. While keeping most of the pipelines in service, Black & Veatch conducted internal leak detection, video inspections, non-destructive testing (ultrasonic testing, slab impulse response, and mortar sample testing), visual inspections, soil corrosivity testing, and a geotechnical evaluation of each pipeline alignment in order to document the liner integrity, structural integrity, and other localized defects that will affect the reliability or serviceability of the pipelines either now or in the future. As an example, Figure 3 shows the various inspection methods that were used, and their coverage, for the Elliot potable water pipeline. The Project also included a field evaluation and assessment of over 200 valves and appurtenances on the potable water pipelines, including inline valves, isolation valves to branch transmission lines, air vacuum and air relief valves, and blow-off valves. The in-service condition assessment inspections yielded comprehensive information with the least impact on water operations.

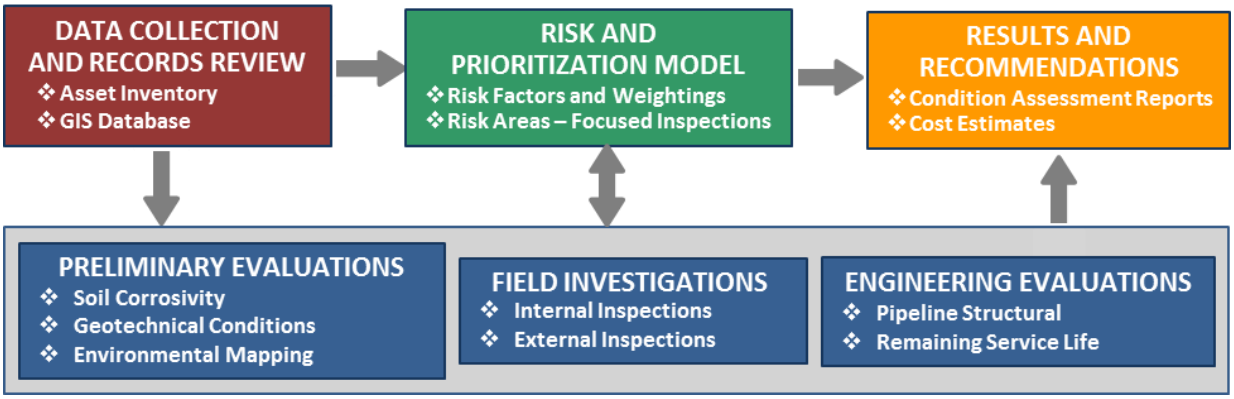

Figure 2. Project approach

Black & Veatch developed a risk model to prioritize repair and rehabilitation projects. The risk model was used to identify potential direct and indirect failure mechanisms and determine, by individual pipe segments, the risk of failure through application of likelihood of failure and consequence of failure factors. The model is specific to the City's water transmission system and is designed to be expandable to include all the City's pipelines. Black & Veatch updated and expanded likelihood of failure and consequence of failure factors, as necessary, based on the findings and recommendations of the detailed pipeline assessments. Risk model results were used to develop a management program to recommend future program-wide pipeline inspection, monitoring, rehabilitation, and repair frequency and coverage.

The project involved extensive coordination with the City. City staff were directly involved in the decision making and planning and execution of the project, through formal workshops, coordination meetings, and status/update meetings conducted in the office or in the field. The early and continued involvement by water field operations staff saved the City time and money. The inspections of both the raw water and potable pipelines were accomplished via the coordination of many different parties (Black & Veatch, general contractor, City, technology vendors, and subconsultants).

3.0 ASSESSMENT METHODS

Available background information on the pipelines included in the Project provided the initial basis for developing a prioritization of planned activities for desktop evaluations and field assessments to ascertain current pipe condition. City record information was collected and logged into a shared data warehouse. The locations and extent of the field investigations were initially planned and defined in the scope of services, with an understanding that the prescribed inspection coverage would be extrapolated to determine pipeline condition.

The characteristics of the three predominant types of pipe in the City's transmission system (CML&C, RCSC, and SCRW) are different, and knowledge of these differences played a critical role in understanding, interpreting, and evaluating inspection data. B&V identified the failure mechanisms and potential causes of failure for each of the three types of pipe and conducted a workshop with the City to develop an action plan for the assessment program. The goal of each pipeline inspection was to be as minimally invasive as possible. Performed assessment methods are presented in Table 1.

Table 1. Assessment methods performed

Assessment Method	Raw Water Pipelines	Potable Water Pipelines
Background data and records review	X	X
Geotechnical desktop study	X	X
Soil corrosivity evaluation	X	X
Environmental evaluation	X	X
Internal inspection	CCTV, leak detection, manned entry	CCTV and leak detection
Valve assessments	X	X
External inspection	Visual, soil samples, SPR, SIR, mortar coating samples, UT	Visual, soil samples, SIR, mortar coating samples, UT
Structural analysis	X	
Risk analysis	X	X
Program development		X

The raw water pipelines were inspected first to set a precedent for the potable water pipeline inspections. The raw water pipelines are some of the highest risk pipelines in the transmission system yet were easier to take offline and inspect than the potable pipelines because of system redundancy and downstream reservoir capacity. Originally, manned-entry inspections had been planned to supplement the CCTV inspections for the raw water transmission pipelines. However, some pipelines required the addition of new access manways for CCTV equipment insertion. Additionally, CCTV results justified an increased scope for manned-entry inspections. Along with the relative importance of the raw water pipeline system, a revised plan for internal inspections relying predominantly on physical manned entry was proposed by Black & Veatch. The revised plan provided a substantial increase in the inspection coverage, as shown in Figure 3, and contributed to the discovery of several areas of damage.

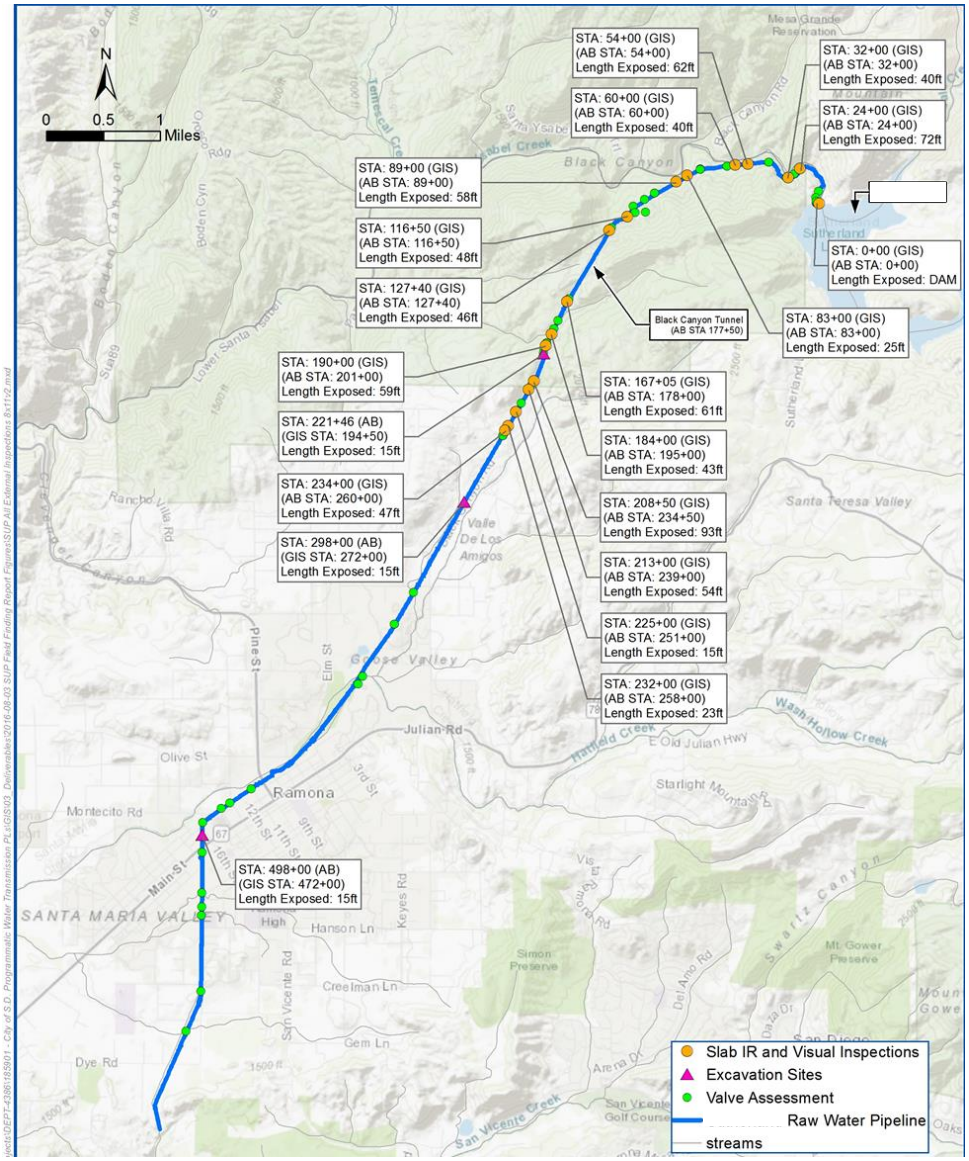

Figure 3. Example inspection methods and coverage for raw water pipeline

The potable water pipeline inspections were conducted in two phases. Black & Veatch performed a preliminary risk analysis based on the background data and records review and preliminary investigation results. This categorized the potable water pipelines according to overall risk and established groups of pipelines as high, medium, and low priorities for Phase 1 inspection. The Phase 2 inspections were intended to verify concerns identified during the preliminary investigation and Phase 1 inspections. Potable water pipelines tended to be smaller diameters then raw water pipelines which resulted in different inspection approaches, as shown in Table 1. The City also preferred to keep these pipelines in service, so manned-entry inspection could not be performed. An example of inspection methods and coverage for a potable water pipeline is presented in Figure 4.

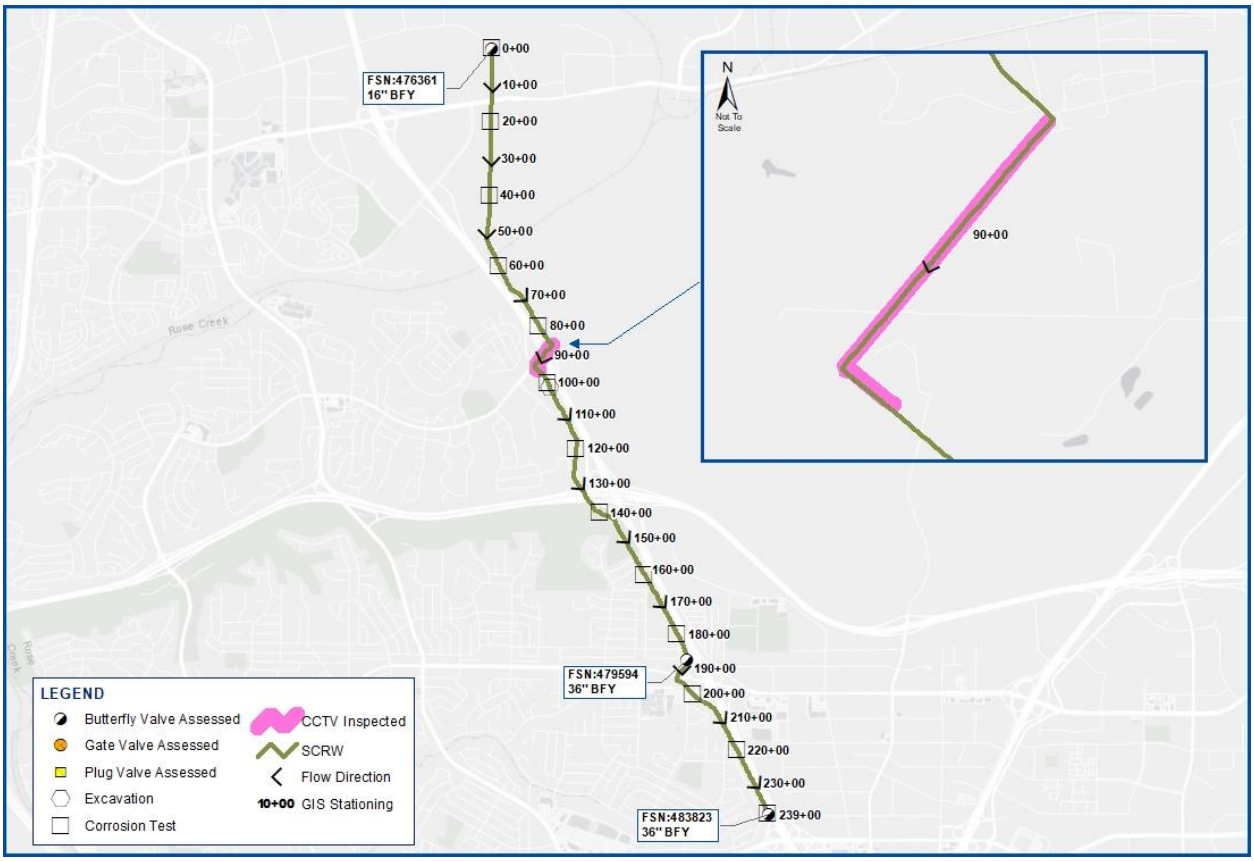

Figure 4. Example inspection methods and coverage for potable water pipeline

4.0 PROJECT RESULTS

The Project has been successful in identifying high-risk pipeline segments and performing emergency rehabilitation at areas that have failed or are at risk of imminent failure. Pipeline condition was determined by correlating as-built information, historical performance records, field investigations, and phase 1 and/or phase 2 inspections. Figure 5 shows an example correlating the condition assessment results for a potable water pipeline. A rating system based on a 1 through 5 scale was used to score pipe segments.

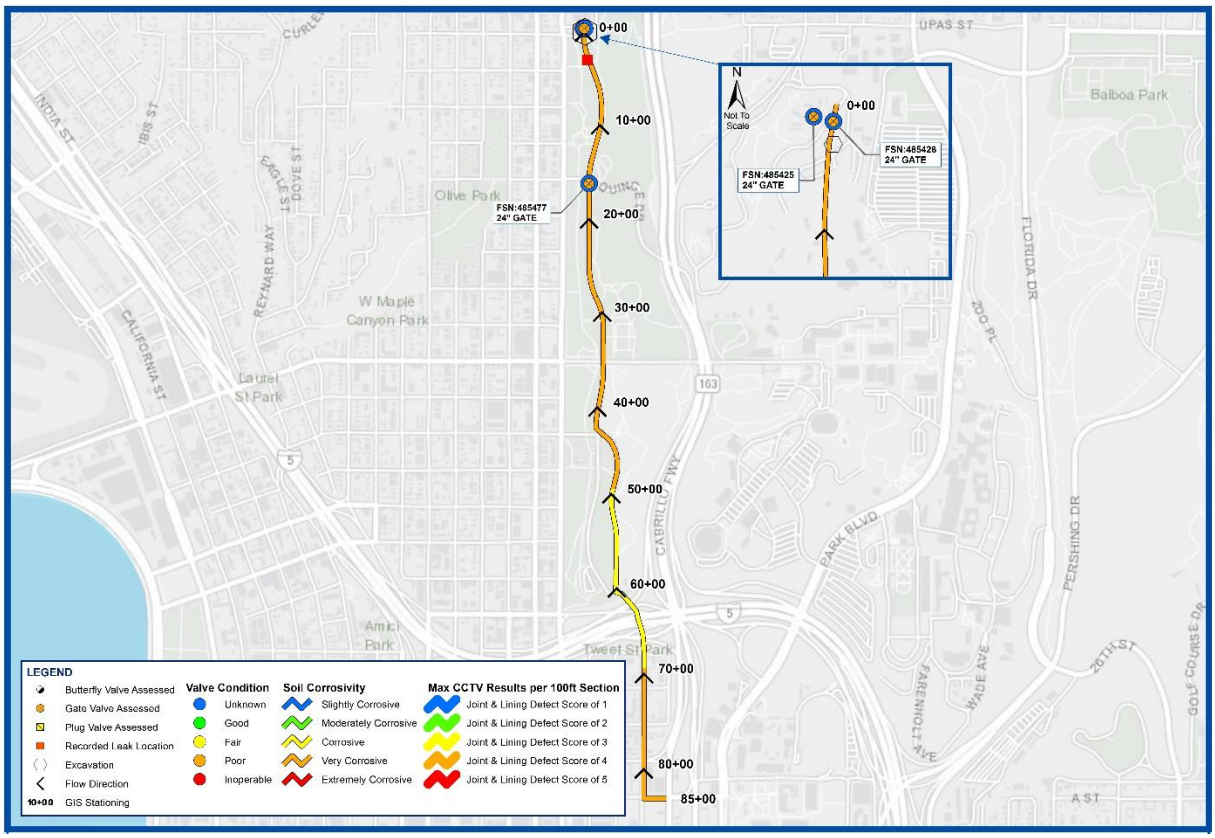

Figure 5. Example inspection results for potable water pipeline

This assessment of pipeline conditions was bolstered by a risk analysis of each pipeline, along with a review of remaining useful life. The likelihood and consequence of failure factors used in the risk analysis were calibrated using field inspection data and Black & Veatch's knowledge and experience with similar condition assessment projects. The model was used to predict the rate of deterioration and forecast when the pipeline may be no longer cost effective to maintain. Examples of the risk analysis results are presented in Figure 6 and Figure 7.

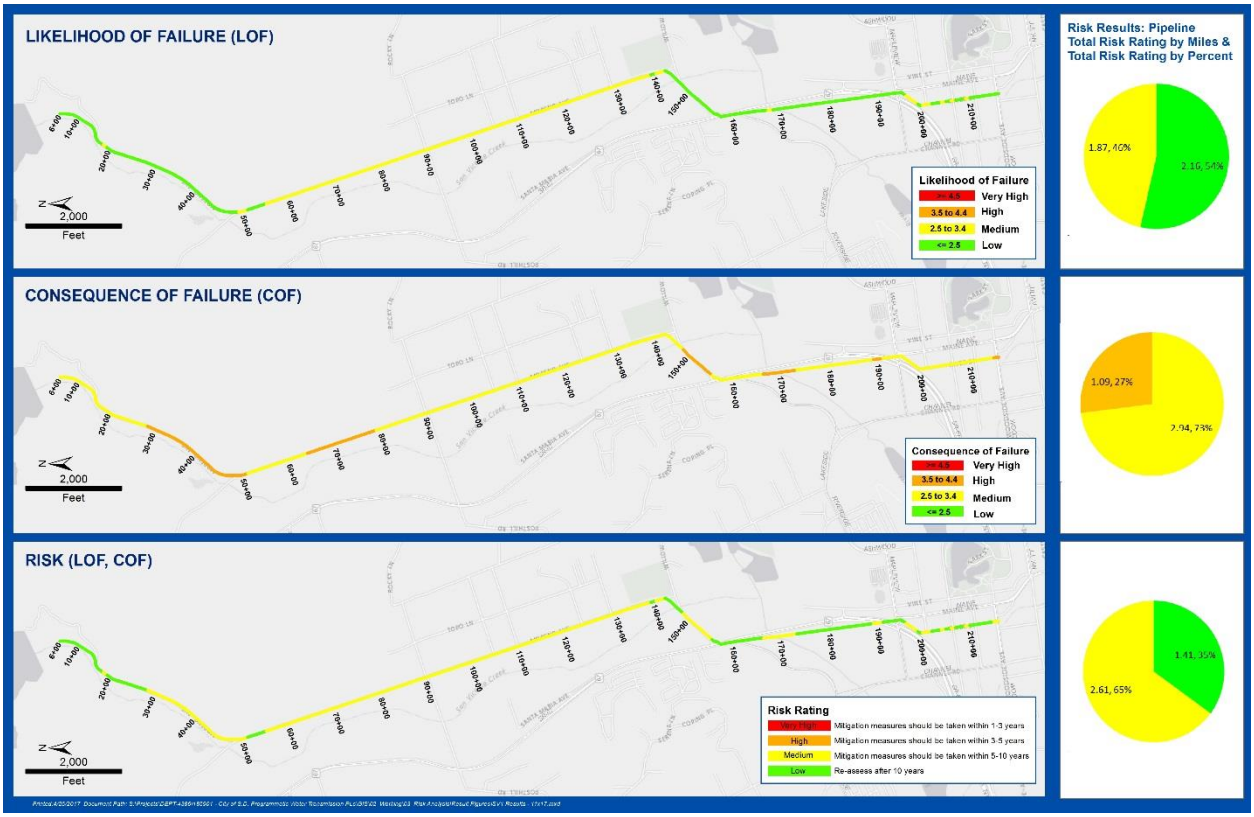

Figure 5. Example risk analysis results for raw water pipeline

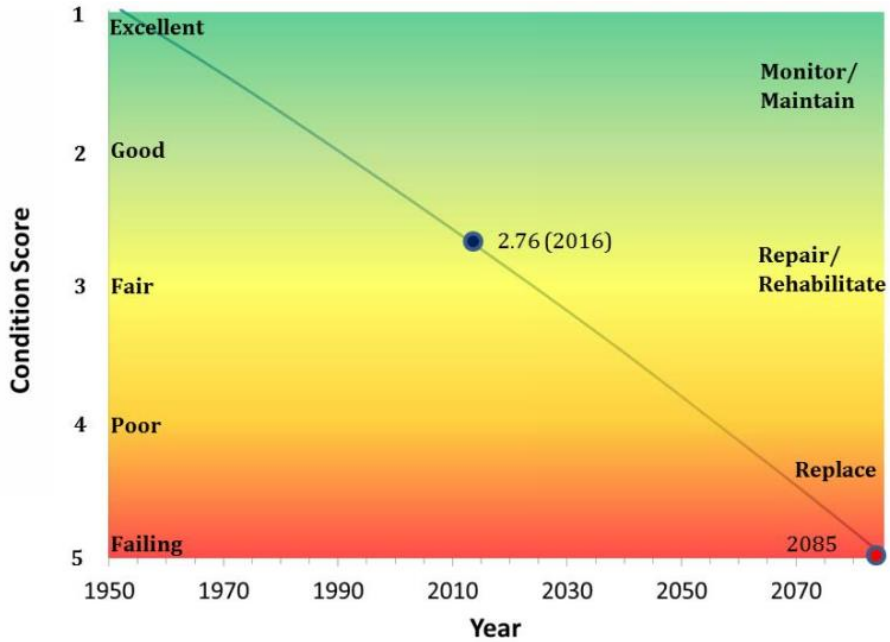

Figure 6. Example condition curve for raw water pipeline

5.0 LESSONS LEARNED

The programmatic approach to the inspections included within this Project were successful in determining both the condition and rehabilitation needs of a significant portion of the City's large diameter water transmission system. Below are the lessons learned during the pipeline inspections.

- Many of the potable pipelines were able to be inspected without taking them offline. It was critical to work with the City to coordinate on equipment insertion locations for internal inspection to assure that minimum flow rates and planned inspection distances were achieved. B&V also worked with the City to identify environmental and social risks to mitigate impacts during the Project.
- The programmatic inspection approach was very successful, with the results justifying future work as well as urgent repair of observed liner defects.
    - Manned-entry of a raw water pipeline that was already taken offline lent itself well to being rehabilitated during the shutdown that was already in effect. An example defect that was rehabilitated as part of the manned-entry raw water pipeline inspection is shown in Photo 1 below.
- Some inspection methods provided more conclusive data than others:
    - Video capture and image quality of interior condition of pipelines can be affected by in-service conditions, including consistency of minimum flowrates. Use of a higher-resolution camera or different inspection technologies may improve future live-flow inspections.
    - Leak detection was useful to identify potential pipeline failures, yet results could be improved when supplemented with televised inspection. For example, leak detection equipment may have mislabeled a leak signature at an open valve.
    - There is no silver bullet—all inspection results were used in conjunction to identify potential trends and root causes. Photo 2 shows an example of Phase 2 external inspection confirming preliminary investigation and Phase 1 internal inspection results.
- A proactive and engaged Client is invaluable. The City needed to be heavily involved for B&V to perform the planned inspection activities.
- The Project proved how valuable preemptive pipeline assessment can be. There were numerous instances of high-risk areas that were discovered, preventing future pipe failures and service disruptions. Photo 3 shows an example of a minor leak that was subsequently repaired by the City. The Project also provided the data necessary to form a condition baseline and to manage an entire water transmission system.

Photo 1. Example internal inspection on raw water pipeline


Photo 2. Example external inspection on potable water pipeline

Photo 3. Example leak identified by inspections and repaired on potable water pipeline