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UTILITY EVALUATION PLAN FOR THE METRO RECLAMATION DISTRICT'S CENTRAL TREATMENT PLANT IN DENVER, CO

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ABSTRACT: The Metro Wastewater Reclamation District has completed an approach for their five-year program to assess the condition of all utilities located at their Central Treatment Plant. Over 260 utilities including diffused air, centrate, drains, sludge, effluent and influent wastewater, grit, hot water, service water, natural gas, potable water, sanitary sewer, storm drain, process fluid, waste oil, and well water pipes will be inspected and rehabilitated over a five-year period. Inspection technologies will include proven approaches such as closed-circuit television inspection, ground-penetrating radar, core sampling, visual inspections, and pipe-to-soil potential surveys, but may also include emerging technologies such as acoustic monitoring, non-destructive testing of insulated pipe, impact echo testing, and others.

A criticality evaluation to set inspection priorities, existing and emerging inspecting technologies that could be applied to pipes within the project area were reviewed, evaluation criteria established, and potential rehabilitation technologies assessed as part of the approach for the five-year program. The program will also establish standards to be used for the inspections during the preliminary design phase. By establishing an approach at the start of the project, before any inspection work is undertaken, the District will be able to select technology-specific contractors and ensure that data is collected and evaluated on a consistent basis for this work and in the future.

This paper provides a summary of the various activities undertaken to develop the five-year program and demonstrates the various project tools utilized to complete the plan such as decision support tools and flow charts.

1. INTRODUCTION

The Metro Wastewater Reclamation District (District) authorized a study to identify specific rehabilitation needs for the utility conduits[1] at the Central Treatment Plant in Denver, Colorado. Over 260 utilities including diffused air, centrate, drains, sludge, effluent and influent wastewater, grit, hot water, service water, natural gas, potable water, sanitary sewer, storm drain, process fluid, waste oil, and well water pipes will be inspected over a five-year period. Also, yearly rehabilitation/replacement projects will be

[1] In the context of this project, the term conduit applies to any pipe or closed channel conveying a fluid. Open channels, tanks, electrical, chlorine, and communications conduits were categorically excluded from the scope of this project.

recommended for implementation the following year. Maintaining pipelines at the Plant is essential to ensure continued compliance with discharge permits and to ensure the cost-effective operation of the wastewater treatment system. HDR Engineering, Inc. (HDR) was selected to provide the condition assessment and evaluation for this project. The overall approach was centered on developing a five-year program, prior to conducting any investigations, that would allow a rational and systematic approach to establish the order in which conduits would be further investigated, the methods to be applied in investigating the condition of the conduits, and the evaluation process for the data collected.

The primary objectives for the five-year program were developed at the start of the project when the planning effort was implemented:

- Use of interactive workshops to incorporate engineering and maintenance perspectives in the project approach,
- Provide a systematic approach to implementation to ensure that the District's funds are invested wisely,
- Involvement of experienced District and consultant experts to define inspection and rehabilitation approaches.

As the first step in the development of the five-year program, a criticality evaluation was performed to prioritize the all conduits included in this project. Based on a set of developed criteria, the criticality evaluation determined which conduits have a higher potential for failure that would severely impact plant operations. Based on the outcome of the criticality evaluation, a prioritized listing of the utilities was developed for inspection.

Various methods of assessing pipelines using existing and new internal and external inspection technologies that may be selected for implementation during the five-year program were identified. The following pipeline inspection/testing methods were considered:

Inspection Methods

- Visual Inspection
- Pipe-to-Soil Potential Survey
- Direct Assessment
- Pressure Testing
- Acoustic Monitoring
- Non-Destructive Testing (NDT) of Insulated Pipe
- Ground Penetrating Radar (GPR) Testing
  -
- Internal Inspection
  - Closed Circuit Television (CCTV)
  - Digital Scanner and Evaluation Technology (DSET)
  - Focused Electrode Leak Locator (FELL) 41 Testing
- Sonar Inspection
- Impact Echo Testing

The primary objective of pipeline renewal for the District is to implement the most cost-effective, long-term solution to correct the identified deficiencies. The plan incorporates aspects of asset management[2] that demonstrates an approach to minimize risk and costs of operating and maintaining specific assets. Tools were developed for the five-year plan such as the criticality evaluation, flow charts, and reference tables that provide a repeatable and defendable process from year to year as conduits are selected for inspection and potential rehabilitation.

[2] One definition of asset management is, "The goal of infrastructure asset management is to meet a required level of service in the most cost-effective way through the creation, acquisition, maintenance, operation, rehabilitation, and disposal of assets to provide for present and future customers" (International Infrastructure Management Manual – Version 2.0, 2002©)

As an alternative to full replacement of deteriorated conduits and appurtenances, rehabilitation provides methods to reduce the cost of construction by minimizing excavation, pedestrian and vehicular disruptions, surface restoration, and contractor's liability. Various rehabilitation methods, listed below, are available today to effectively repair structural and non-structural deficiencies.

Pipe Rehabilitation	Manhole/Structure Rehabilitation
• Point repairs	• Raise to grade
• Joint seals	• Replace frame and riser
• Sliplining	• Repair cone and barrel
• Cured-in-place pipe (CIPP)	• Install manhole/structural liner
• Folded/formed pipe	• Seal manhole/structure walls
• Spiral-wound liners	
• Pipe bursting replacement	• Repair or replace bench and channel
• Open-cut replacement	• Line manhole/structure
• Directional drilling	• Replace manhole/structure
• Tunneling	

2. CRITICALITY EVALUATION

As the first step in the development of the five-year plan to inspect the utilities, a criticality evaluation was performed to prioritize all conduits included in this project. Based on a set of developed criteria, the criticality evaluation determined which conduits have a higher potential for failure that would severely impact plant operations. The criteria were developed during a workshop and based on some criteria used in a prior study:

H_2S – This is an important criterion for all sewer, scum, sludge, effluent, influent, and some drain lines. The expected H_2S level is based mostly on system experience and engineering judgment; however, in some cases, high levels of H_2S are evidenced by the amount of corrosion visible in the pipe.

Percent of Service Life Used – Rather than rating the utility just on its age, using a percent of service life better reflects the remaining useful life of the pipe. For example, if two pipes were installed in 1960, but one has a 50-year service life and the other a 75-year service life (based on material, location, and use), the evaluation would rate the pipe with a 50-year service life as more critical at 88% than one at 59% of service life used.

Coatings/Linings – This criterion reflects the need for some materials to have a lining. For example, if a PVC pipe does not require a coating or lining, it should receive a low score (less critical). If a pipe material requires a coating/lining for the application and does not have one, then it would be scored high (more critical).

Process Importance – This criterion addresses the importance of the pipe to the overall operation of the plant. It also covers permit compliance and safety. If a system has redundancy, such as parallel lines, it would be scored low.

Impacts from Future Projects – If pipes are scheduled to be replaced in the near future, they would be scored low in terms of inspection priority. For example, an oxygen line that may be eliminated or replaced in the near future would be a low priority for inspection. A utility not scheduled for replacement or modification would receive a higher score.

Performance History – Only the historical performance of the pipe was addressed by this criterion and a separate criterion was established for maintenance frequency. For example, if a pipe has a history of failures it would be scored high, while pipes that have never failed would be scored low.

External Environment – This criterion addresses hot soil areas based on field resistivity tests and poor trench construction as evidenced by surface failures or known conditions. This category also covers UV exposure for plastic pipes.

Pipe Material – This category addresses the predicted performance of specific pipe materials for the application in which they are used. For example, if an unlined concrete pipe is used to carry sludge, it would receive a high score. If a plastic pipe is used for potable water, it would receive a low score.

Accessibility – If a pipe is located under a structure, but is shallow, it would receive a high score for accessibility. A pipe that is very deep would also receive a high score. If the pipe is not very accessible, it is likely that routine maintenance and inspection has not been performed on the pipe. A pipe located in an open area, away from structures and other utilities, would receive a low score.

Maintenance Frequency – This category addressed whether the pipe requires high, medium, or low maintenance (including repairs) frequency.

A system to weight the criteria using a decision-support tool, Pair Wise Comparison (Engi 1995), provided a simple way to compare criteria in a group rating environment. The criteria were evaluated against each other to determine the relative rankings based on the sum of scores and the weighting factors resulted from the scores. A weight is a fractional value between 0 and 1 and all the weights must sum to 1. District and project staff familiar with the utilities scored the criteria for each pipe. Based on the outcome of the criticality evaluation, the prioritized listing of the utilities is used to identify projects for each year of this five-year program and beyond.

3. INSPECTION METHODS

The inspection techniques selected for consideration will vary depending on the type of pipe, pipe material, pipe size, and location. The integrity of the supporting soil structure is very important to the performance of a pipe, and the loss of soil support may lead to collapse. Some of the inspection technologies will provide information about the soil around the pipe. During the inspection phase for this project, selection of the preferred inspection method for specific pipes may be dictated by access, schedule, and cost where there is more than one potential method from which to select.

Each inspection method implemented results in a unique set of condition data that needs to be evaluated to determine the specific condition of the pipe. The inspection method and the types of data collected by each method were evaluated to develop a flow diagram illustrating the data processing and potential rehabilitation or replacement options. Figure 1 provides an example of the flow diagram developed for selection of the inspection method.

The range of possible defects expected for the different types of inspection methods were defined so that data acquisition formats could be developed later during the preliminary design phase. A detailed description of pipe inspection methods are provided in previously published materials (Ratliff, 2003 and WERF 2002). Inspection methods not described in either of these publications, but considered for this work, are described below. Two other methods were also considered, but are not expected to be implemented because they either duplicate information expected from another method, or were considered not desired for application to pipes at the plant: impact echo and sonar inspection. Flow charts were also developed for each inspection method describing the type of defect and potential rehabilitation method that may apply.

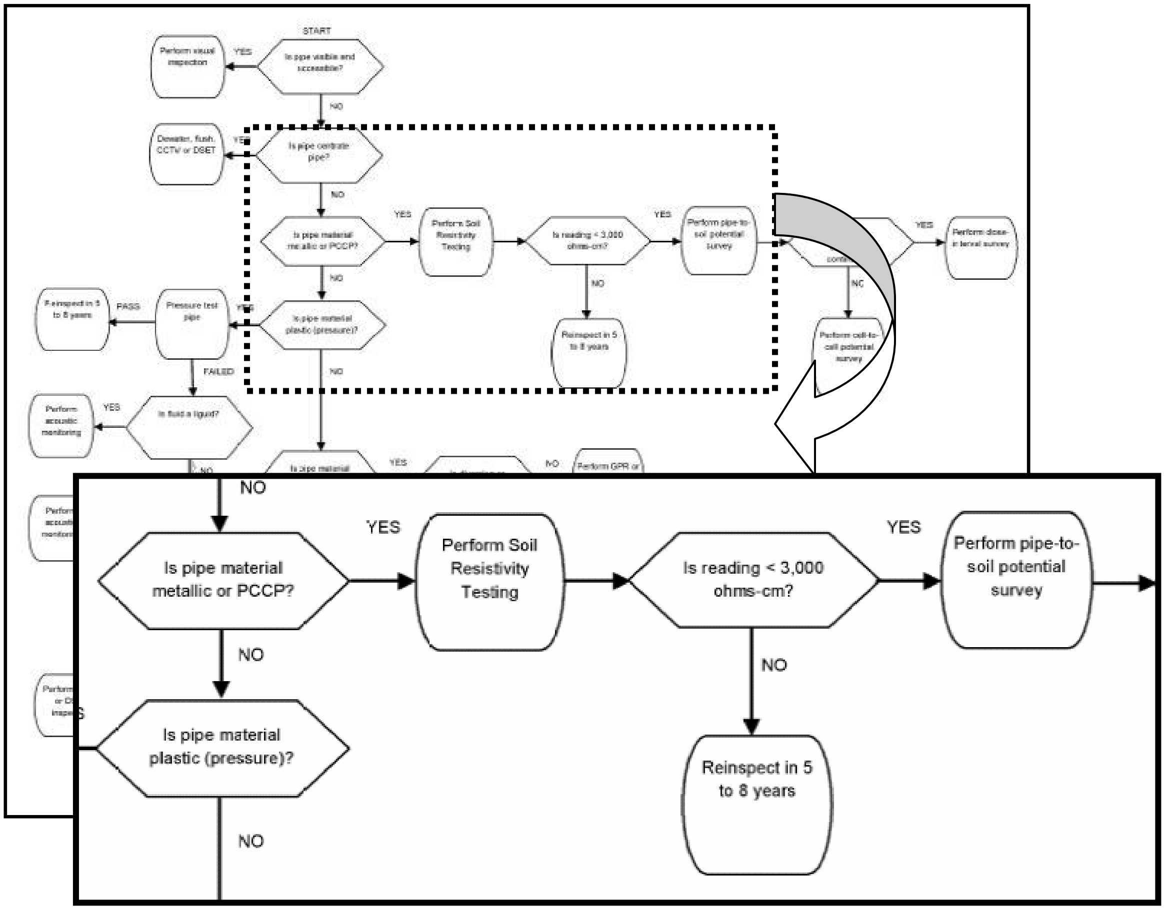

Figure 1. Program Flowchart for Selecting Inspection Method.

Visual Inspection

The types of defects typically found during visual inspections include:

Type of Defect	Common Causes
Joint leaks	Weld failures
	Rolled gaskets
	Glue failures
	Over pressurization
External corrosion	Lack of coating
	Stray currents
Coating failures	Damaged coating
	Improper application

***Joint Leaks* –** Joint leaks typically occur when welds fail, gaskets are rolled and no longer seal the joint, or when the operating pressure is higher than the design pressure. Joint leaks are visually seen as wet spots (or steam escaping hot water pipes) at the joint or a buildup of minerals/material at the joint. Common repair methods for joint leaks based on the type of failure mode include:

Type of Defect	Common Repair Method
Weld failure	New sleeves
	Reweld Joint
Rolled gasket	New sleeves
	Disassemble and reinstall
Over pressurization	Replace with pressure pipe designed for the higher operating pressures

External Corrosion – Corrosion that is visible on the outside of the pipe can be due to a lack of outside coatings on the pipe, existing coatings that have failed, or stray currents that are causing the pipe to corrode. Repair methods for outside corrosion could include the following:

Type of Defect	Common Repair Method
No coating	Major damage: replace pipe Minor damage: clean and coat pipe
Stray currents	Cathodic protection

Coating Failure – If an existing coating is damaged, the pipe underneath can be subject to corrosion. Repair methods will be dictated by the presence of pipe corrosion at the site of the coating damage:

Type of Defect	Common Repair Method
Damaged coating	Pipe corrosion – replace pipe No pipe corrosion – repair coating

Pipe-to-Soil Surveys

Corrosion of metals is a result of electrochemical reaction in which a chemical reaction is accompanied by a flow of electrical current. The driving force for the corrosion of metals through electrochemical reactions is the free energy of the metal atoms in their metallic form. If corrosion products are analyzed, their chemical composition is usually identical to the ore from which the metal was originally obtained. Three types of measurements are possible: 1) direct measurement of applied voltage (across the output terminals of a rectifier); 2) structure-to-electrolyte potential measurements; and 3) structure-to-structure potential. The objective of this indirect survey is to detect coating damage, which is a necessary precursor to external corrosion metal loss.

Structure-to-electrolyte potentials are not common because an understanding of the electrical principles involved is necessary to make sure that the measurements are accurate and furnish a true picture of conditions as they actually exist.

Pipe-to-soil readings may be used at various stages in the corrosion evaluation process. They are used to determine the corrosiveness of the environment, since potential measurements, coupled with other types of measurements, are indicative of the corrosion activity taking place on a structure. Figure 2 shows a typical pipe-to-soil potential profile on a pipe that is experiencing corrosion activity.

By taking profiles over a fixed distance lateral to the pipe being studied, the corrosion mechanism that is affecting the pipe can be determined (provided there are no other unusual factors affecting the situation). In general, anodic areas (areas of active corrosion) are at the locations where the over-the-pipe potentials are more negative than the cathodic areas. Where interference from other protected structures exists, other patterns will be observed. The data will indicate the electrical characteristics exhibited by the pipe or structure in its natural state. Thus, any corrosion proceeding will be indicated by specific patterns of pipe-to-soil potentials at various points along the structure. A pipe-to-soil potential survey is normally used in conjunction with other types of corrosion surveys to gain the data necessary to determine the severity of the corrosion. These surveys include:

- Line current survey - measurement of the electrical current flowing on the pipeline,
- Measurement of the electrical resistivity of the environment surrounding the pipe,
- Determination of the alkalinity or acidity of the environment surrounding the pipe, and
- Determination of conditions suitable for anaerobic bacterial corrosion.

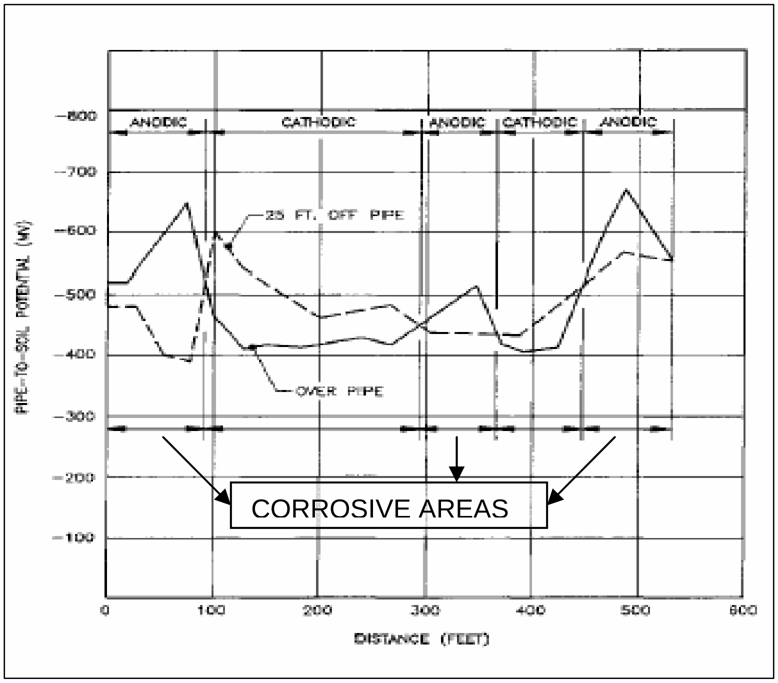

Figure 2. Example of Pipe-to-soil Potenital Survey Results

Cell-to-Cell Potential Survey – Cell-to-cell potential testing is performed to determine the direction of current flow in the soil. This is especially useful on unprotected pipelines to locate anodic areas. These procedures are not normally used on protected structures. On unprotected pipelines when cathodic protection of the complete line is not feasible or economical, “hot spot protection” is sometimes used. This test procedure is used to identify the anodic areas of the pipeline for application of cathodic protection to those locations.

Close-Interval Survey – Close-interval surveys (CIS) on underground pipelines are extremely valuable for locating areas of coating damage and areas of probable corrosion damage. The advantage of this method is that the data is easily obtained with a connection to the structure under test. The CIS survey is reproducible and will accurately locate coating holidays which can be excavated and repaired. Other problem areas related to interference, current attenuation, foreign contacts and electrical shielding are also detected.

Direct Assessment

If the pipe-to-soil potential survey (indirect assessment) indicates the existence of a corrosive environment, a direct assessment is performed as a follow-up. The structured method for direct assessment is detailed in the NACE TG 041 Committee Recommended Practice for direct assessment.

This standard is applied to many pipelines to demonstrate the capability of direct assessment in the determination of pipeline integrity. Figure 3 shows an example of direct assessment for a validation study that demonstrated the direct examination results and was found to be an effective and economically viable method for screening various pipelines.

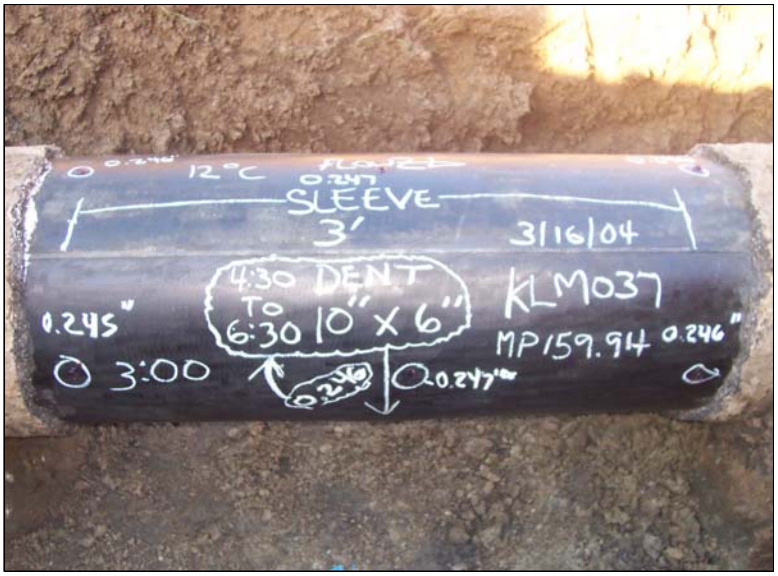

Figure 3. Example of Direct Assessment

Pressure Testing

Plastic pipes scheduled for inspection will be pressure tested. If the pipe fails the pressure test, it will be scheduled for acoustic monitoring to locate leaks in the pipe.

Acoustic Monitoring

Acoustic monitoring will be used to inspect plastic pipes that fail a pressure test. The technology will provide fairly accurate locations of active leaks. Repair of the pipe will be limited to replacing segments of pipe with active leaks.

Non-destructive Testing (NDT) of Insulated Pipes

The project includes preinsulated copper and steel pipe. Insulation for these pipe materials typically is comprised of R30 insulation, which is made from rolled fiberglass, blown fiberglass, or blown cellulose. Insulation is measured in two ways - inches and "R-value". Insulation R-value is a relative measure of an insulating material's resistance to heat transfer. Inspection of insulated piping has long been a challenge and conventional techniques such as ultrasonics are often impractical or cost-prohibitive because of limited productivity, insulation removal cost, or temperature restraints. There are, however, new technologies that are designed for online corrosion inspection of insulated pipe. These technologies are: profiler portable real-time radiography (RTRT) and pulsed eddy current.

These NDT technologies provide new options and resolutions for inspection of insulated pipes. When rough, encrusted, or coated surfaces are present, NDT can be more practical than ultrasonics (Pechacek, 2004). NDT testing is considered specifically for the insulated high temperature piping. Without removing the insulating barrier the process determines the internal piping wall thickness, it works similar to that of the conventional ultrasonic thickness gauging, and can find the following defects:

- Metal losses – determine remaining thickness and if repairs are needed,

- Pitting areas – determine pitted areas: are pits deep enough to require remedial action.

Internal Inspection

Internal inspection using CCTV or DSET technolgies for concrete or plastic pipes where the flow is low enough to allow the insertion of internal inspection equipment will be used to identify pipe defects. Common repair methods for typical defects include:

Type of Defect	Common Repair Method
Fractured or collapsed pipe	Replace
Isolated joint leaks	Joint seal
Isolated holes, cracks	Point repair
Multiple holes, cracks	Minor: liner pipe Major: replace
Corrosion	Minor: coating, liner or sleeve Major: replace
Pipe sags	Replace
Protruding connections	Cutting tool
Broken connections	New connection

FELL 41 Inspection - The sewer electro-scan or focused electrode leak locator provides a first-step technique for identifying leak sources in reinforced concrete, clay, brick, plastic, or plastic-lined steel pipe from 3 to 60 inches in diameter. The output is a plot of the electric current flow between a surface electrode and an in-pipe, radially-focused electrode (sonde) as it is pulled through the sewer pipe. When the sonde passes a leaking joint, service connection, or crack the current flows and is recorded. Statistical analysis results provides a means to prioritize pipe segments by comparing anomaly length to pipe length tested, which normalizes the results to indicate the pipes with the worst problems.

***Manhole/Structure Inspections* -** Access structures often have a lot of individual problems such as defective frame/cover, unsealed frame or chimney, cracks, leaking joints, or damaged bench and invert. A visual inspection of the structures determines the specific defects that need to be addressed. Specific localized problems and their associated repair options include:

Type of Defect	Common Repair Method
Below grade and subject to flooding	Raise to grade
Damaged or misaligned frame or cover	Realign or replace frame and cover
Unsealed frame	Internal and external frame seals
Unsealed riser	Internal seals or external wrap
Damaged riser, cone, shelf, barrel, or channel	Repair structure
Unsafe steps	Replace steps or remove steps, seal structure
Infiltration	Seal structure
Leaking joints	Seal joints

Ground Penetrating Radar (GPR) Inspections

GPR inspections on concrete structures typically find the defects such as internal corrosion where the wall thickness is reduced that is shallow (rebar not exposed) or deep (rebar exposed), moderate to severe corroded rebar, or moderate to large voids behind the wall.

Internal Corrosion – If corrosion is occurring on the pipe crown or side walls, the original wall thickness will be reduced. Light to moderate corrosion may have occurred that has not reached the reinforcing steel. Severe corrosion occurs when the wall is reduced in thickness to the rebar and beyond. Possible repair methods are based on the level of corrosion and include:

Type of Defect	Common Repair Method
Wall thickness reduced less than the rebar depth	Structural liners
Wall thickness reduced to the rebar and beyond	Replace pipe

Corroded Rebar **–** Sometimes concrete pipe is deteriorated but not significantly impaired based on the appearance of the concrete, but the reinforcing steel is deteriorating within the concrete. This can be due to stray currents or chlorine attack. Chlorine attack is more common in marine environments; therefore, it is more likely that stray currents would be the primary cause of corroding reinforcing steel in concrete structures at the plant site. Repair methods for rebar corrosion would include the following:

Type of Defect	Common Repair Method
Corroding rebar	Major damage: replace pipe Minor damage: structural liner

Voids Behind the Wall **–** If voids behind the pipe wall are identified, it usually signifies severe defects in the pipe and open cut replacement is recommended to correct the pipe and repair trench defects.

6. RECOMMENDATIONS

Understanding the limits of various technologies and selecting the appropriate diagnostic tool for condition assessment is important. However, selection of the proper tools is only part of the answer. Selecting the appropriate field inspection method and applying standards for the acquisition, quality control, and integration of the data will provide the engineer with valuable information on which to base rehabilitation design decisions and implement proper levels of Operations and Maintenance (O&M). Often, overall total project savings and reduced construction change orders are the result of a well-organized and effective program for pipeline condition assessment. For the Metro Wastewater project, specific inspection methods will be used for the pipe materials that exist at the project site. During the design phase for this project, selection of the preferred inspection method for specific pipes may be dictated by access, schedule, and cost (not in order of importance) where there is more than one potential method from which to select.

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