Bend Plant Interceptor Condition Assessment

Prepared for

City of Bend, OR

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Executive Summary

The City of Bend (City) hired Brown and Caldwell (BC) to inspect the Plant Interceptor (PI) that conveys sewage roughly 5 miles from the sanitary collection system to the Water Reclamation Facility (WRF). The purpose of the inspection was to identify areas of required maintenance as well as any defects that may compromise the sewer's structural and operational integrity. Inspected sewers include the following:

- 11,400 linear feet (LF) of 30- to 42-inch American Society of Testing and Materials (ASTM) C76 Class III reinforced concrete pipe (RCP)
- 8,800 LF of 36- to 42-inch ASTM C361 low-head pressure RCP
- 9,800 LF of ASTM C361 low-head pressure pipe in a siphon from the siphon structure to the WRF. The siphon is comprised of parallel 21-inch and 36 inch pipes.

The gravity portion of the PI was inspected using a combination of digital scanning, laser profiling, and sonar profiling. The manholes and access structures were inspected using a combination of digital scanning and man-entry inspection. Both barrels of the siphon were inspected using sonar profiling. The general condition of each trunk is summarized as follows:

- Gravity Portion: Approximately 37 percent of the pipe segments in the gravity portion exhibit structural Grade 5 defects with reinforcement visible being the most prominent Grade 5 defect. Approximately 31 percent of the gravity portion exhibit Grade 4 defects, such as localized reinforcement visible. The laser profiling indicated a significant loss of pipe wall which corroborated with the visual observation of corrosion. The majority of the manholes were in good condition with only ten exhibiting grade 4 or 5 defects. Operationally, the gravity portion of the PI is in good condition.
- Siphons: The sonar profiling did not detect any structural issue in either siphon barrels. However, there is a large accumulation of grease and debris which has restricted the flow significantly and reduced hydraulic capacity. Approximately a cumulative 700 cubic yards of debris is estimated to be in both siphon barrels.

The possible options for addressing the structural and operational defects in the PI are summarized in Table ES-1, with the estimated remaining useful life of the PI after the rehabilitation option is implemented.

Table ES-1. Rehabilitation Options for PI		
Option	Project cost, $	Remaining useful life, years
Option 1: Address Grades 4 and 5 segments	4,526,000	7 to 10
Option 2: Address Grade 5 segments and implement corrosion control	4,288,000	10 to 15 for Grade 4 20 to 30 for Grade 3 and below
Option 3: Address Grade 4 segments with short liners and Grade 5 segments with full CIPP and implement corrosion control	4,799,000	20 to 30
Option 3A: Address Grade 4/5 segments with full CIPP and implement corrosion control	6,418,000	30 to 40
Option 4: Rehabilitate the entire PI	8,701,000	50+
Option 5: Replace the entire PI	21,826,000	50+
Siphon cleaning and inspection	600,000	N/A
New siphon junction box	85,000	50+

BC's recommendations depend on the hydraulic capacity needs of the City, both now and in the future. Table ES-2 summarizes BC's recommendations based on the various hydraulic requirements of the City.

Table ES-2. BC Recommendations Based on Hydraulic Requirements		
Hydraulic capacity need	Recommended option	Project cost, $
Adequate capacity for next 20 years	Option 3 + siphon cleaning + siphon junction box	5,484,000
Adequate capacity for foreseeable future	Option 4 + siphon cleaning + siphon junction box	9,386,000

Section 1

Introduction

Brown and Caldwell (BC) was retained by the City of Bend (City) to inspect the Plant Interceptor (PI). As the sole means of conveyance for most of Bend, the primary objectives for performing this work include the following:

- Obtain a thorough understanding of the PI's condition.
- Estimate the remaining useful life of the PI.
- Develop a strategy to implement the appropriate upgrades at the appropriate times.

The inspection work was conducted with these objectives in mind. This document provides an overview of the condition assessment and findings.

1.1 Plant Interceptor

The PI was constructed in 1978 and is the sole means of conveyance from the sanitary sewer collection system to the Water Reclamation Facility (WRF). The PI measures approximately 25,300 feet and includes the following:

- 11,400 linear feet (LF) of 30- to 42-inch American Society of Testing and Materials (ASTM) C76 Class III reinforced concrete pipe (RCP)
- 8,800 LF of 36- to 42-inch ASTM C361 low-head pressure RCP
- 4,900 LF of ASTM C361 low-head pressure pipe in a siphon from the siphon structure to the WRF. The siphon is comprised of parallel 21- and 36-inch-diameter pipes.

Figure 1-1 illustrates the PI configuration and material. The PI varies in diameter with larger sewer diameters discharging into smaller sewer pipe.

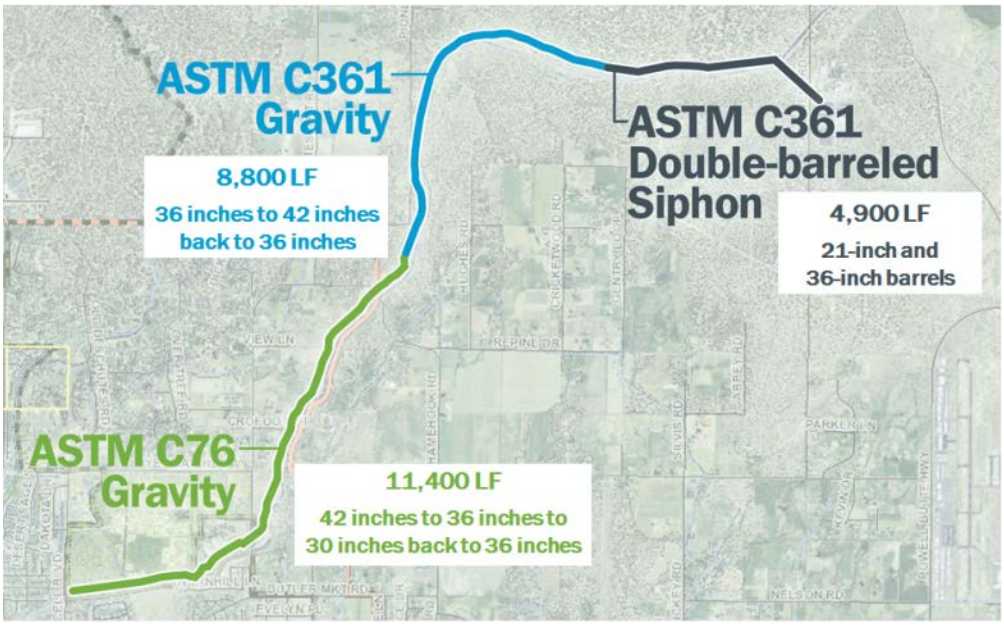

Figure 1-1. PI size and material

While the actual details of construction were not available, current ASTM manufacturing standards present a wide range of tolerances. Pipe characteristics for each of these standards are listed in Table 1-1.

Table 1-1. ASTM Requirements For Reinforced Concrete Pipe

Pipe diameter, inches	ASTM C76 (Class III RCP)	ASTM C361 (Low-head pressure RCP)
21	N/A	• Single cage of reinforcement • Wall thickness 2-3/8 to 3 inches • 0.95-inch minimum concrete cover over rebar
30	• Single cage of reinforcement • Wall thickness 2-3/4 to 4-1/4 inches • 0.5-inch minimum concrete cover over rebar	N/A
36	• Single or double cage of reinforcement • Wall thickness 3 to 4-1/4 inches • 0.5-inch minimum concrete cover over rebar	• Single cage of reinforcement • Wall thickness 3-1/4 to 5 inches • 0.75-inch minimum concrete cover over rebar
42	• Double cage of reinforcement • Wall thickness 3-1/2 to 5-1/4 inches • 0.5-inch minimum concrete cover over rebar	• Double cage of reinforcement • Wall thickness 3-3/4 to 5 inches • 0.75-inch minimum concrete cover over rebar

1.2 Inspection History

The PI was last inspected in 2005. Recommendations are provided in the 2007 Yeoman Interceptor CCTV Review Report. The inspection indicated the presence of large quantities of grease throughout the PI. However, the pipe was reported to be in good condition with no major structural defects identified. Minor defects such as surface roughness increased and surface aggregate visible were detected in the downstream reaches with minimal to no defects in the upstream portions of the PI. The remaining useful life, as stated in the 2007 Yeoman Interceptor report, ranged from 25 to 50 percent of the original 50 year design life. Because none of the segments were in need of immediate repair or rehabilitation, implementation of the improvement work could be delayed. The report recommended the City to re-inspect within the next 7 to 10 years. In the meantime, the City was advised to plan for a $9.2 million cured-in-place pipe project and undergo high-pressure cleaning to remove the grease.

In 2013, the City issued a request for proposals for re-inspection of the PI. As part of the proposal process, BC reviewed the 2005 inspection video and determined that six pipe segments had major structural defects due to corrosion, such as reinforcement visible. Example screen shots from the 2005 inspections are shown in Figure 1-2.

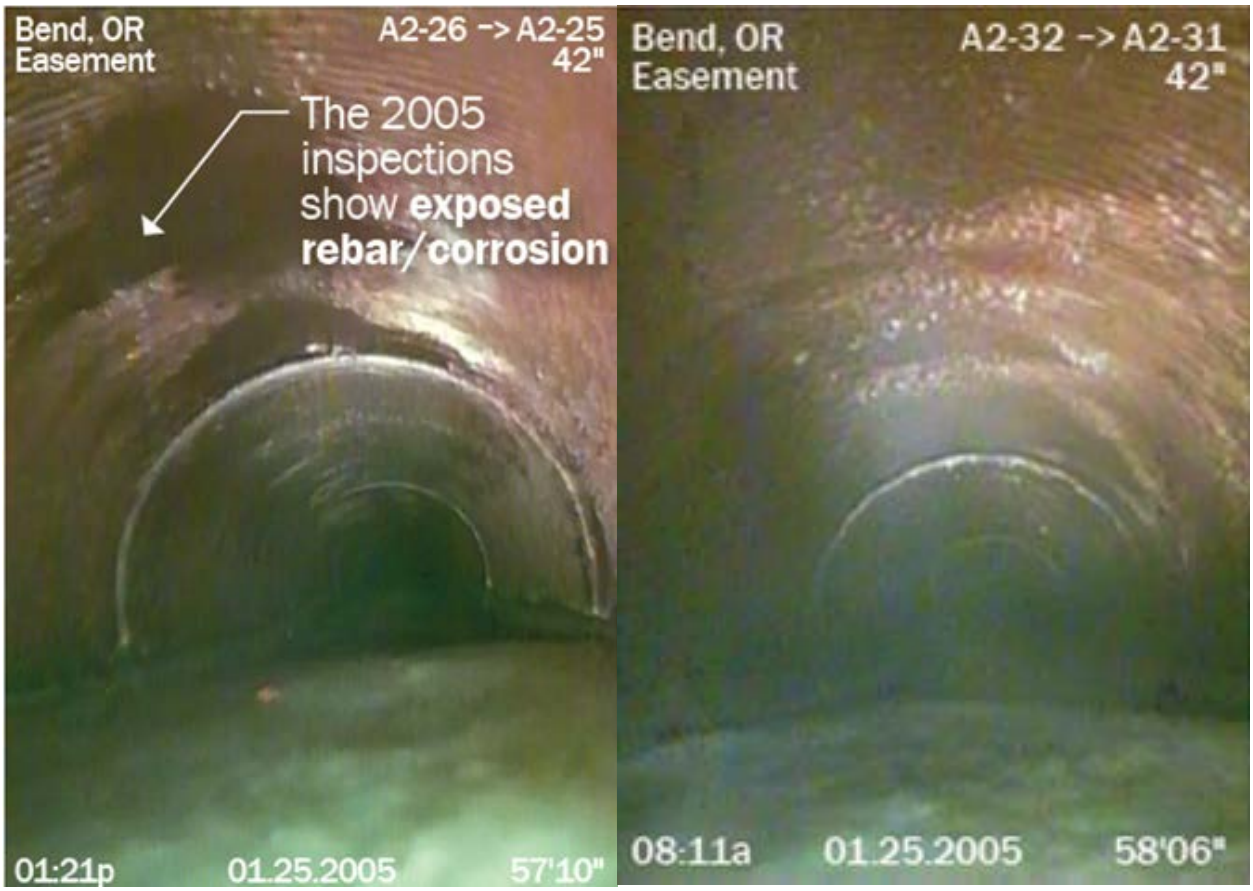

Figure 1-2. Screen shots of defects from original 2005 inspection

The discovery of severe defects within the PI helped to determine the most appropriate inspection technologies for its 2013 re-inspection.

Section 2

Sewer Inspection

This section describes the pre-inspection activities, equipment, and methods used to perform the fieldwork inspection of the sewer pipe and manholes along the Plant Interceptor (PI).

2.1 Pre-Inspection Activities

Prior to implementation of the PI inspection, planning activities were conducted that include a planning workshop, property owner notifications, and contracting access to the siphon box.

2.1.1 Pre-Inspection Workshop

Brown and Caldwell (BC) and the City of Bend (City) participated in a pre-inspection workshop. The purpose of the workshop was to discuss the following topics: project critical success factors, scheduling constraints, current and future hydraulic capacity of the PI and Water Reclamation Facility (WRF), inspection technologies, and end goals for the inspection project. Copies of the presentations given at the workshop and resulting meeting minutes are provided in Appendix A.

At the workshop, the project team determined the critical success factors (CSFs) that would need to be met for the success of the project. The following CSFs were identified:

- Meet the project objectives within the project cost.
- Obtain high quality data that can be used to track degradation of pipes over time.
- Confirm the remaining useful life of the pipe and determine whether the capacity is sufficient to support future population growth projections.

Numerous inspection technologies are available to serve specific purposes. BC presented the City with multiple options with the purpose of identifying those that would best meet the City's goals within the budget and time frame. The following technologies were reviewed: closed-circuit television (CCTV), digital scanning, laser, sonar, pipe penetrating radar, zoom cameras, electro scanning, and gyroscopic positioning. Table 2-1 summarizes the various technologies. A memorandum comparing and contrasting these technologies is included in Appendix B.

Table 2-1. Summary of Inspection Technologies

Technology	Data provided	Purpose
CCTV	Visual inspection	Qualitative assessment
Sewer scanners	High-resolution visual inspection	Qualitative assessment (higher confidence)
Sonar	Under-the-flow inspection (holes, grease, debris)	Hydraulic capacity, cleaning, gross defect identification
2D laser ring profiling	Geometric data	Precise defect identification (particularly siphons)
3D LIDAR scanning	Geometric data	Corrosion measurement, rehabilitation design (straight pipe)
Electro-scan	Leak potential	Corrosion measurement, rehabilitation design (larger diameters, non-round pipe, bends)
Pipe-penetrating radar	Wall thickness, rebar cover, voids beyond pipe	Corrosion measurement, estimating remaining service life
XYZ mapping	Gyroscopic mapping	Precise locating

Based on the workshop and information present, the project team determined that visual inspection coupled with the quantitative data gleaned from laser profiling or scanning and sonar were the best technologies for this application.

BC contacted HydroMax USA, Northwest Underwater Construction, AquaCoustic Remote Technologies, RedZone Robotics, and Interactive Pipeline Inspections to obtain proposals for the work. RedZone Robotics was chosen to perform the inspections based on experience, scheduling availability, and comparable costs.

2.1.2 Public Notification

The PI conveys wastewater through a sparsely inhabited area on the eastern side of Bend. Most of the manholes could be accessed via a public dirt road that parallels a canal. However, a number of the manholes were located on private property and/or were located behind fences or under private property improvements. Prior permission for access was required to inspect the gravity portion of the PI as well as the manholes themselves. A letter was sent in advance to the property owners to solicit consent to perform the inspections. Door hangers were also delivered to each property as a notification of work to occur within 48 hours.

Examples of public and private property access types are shown in Figure 2-1. Copies of the various types of materials provided to property owners are included in Appendix C. Figure 2-2 is a map that shows the locations of the inspected manholes.

Manhole on private property

Public road paralleling the PI

Figure 2-1. Public and private access areas along PI

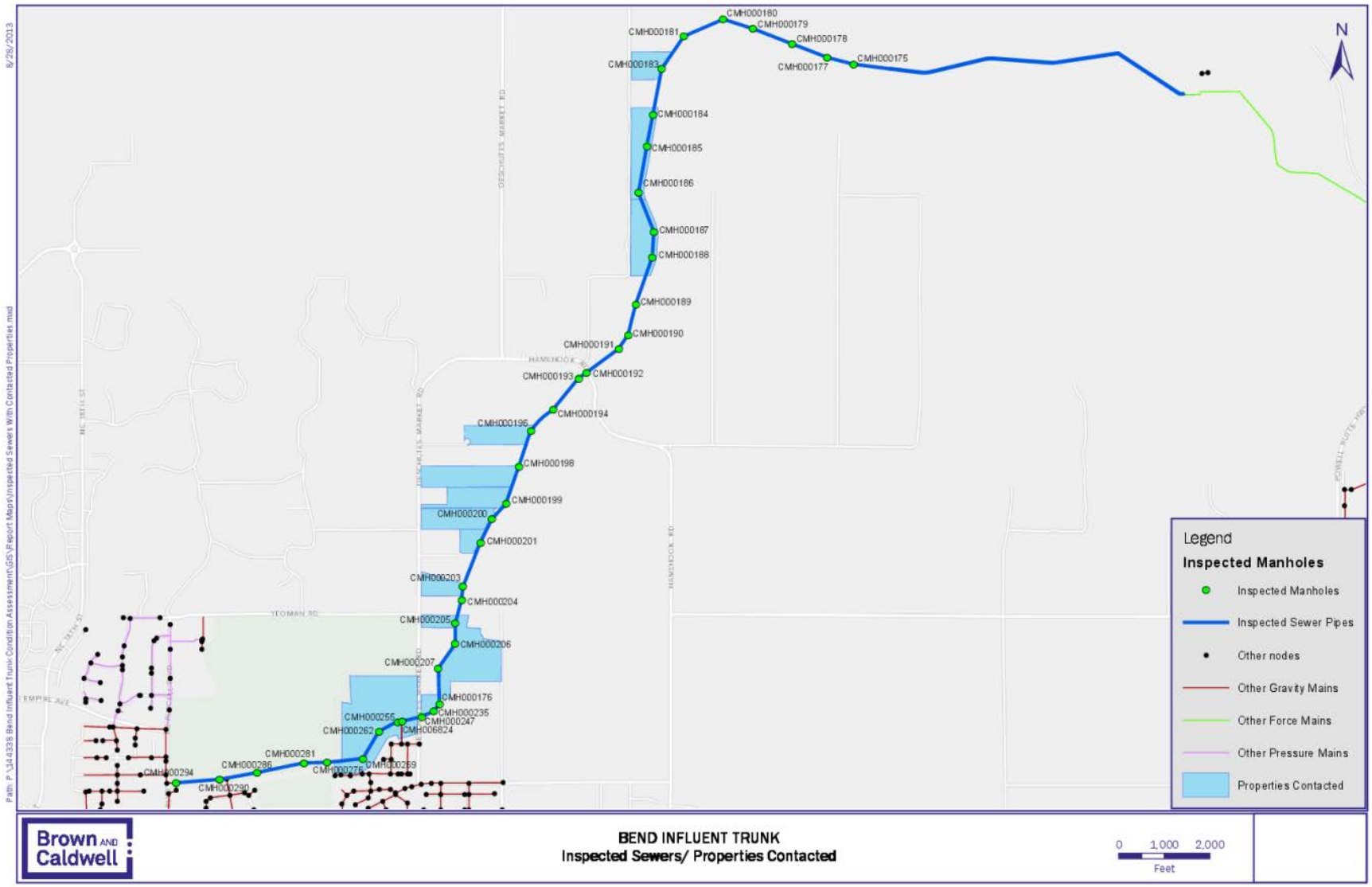

Figure 2-2. Inspected manholes located on private property

2.1.3 Siphon Access

The siphon conveys flows for a little under a mile underneath the main irrigation canal and back up to the WRF. The numerous bends within the siphon created ideal conditions for debris accumulation. The siphon barrels were not inspected in 2005 and have never been cleaned nor inspected since they were originally constructed. The siphon profile is shown in Figure 2-3.

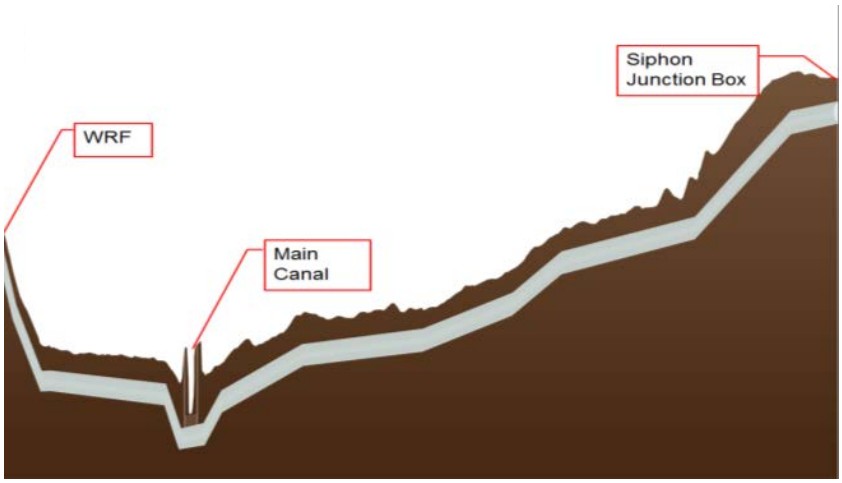

Figure 2-3. Siphon profile

2.1.3.1 Intertie Box

Inspection of the double-barreled siphon required preplanning due to some unique issues. First, the barrels are just under a mile in length with no intermediate access. The only point of access is the upstream siphon junction box. While remote-operated vehicles (ROV) could be used to propel the sonar probe through the siphon, the length, numerous bends, unknown amount of debris, the typical floatables associated with a wastewater stream (e.g., rags, grease) that could hinder the ROV propellers, and cost were all factors that made this option less attractive. To perform the inspection cost-effectively, access at both ends of the siphon was investigated to allow for a more traditional winch-assisted sonar inspection. The siphon enters the WRF at an intertie box, as shown in Figure 2-4. The intertie box is capped with a fixed concrete slab.

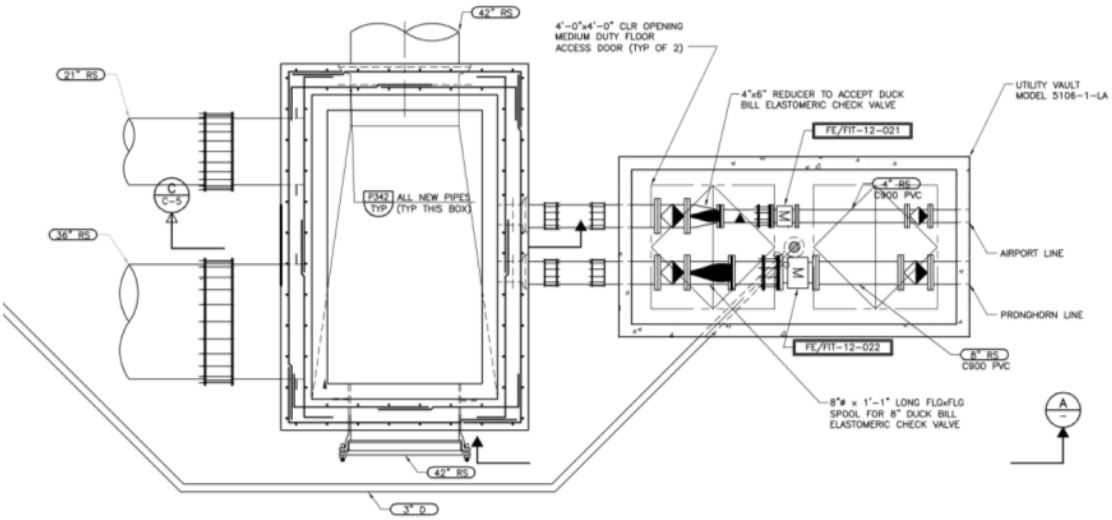

Figure 2-4. Plan view of the intertie box

A concern that was raised was that the intertie box was pressurized and once the top slab was removed, raw sewage would overtop the box with diurnal changes in flow. After visually observing the available freeboard within the intertie box once the top slab was removed, overtopping was no longer deemed to be a concern. A specification was developed to direct the contractor to remove and store the top slab for the duration of the inspection and replace the top slab post-inspection. The specification is provided in Appendix D.

A crane lifting the top slab from the intertie box is shown in Figure 2-5.

Figure 2-5. Removal of the intertie box top slab

2.2 Inspection Methodology

The inspection technologies used for the condition assessment include digital scanning, sonar, and laser scanning.

2.2.1 Digital Scanning

Digital scanning is a method that uses an optical sensor to inspect the inner surface of pipelines or manholes, capturing multiple images per second. The images are recorded digitally and stitched together to produce an image that gives the reviewer the ability to focus, pan, tilt, or zoom the camera to investigate potential defects after the inspections are complete. Unlike CCTV which returns a live feed to the operator, the digital scans can be reviewed only after the inspection is completed. More information about the technology can be found in Appendix B.

2.2.1.1 Interceptor Digital Scanning

The camera used by RedZone Robotics is mounted to the front of the float and is shown in Figure 2-6. Digital data were recorded for the gravity sewer totaling roughly 20,000 linear feet (LF) of footage.

Figure 2-6. HD profiler rear view to show CCTV camera

2.2.1.2 Manhole Digital Scanning and Inspection

Digital scanning was also used to inspect the 40 manholes along the interceptor. The digital scanning equipment and setup used by RedZone Robotics is shown in Figure 2-7.

Figure 2-7. Digital scanner used for manhole inspections

In addition to the digital scans, the manholes were entered manually to perform hardness and scrape tests. Hardness and scrape tests consisted of scraping the concrete at various points within the manhole to determine its competency.

2.2.2 Laser Profiling

Laser profiling is an emerging technology that is often used to supplement visual inspection technologies such as CCTV. The laser profiler is used in low visibility conditions and provides information such as accurate pipeline dimensions and shape, protruding lateral length, water depth, deformations, pipe wall material loss, and offset joint distance. The laser used for the PI consists of a laser wand that projects a ring of light onto the wall of the pipeline in a circular pattern. The rear facing camera obtains digital images of the laser ring and post-processing converts the optical images into geometric measurements. The laser wand on the RedZone Robotics float is shown in Figure 2-8. More information about the technology can be found in Appendix B.

Figure 2-8. HD profiler with laser wand

2.2.3 Sonar Inspection

Sonar profiling occurs below the water surface and measures the speed and distance of travel of acoustic sound in water. Sonar profiling systems consist of a sonar emitting head mounted to a camera transporter such as a moving float platform. An example is depicted in Figure 2-9. Sonar is used to make measurements of pipeline dimensions and shape, water depth, large deformations, gross pipe wall material loss, offset joint distance, and volume of sediment deposition. In this case, sonar was used to inspect the 10,000 total linear feet (LF) of the 21- and 36-inch siphon barrels.

Additional information about the technology can be found in Appendix B.

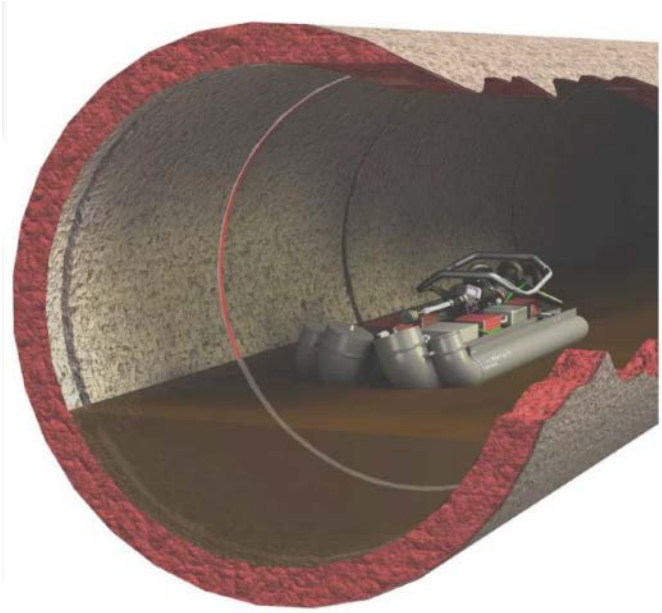

Figure 2-9. Sonar and laser inspection float in pipe

2.3 Field Work

The actual inspection work began on July 15, 2013 and concluded on July 26, 2013. The first week was planned for the inspection of the gravity components of the PI and the second week was set aside for the sonar inspection of the siphon barrels.

2.3.1 Gravity Inspection

The gravity pipe portion of the PI was inspected in in five deployments. RedZone Robotics used its HD Profiler, a multi-sensor platform deployed on a float using digital scanning, laser profiling, and sonar. As mentioned above, the manholes were inspected using digital scanning combined with man-entry inspections to gauge the competency of the concrete. The manhole inspections were originally conducted concurrently with the gravity inspections but improper data collection required reinspection of the manholes to obtain the needed scrape test information. The reinspection was completed in October 2013.

2.3.2 Siphon Inspection

The siphon inspections consisted of floating a tag line from the upstream siphon junction box, retrieving the tag line at the downstream WRF intertie box, and pulling the sonar probe through the siphon. A parachute was used to propel the tag line through the 36-inch siphon barrel initially, but

numerous attempts were unsuccessful due a large amount of debris and grease buildup within. Ultimately, a combination of neutrally-buoyant bottles combined with plug-and-release of flow to propel the bottles through the suspected constrictions resulted in successful tagging of the line. Significant volumes of grease and debris, as well as large obstructions, were moved through the 36-inch barrel as a result of the inspection work. Information regarding the remaining debris in the 36-inch barrel is described in Section 3.

The 21-inch siphon barrel was tagged and inspected successfully on the first attempt.

Figure 2-10 illustrates the debris, grease, and other obstacles removed from the intertie box during the inspection of the siphon.

Figure 2-10. Couch cushion and grease blocking the 36-inch siphon barrel

2.4 Inspection Data Management

Inspection data including the digital scanning, laser, and sonar were post-processed and delivered via the RedZone's proprietary software platform, ICOM3. A separate software program, FlyViewer, is required to utilize the full-functionality of the in-pipe digital scanning data. Both software programs were made available to the City.

Video files of the gravity inspections were created. A Pipeline Assessment and Certification Program-compliant database with all the defect codes was exported and delivered to the City for importation into the City's computerized maintenance management system, Granite XP.

Section 3

Condition Assessment

This section presents the approach used to assess the condition of the sewers and the findings of the inspections.

3.1 Pipe Condition Assessment Approach

The City of Bend uses the National Association of Sewer Service Companies' Pipeline Assessment Certification Program (PACP) for defect coding its sanitary sewers. Sewer defects identified during the inspections were recorded using the PACP standardized defect identification procedure, which assigns a score for each defect.

Two levels of classification are used to evaluate pipe condition: structural and operational. Defect ratings are based on the defects observed during the inspections and are used as the basis for assigning a rating to each pipe.

- Structural defects: Structural defects are those that impair the structural condition of the pipeline directly, such as joint separations, joint deflections, cracks, fractures, holes, broken and collapsed pipe, corrosion, worn inverts, and reinforcement visible.
- Operational defects: Operational defects include a range of conditions that can either directly affect the performance of the sewer or are indicators of potential structural defects, such as debris, grease, intrusions (root or service laterals), sags, and hydraulic (undersized pipe) problems. The PACP classifies infiltration as an operational defect.

The inspection firm, RedZone Robotics, was required to code the defects per PACP standards. RedZone provided coding of the pipe initially, but RedZone's coding was not consistent with PACP standards, with numerous defects missed or not coded properly. Brown and Caldwell (BC) disagreed with the level of coding and performed an independent review of the inspections. For each pipe segment, BC discovered on average over 15 additional defect codes that RedZone either missed or did not agree with even though the laser data demonstrated otherwise (e.g., RedZone did not code "Surface Damage Reinforcement Visible" even though the laser data demonstrated a significant loss of inner pipe wall). As a result, the final PACP coding was completed by BC.

The final RedZone Robotics report is included in Appendix E.

3.1.1 Pipe Condition Grades

Based on the defects identified, BC assigned an overall structural and operational rating to each sewer pipe or reach. Often the score was based on the most critical or **peak** structural and operation defect score within each sewer reach.

Peak defect ratings are calculated for the two primary defect categories (structural and operational) described above according to their impact on the system. The peak rating is the highest single structural or operational defect score within any section of sewer. The peak condition rating helps to identify serious flaws or defects in the sewer and becomes the primary basis for the structural and operational grades. A secondary criterion for determining the structural and operational grades is the presence of continuous defects. A continuous defects is defined as a defect that continues down the length of the pipe for greater than 3 to 5 linear feet (LF).

Structural and operational condition grades are assigned to each inspected pipe reach to provide a summary of the structural and operational conditions of the sewer, respectively. Grade 5 represents the worst condition and Grade 1 represents a sewer in excellent condition. Table 3-1 provides a definition for each condition grade.

Table 3-1. Structural and Operational Condition Grades for Sewers

Condition grade	Grade description	Defect description
5	Immediate attention	Sewers requiring immediate attention
4	Poor	Severe defects that will continue to degrade with likely failure in 5 to 10 years
3	Fair	Moderate defects that will continue to deteriorate
2	Good	Minor and few moderate defects
1	Excellent	No defects; condition like new

Structural condition grades can be used to prioritize rehabilitation or replacement. Operational condition grades can be used to prioritize maintenance, such as cleaning or additional inspection. The required activity could include rehabilitation, replacement, major repair, or maintenance, depending on the type and severity of the observed defects.

Professional judgment is used to assign the final structural and operational condition grades. In this way, the variability of a given defect can be assessed. For example, in a 36-inch-diameter pipe, visible reinforcement at a break-in connection and visible reinforcement for hundreds of LF within a pipe reach will yield the same rating of 5; however, the extensive length of visible reinforcement presents a much greater risk of failure. Thus, for each pipe reach, a final recommendation is given that takes into account peak score as well as the variability of the defects. During post-inspection review of the digital videos, the severity of defects were noted and used to develop the rehabilitation recommendations.

3.2 Plant Interceptor (PI) Structural and Operational Condition Grades

The inspection results indicate there are two main regions of the gravity portion of the PI with advanced corrosion. These areas exhibited extensive Grade 5 defects with surface reinforcement visible (SRV) totaling 7,319 LF of pipe. This area makes up roughly 37 percent of the gravity portion of the PI, as listed in Table 3-2.

Table 3-2. Structural Results for the Gravity Portion of the PI

Condition grade	LF of pipe segments	Percent coverage
5	7,319	37
4	6,112	31
3	4,627	23
2	1,717	9
1	-	0

As described above, the structural condition grades assigned to each pipe segment represent the peak defect score based on BC's best professional engineering judgment. The majority of pipe within the gravity portion was assigned a Grade 5 or 4 defect score. Most of the Grade 4 pipe contains SRV defects but with much fewer instances within a segment and each instance is over a much smaller area of pipe. The Grade 3 defects found in roughly 4,600 LF of pipe were primarily surface aggregate visible (SAV). This is an early indicator of surface degradation of the concrete comprising the pipe walls. Concrete is a combination of aggregate and cement. In this case, the cement has sufficiently degraded such that the aggregate becomes visible. Finally, the remaining 9 percent of segments exhibited surface spalling. This is the earliest stage of degradation when the surface of the pipe begins to degrade or slough off the wall in patches.

Laser data collected indicate that the pipe continues to hold its round shape, meaning that the rigid pipe has not been structurally compromised to the point of fracturing and displacement. However, the laser data also corroborate very well with the visual indications of severe corrosion.

For the siphon, the sonar results were relied upon to determine structural condition grades. Concrete pipes that are constantly full are generally not expected to have significant corrosion, because sewer head space and oxygen are necessary for the biogenic reactions that lead to concrete corrosion. The sonar did not reveal any gross structural defects in either the 21- or 36-inch siphon barrels. However, there were areas of the 36-inch siphon barrel where the water level was below the crown, either due to grease accumulation on the crown or air pockets. In either case, these areas of the siphon could be susceptible to concrete corrosion over time and should be investigated further.

Figure 3-1 summarizes the structural condition grades of the PI. Table 3-4 summarizes each pipe reach.

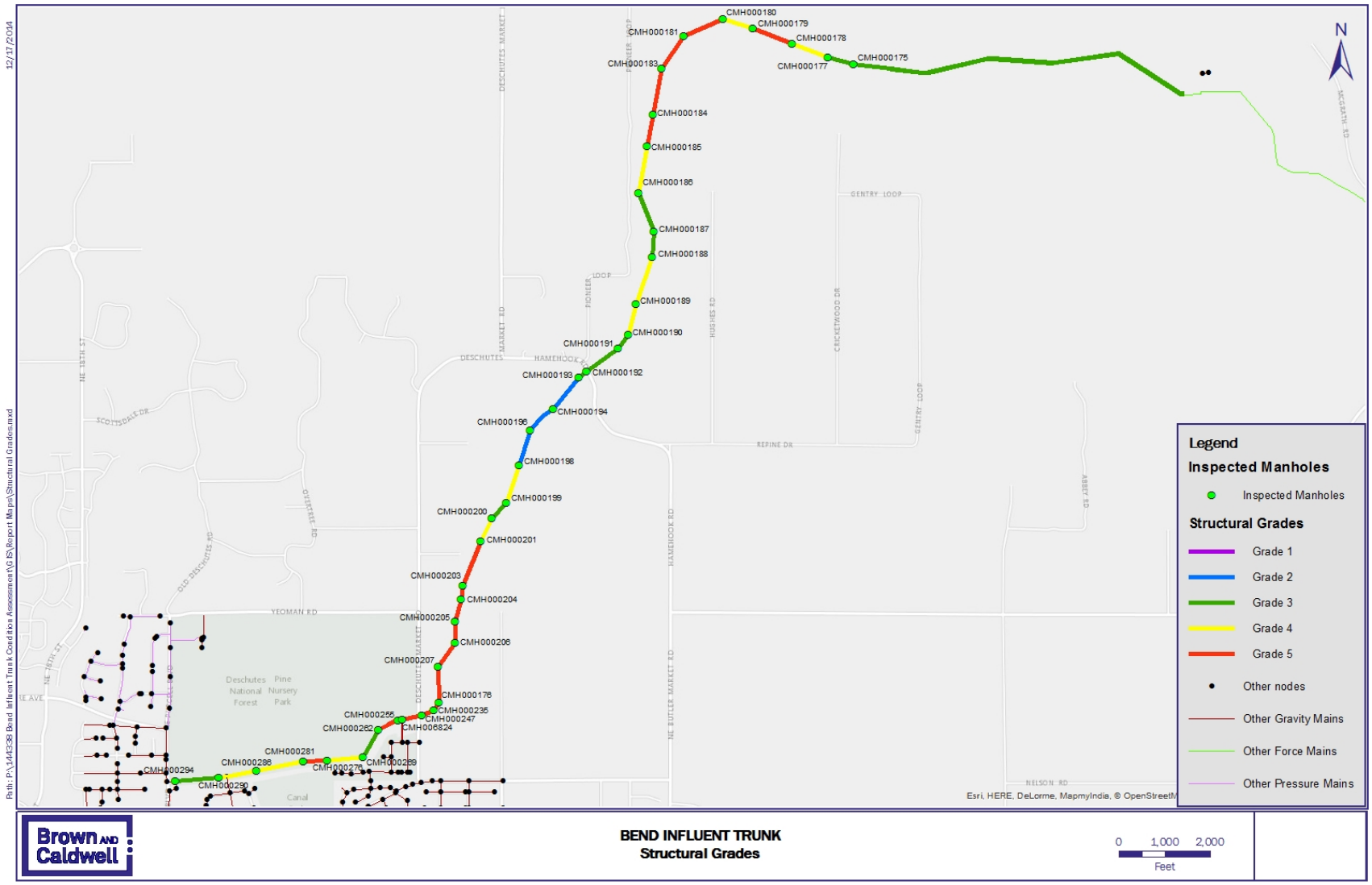

Figure 3-1. Structural grades for the PI

The results of the sonar inspection for the 21-inch barrel are shown in Figure 3-2. The blue line represents the crown of the pipe and the red line represents the pipe channel. The blue line appears continuous at 21 inches along the crown of the pipe indicating that there are no structural defects and the 21-inch barrel is completely full. The red line oscillates indicating buildup or debris accumulation along the floor of the pipe.

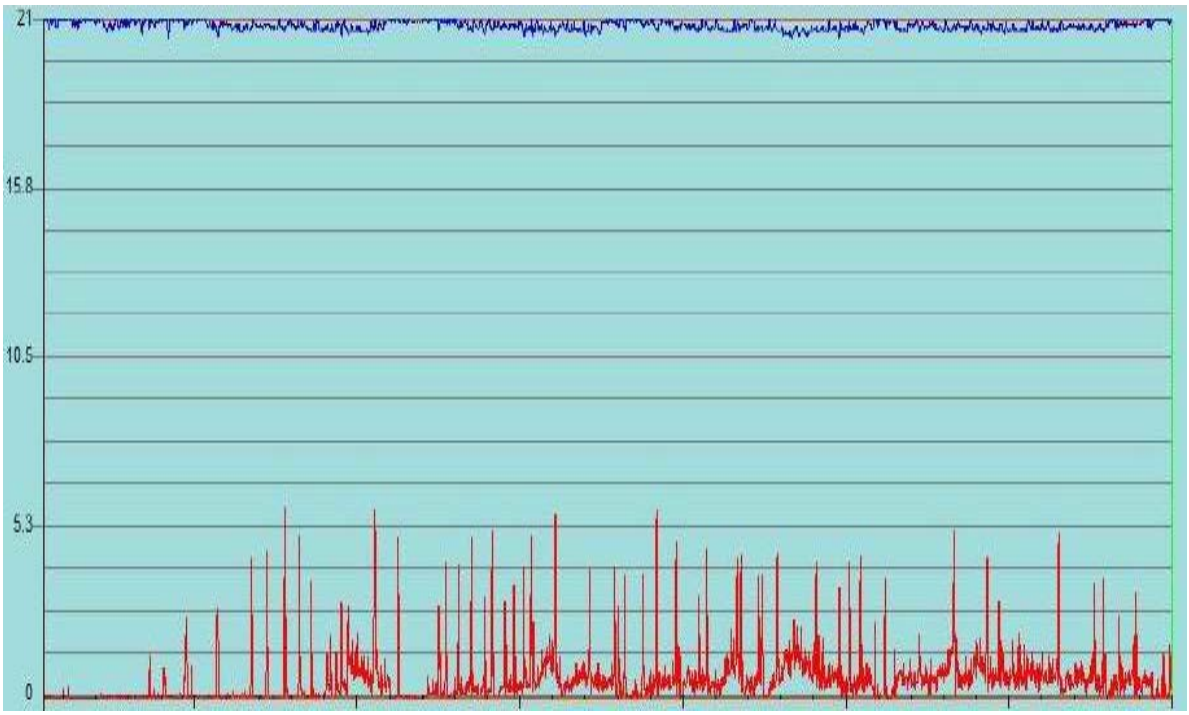

Figure 3-2. Sonar inspection of the 21-inch siphon barrel

Figure 3-3 shows examples of the cross-sections in the 21-inch barrel. In some locations the debris accumulation is as great as several inches, reducing the hydraulic capacity of the pipe by as much as 25 percent.

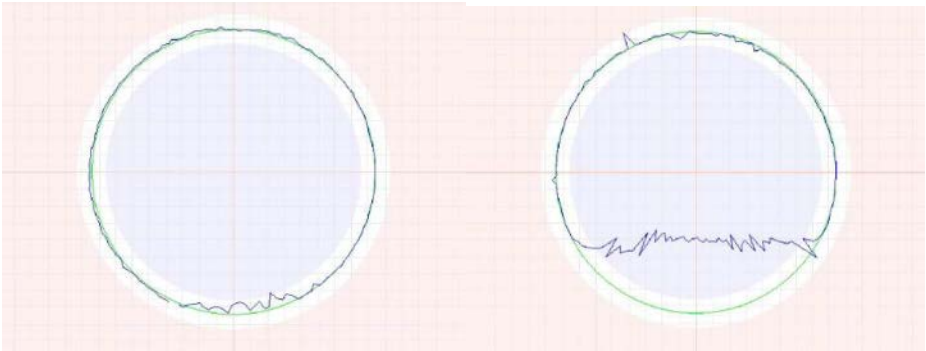

Figure 3-3. Sonar cross-sections of the 21-inch siphon barrel

The sonar data for the 36-inch barrel is much different than it is for the 21-inch siphon barrel. At the upper end of the siphon barrel between 11 and 455 LF, the pipe was not fully submerged due to its configuration and because the WRF opened up the primary screens to pass the maximum amount of

flow during the sonar inspections. Just after 455 LF, debris accumulation on the floor of the pipe is approximately 14.5 inches. However, from 2,600 to 3,200 LF, there is significant loss of hydraulic capacity due to either grease accumulation or air pockets at the crown of the 36-inch siphon barrel. From about 4,000 LF onward in the lower end of the siphon barrel (as-builts indicate that this is on the WRF side of the Main Canal crossing), the blue and red lines oscillate erratically. This is because grease and debris were loosened during passage of the sonar probes and most likely interfered or weakened the sonar signal.

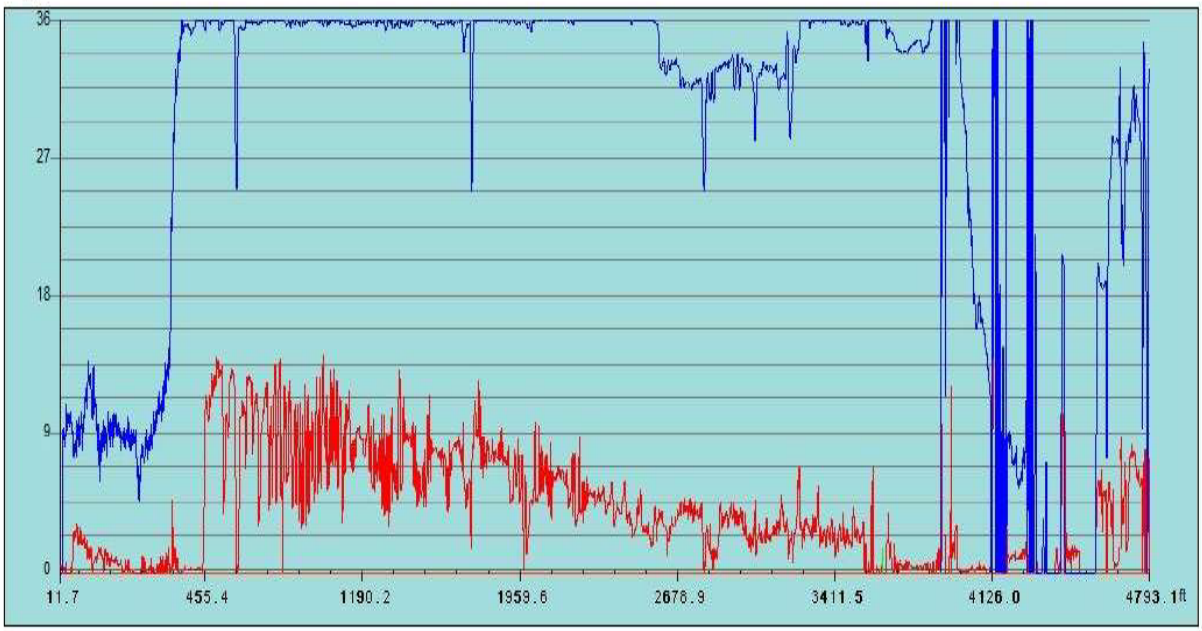

Figure 3-4. Sonar inspection of the 36-inch siphon

Figure 3-5 shows examples of the cross sections in the 36-inch barrel. However, significant hydraulic restrictions exist due to the accumulation of grease and debris.

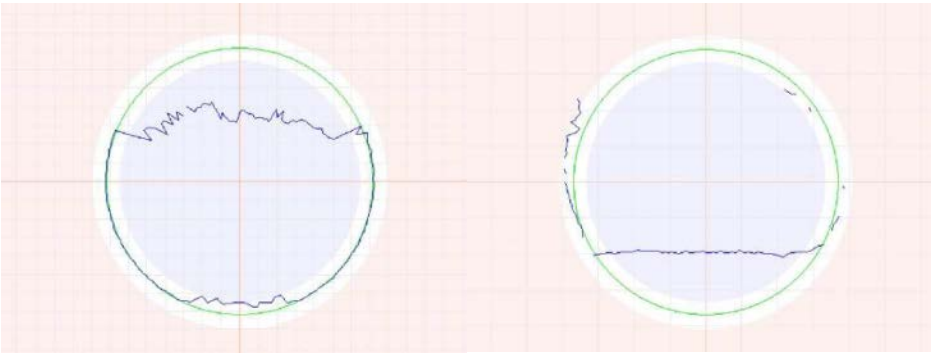

Figure 3-5. Sonar cross-sections of the 36-inch siphon barrel

Operationally, the gravity portion of the PI did not exhibit any significant operational defects. There was only minor debris detected by the sonar probe, and only a few instances of infiltration, roots, or other operational defects. Figure 3-6 summarizes the operational condition grades of the PI.

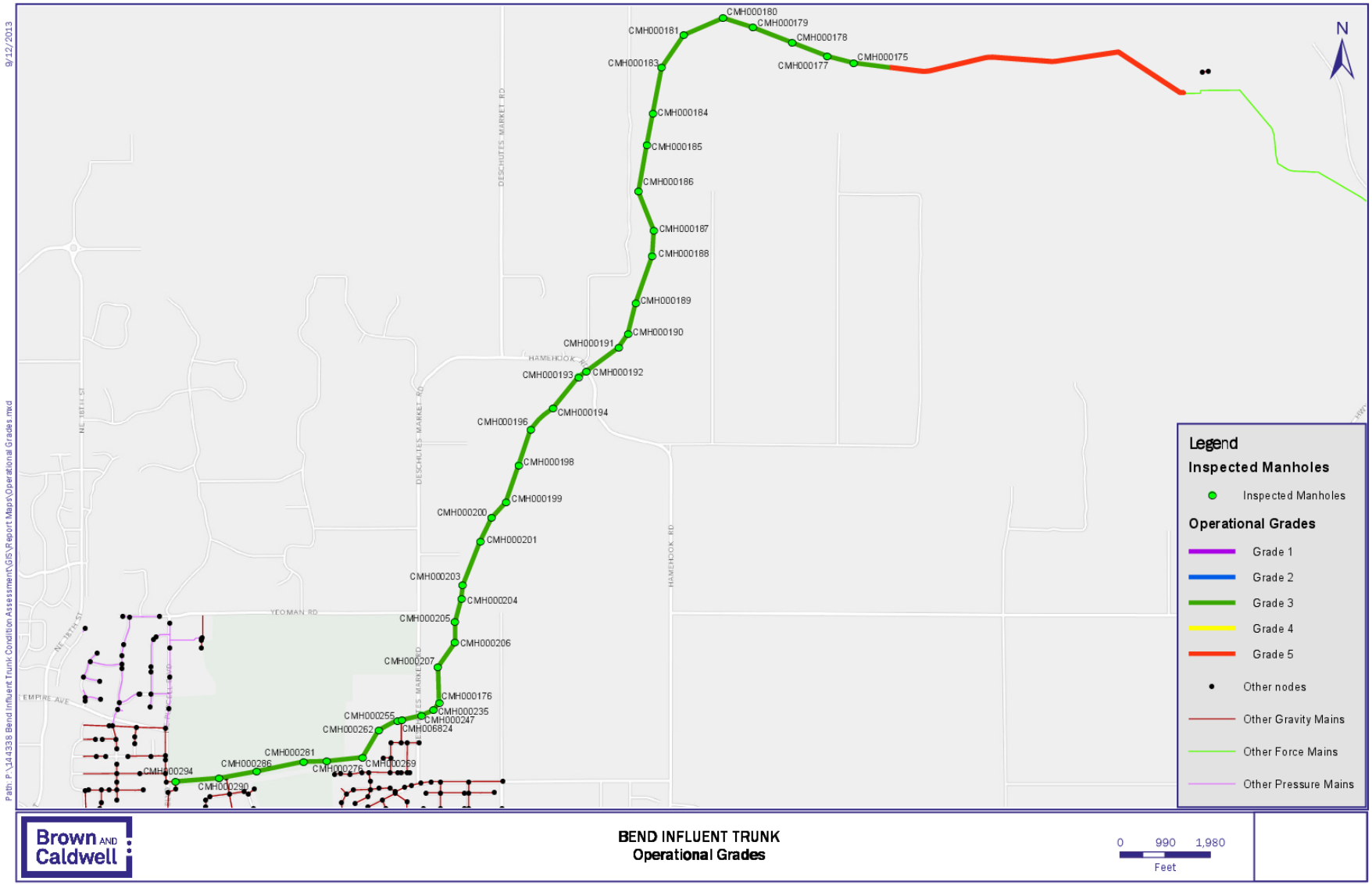

Figure 3-6. Operational grades for the PI

3.3 Manholes

Each manhole was inspected by digital scanning to obtain a visual record and inspected by man-entry to perform scrape and hardness tests to determine the relative competency of the concrete. Manhole scrapes were conducted at three clock positions at three different vertical points in each manhole (top, middle, and bottom) and the depth of the scrape is measured in 1/8-inch increments. Scrape photos are shown in Figure 3-7. Manholes were assessed using a simplified version of NASSCO's Manhole Assessment Certification Program (MACP). Gross defects were noted. Manhole inspection reports are included in Appendix F.

Figure 3-7. Scrape test results

While these tests seem rudimentary, they provide crucial knowledge of the competency of the concrete within the manholes. The results are summarized in Table 3-3. The majority of manholes were in good to fair structural condition; only ten had scrapes equal to or greater than 1/4-inch in depth. The siphon junction structure was in fair structural condition. The inner cement layer is beginning to corrode away with aggregate becoming visible. The presence of the ventilation stacks most likely helped limit the rate of corrosion; removal of these stacks will likely accelerate the rate of deterioration of the concrete.

Table 3-3. Summary of Manhole Scrape Test Results

Maximum depths, inch	Structural condition grade	No. of manholes
0	2	6
1/8	3	24
1/4	4	8
1/2	5	1
1	5	1

Table 3-4 contains detailed PI inspection results and Table 3-5 contains detailed manhole scrape test results.

Figure 3-8 summarizes the overall structural grades of the PI, including manholes Figures 3-9 through 3-50 show pipe inspection video screen shots.

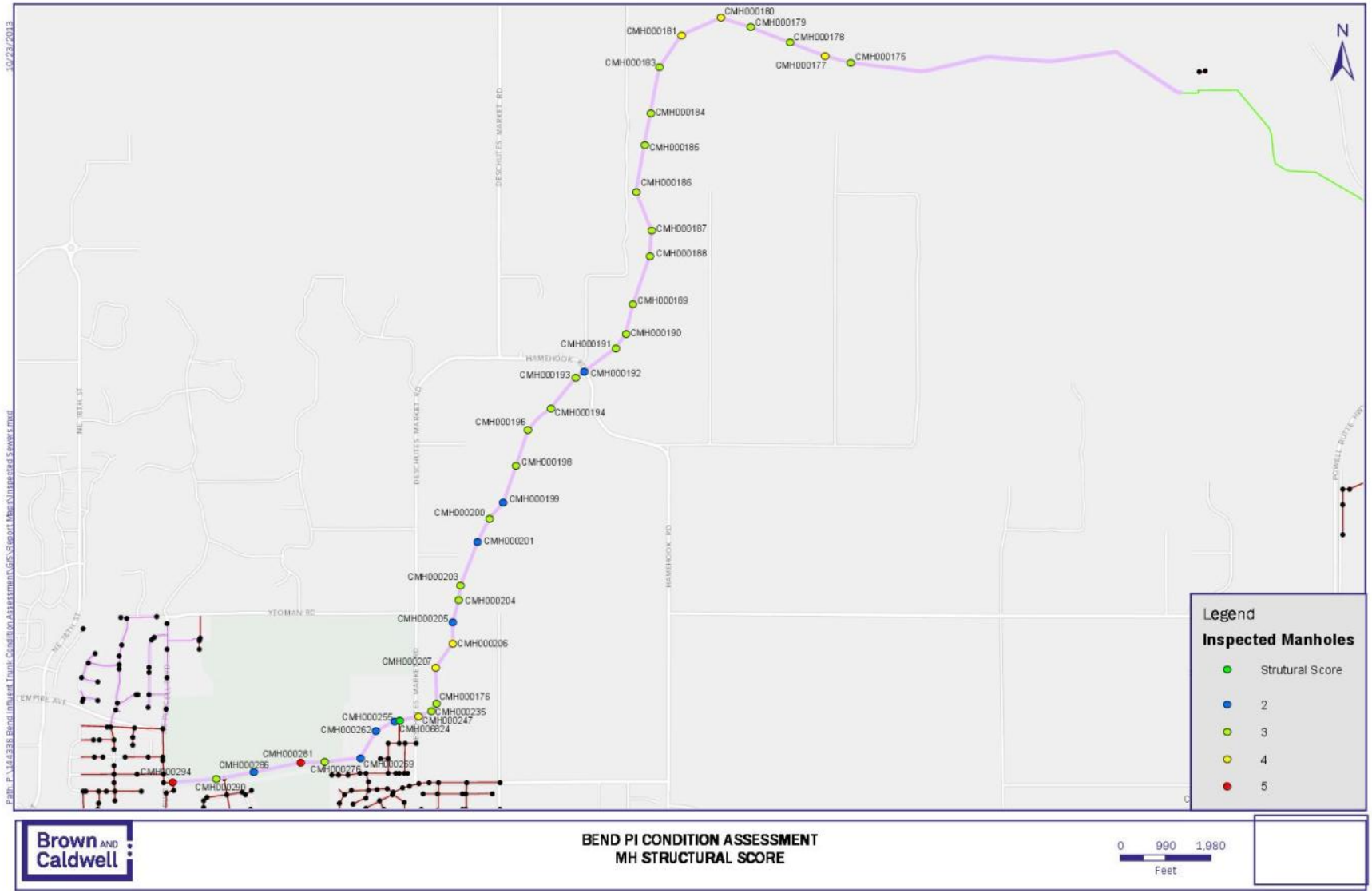

Figure 3-8. Manhole structural score

Table 3-4. PI Inspection Results

US MH	DS MH	Diameter, inches	Material	CCTV length, LF	GIS length, LF	Structural condition grade		Operational condition			
						Structural grade	Structural defect summary	Grade	Defect summary	Max corrosion, inches	Max debris accumulation, inches
CMH000294	CMH000290	42	RCP	690	686	3	SAV from 83 to 372 LF	2	Deposits attached grease throughout	0.91	2.82
CMH000290	CMH000286	42	RCP	607	604	4	Surface roughness increased throughout; SRV at 120 LF (exposed rebar at tap)	2	Tap break in intruding	0.8	1.9
CMH000286	CMH000281	42	RCP	766	757	4	SAM at 436 LF; SAV at 152 and 411 LF	2	Deposits attached grease throughout	0.98	0.31
CMH000281	CMH000276	36	RCP	377	373	5	SRV at 72, 103, 165 to 180, 196 to 203, 243 to 252 and 269to 306 LF	2	Deposits attached grease throughout	1.23	0.25
CMH000276	CMH000269	36	RCP	578	568	4	SRV at 144 and 236 to 247	2	Deposits attached grease throughout	1.54	0.21
CMH000269	CMH000262	36	RCP	497	491	3	16 instances of SAV from 2 to 432 LF	2	Deposits attached grease throughout	2.15	0.17
CMH000262	CMH000255	36	RCP	331	334	5	SRV at 55 to 83, 217 to 224,and 269 LF	2	Deposits attached grease throughout	1.27	0.27
CMH000255	CMH000255A	36	RCP	73	0	5	SRV at 48 to 69 LF	2	Deposits attached grease throughout	1.16	0.21
CMH000255A	CMH000247	36	RCP	319	0	5	SRV at 34, 62, 98 to 106, 109 to 118, and 145 to 161 LF	2	Deposits attached grease throughout	1.34	0
CMH000247	CMH000235	36	RCP	209	212	5	SRV at 135 and 147 to 153 LF	2	Deposits attached grease throughout	0.71	0.2
CMH000235	CMH000176	36	RCP	144	147	5	SRV at 34 to 49 and 96 to 134 LF	2	Deposits attached grease throughout	0.79	0.7
CMH000176	CMH000207	30	RCP	560	561	5	15 instances of SRV from 51 to 504 LF	2	Deposits attached grease throughout	0.93	0.38
CMH000207	CMH000206	30	RCP	467	467	5	SRV at 25, 55 to 72, 124 to 139, and 220 to 261 LF	2	Deposits attached grease throughout	1.61	0
CMH000206	CMH000205	36	RCP	326	325	5	SRV at 116 to 131, 163, 210, 236 to 245, and 284 to 321 LF	2	Deposits attached grease throughout	1.75	0.4
CMH000205	CMH000204	36	RCP	371	372	5	SRV at 7, 17, 30 to 133, and 362 to 369 LF	2	Deposits attached grease throughout	1.39	0.28
CMH000204	CMH000203	36	RCP	218	218	5	SRV at 22 to 67and 113 LF	2	Deposits attached grease throughout	1.24	0
CMH000203	CMH000201	36	RCP	733	740	5	SRV at 336 to 344, 375 to 387, 400 to 425, 555 to 573, 627 to 646, 669 to 674 and 689 LF	2	Deposits attached grease throughout	1.29	0.2
CMH000201	CMH000200	36	RCP	409	410	4	SRV at 128 LF	2	Deposits attached grease throughout	1.18	0.54
CMH000200	CMH000199	36	RCP	331	331	3	SAV at 7 LF	2	Deposits attached grease throughout	1.25	0.39
CMH000199	CMH000198	42	RCP	622	619	4	SRV at 212 to 222 LF	2	Deposits attached grease throughout	0.91	0.38
CMH000198	CMH000196	42	RCP	591	589	2	Crack longitudinal (CL) at 163, 509, and567 to 578 LF	2	Deposits attached grease throughout	0.93	0.43
CMH000196	CMH000194	42	RCP	491	492	2	CL at 209 to 214 and 401 to 408 LF	2	Deposits attached grease throughout	1.25	1.61
CMH000194	CMH000193	42	RCP	635	632	2	Surface spalling at 373, 392 to 396 LF	2	Deposits attached grease throughout	0.66	0.18
CMH000193	CMH000192	42	RCP	160	161	3	SAV at 4 to 157 LF	2	Deposits attached grease throughout	1.29	0
CMH000192	CMH000191	42	RCP	620	621	3	SAV at 11 to 618 LF	2	Deposits attached grease throughout	0.7	0
CMH000191	CMH000190	36	RCP	266	269	3	SAV at 52 to 60, 63 to 68, 78 to 90, 99 to 104, and 117 to 258 LF	2	Deposits attached grease throughout	1.47	0
CMH000190	CMH000189	36	RCP	490	487	4	SRV at 1 LF; 14 instances of SAV from 2 to 481 LF	2	Deposits attached grease throughout	1.48	0
CMH000189	CMH000188	36	RCP	799	795	4	SRV at 491, 551 to 561, and 644 LF	2	Deposits attached grease throughout	1.6	0.41
CMH000188	CMH000187	36	RCP	406	403	3	18 instances of SAV from 1 to 400 LF	2	Deposits attached grease throughout	1.19	0.23
CMH000187	CMH000186	36	RCP	658	652	3	12 instances of SAV from 1 to 644 LF	2	Deposits attached grease throughout	1.5	0
CMH000186	CMH000185	36	RCP	758	750	4	SRV at 483 and 750 LF; 10 instances of SAV from 7 to 366 LF	2	Deposits attached grease throughout	3.47	0.17
CMH000185	CMH000184	42	RCP	490	500	5	SRV at 99 to 115, 150 to157, 163 to 192, 235 to 244, 253 to 364, 372, and 385 to 445 LF	2	Deposits attached grease throughout	1.7	0.18
CMH000184	CMH000183	42	RCP	732	733	5	SRV at 17, 25, 30, 55 to 72, 124 to 139, and 220 to 261 LF	2	Deposits attached grease throughout	1.74	0
CMH000183	CMH000181	42	RCP	621	619	5	SRV at 133 to 189, 196, 196 to 212, 261, 286 to 354, 495, and 504 to 584 LF	2	Deposits attached grease throughout	1.58	0.44
CMH000181	CMH000180	42	RCP	677	677	5	SRV at 93 to 100, 126 to 157, 181 to 251, 611 LF	2	Deposits attached grease throughout	1.71	0.47
CMH000180	CMH000179	42	RCP	490	491	4	SRV at 362, 380 to 412, and 450 to 463 LF	2	Deposits attached grease throughout	1.77	0.31
CMH000179	CMH000178	42	RCP	671	668	5	10 instances of SRV with defect lengths of 10 to 15 LF in each instance	2	Deposits attached grease throughout	1.5	0.3
CMH000178	CMH000177	36	RCP	593	595	4	SRV at 4 to 16 LF	2	Deposits attached grease throughout	1.79	0
CMH000177	CMH000175	36	RCP	421	418	3	SAV at 0 to 416 LF	2	Deposits attached grease throughout	1.7	0.19
CMH000175	CSS000001	36	RCP	578	0	3	SAV at 0 to 576 LF	2	Deposits attached grease throughout	1.58	0.47
CSS000001	WRF intertie box	36	RCP	4751	0	2	No defects noted	5	Heavy deposits attached / settled	NA	13
CSS000001	WRF intertie box	21	RCP	4785	0	2	No defects noted	5	Heavy deposits attached / settled	NA	6

Table 3-5. Manhole Scrape Tests Details

MH	Depth	Median	Max	Rehabilitation recommendation	MH structural grade
CMH000294	7'6"	3/4"	1"	Structural fiber reinforced cementitious liner	5
CMH000290	6'4"	0	1/8"	None	3
CMH000286	7'9"	0	0	None	2
CMH000281	4'6"	1/8"	1/2"	Epoxy coating	5
CMH000276	8'	0	1/8"	None	3
CMH000269	4'6"	0	0	None	2
CMH000262				None	2
CMH000255				Epoxy coating	2
CMH000255A				Epoxy coating	2
CMH000247	5'4"	0	1/4"	None	4
CMH000235	4'	1/8"	1/8"	Epoxy coating	3
CMH000176	3'	1/8"	1/8"	Epoxy coating	3
CMH000207	3'8"	1/8"	1/4"	Epoxy coating	4
CMH000206	5'6"	1/8"	1/4"	Epoxy coating	4
CMH000205	3'	0	0	Epoxy coating	2
CMH000204	3'	0	1/8"	Epoxy coating	3
CMH000203	6'	1/8"	1/8"	Epoxy coating	3
CMH000201	3'	0	0	None	2
CMH000200	3'6"	1/8"	1/8"	None	3
CMH000199	2'6"	0	0	None	2
CMH000198	5'	0	1/8"	None	3
CMH000196	6'	1/8"	1/8"	None	3
CMH000194	5'	0	1/8"	None	3
CMH000193	4'	1/8"	1/8"	None	3
CMH000192	6'	0	0	None	2
CMH000191	4'	0	1/8"	None	3
CMH000190	4'	1/8"	1/8"	None	3
CMH000189	8'	0	1/8"	None	3
CMH000188	4'	0	1/8"	None	3
CMH000187	7'	1/8"	1/8"	None	3
CMH000186	8'	1/8"	1/8"	None	3
CMH000185	4'	1/8"	1/8"	Epoxy coating	3
CMH000184	4'	1/8"	1/8"	Epoxy coating	3
CMH000183	5'	0	1/8"	Epoxy coating	3
CMH000181	3'	1/8"	1/4"	Epoxy coating	4
CMH000180	4'	1/8"	1/4"	None	4
CMH000179	7'	0	1/8"	None	3
CMH000178	4'	1/8"	1/8"	None	3
CMH000177	4'	1/8"	1/4"	None	4
CMH000175	4'	1/8"	1/8"	None	3
Siphon out - 36"	8.5'	-	1/8"		3
Siphon out - 21"	9'	-	1/4"		4
Siphon in	8'	-	1/4"		4

Figure 3-9. Grade 1 surface roughness increased

Figure 3-10. MH CMH000290 to CMH000286 (SRV next to Tap)

Figure 3-11. Grade 2 surface spalling

Figure 3-12. MH CMH000286 to CMH000281 (SAM)

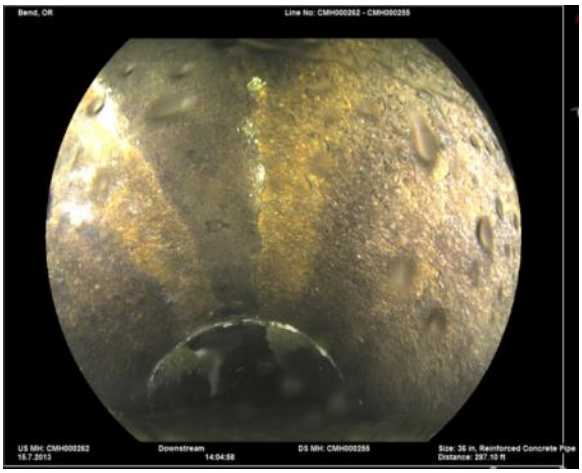

Figure 3-13. Grade 3 SAV

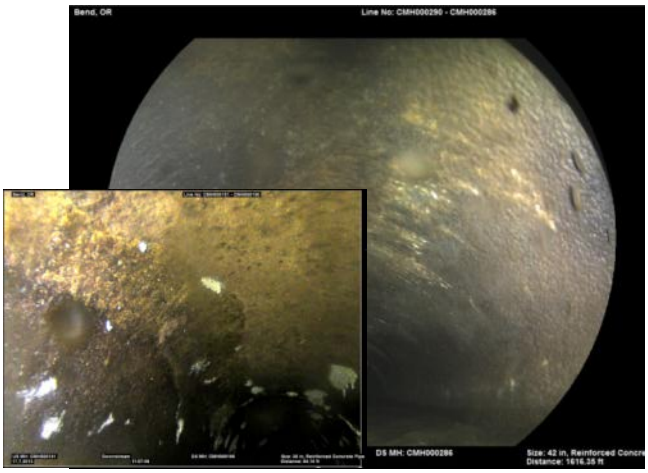

Figure 3-14. MH CMH000281 to CMH000276 (SRV)

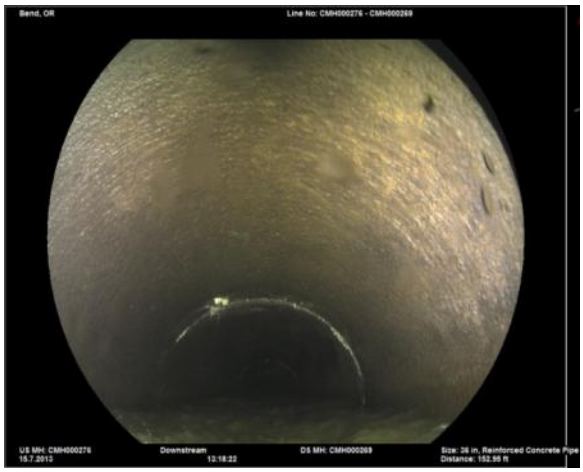

Figure 3-15. MH CMH000276 to CMH000269 (SRV)

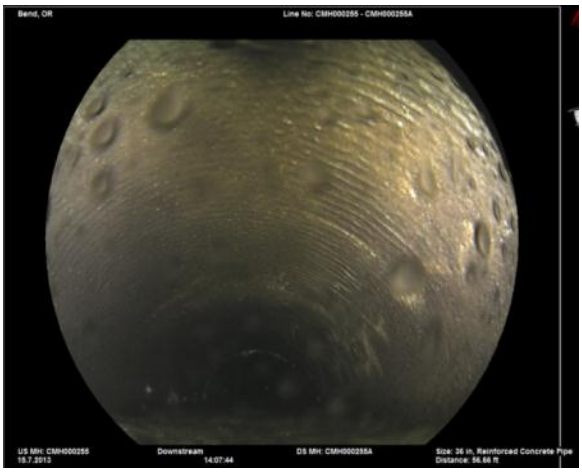

Figure 3-16. MH CMH000255 to CMH000255A (SRV)

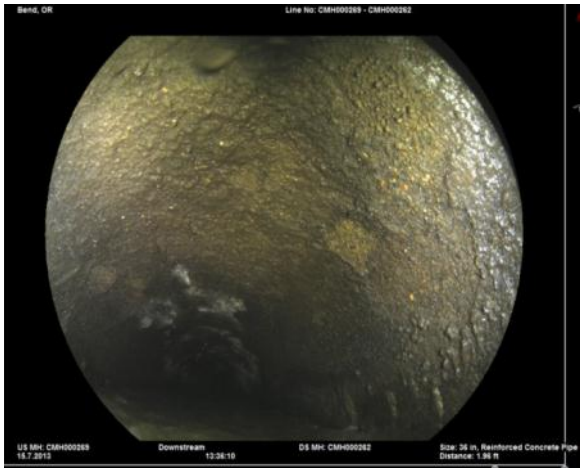

Figure 3-17. MH CMH000269 to CMH000262 (SAV)

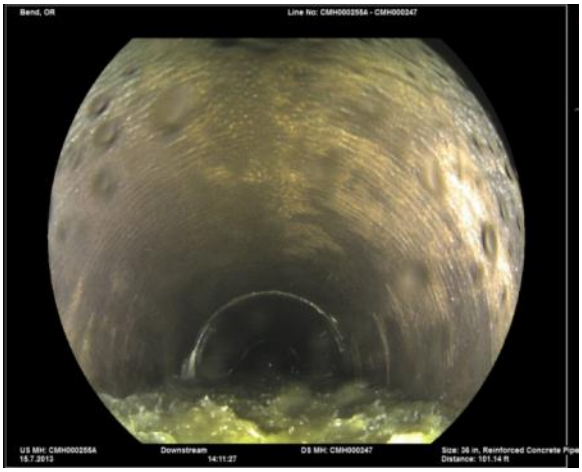

Figure 3-18. MH CMH000255A to CMH000247 (SRV)

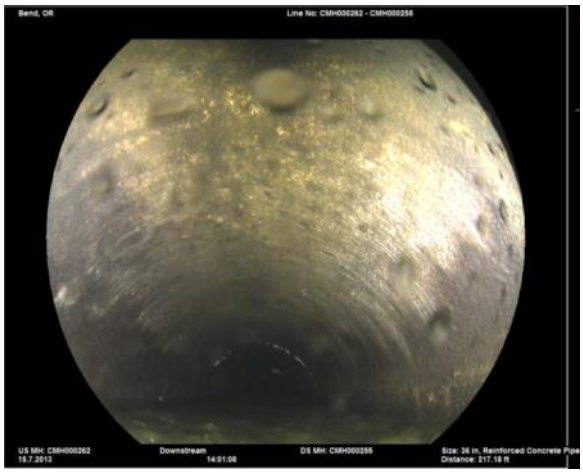

Figure 3-19. MH CMH000262 to CMH000255 (SRV)

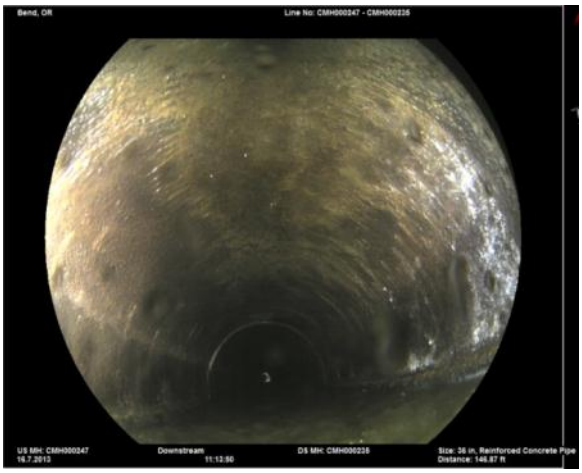

Figure 3-20. MH CMH000247 to CMH000235 (SRV)

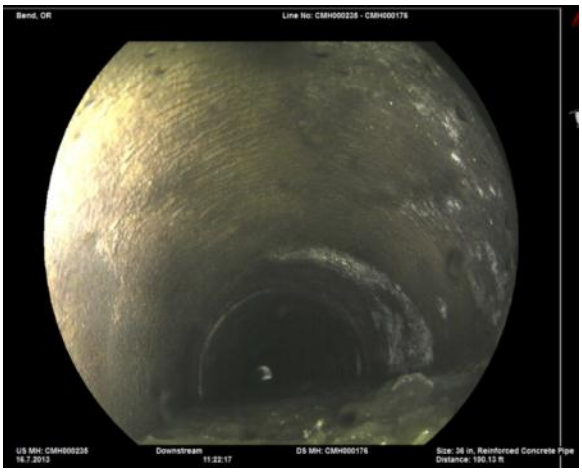

Figure 3-21. MH CMH000235 to CMH000176 (SRV)

Figure 3-22. MH CMH000206 to CMH000205 (SRV)

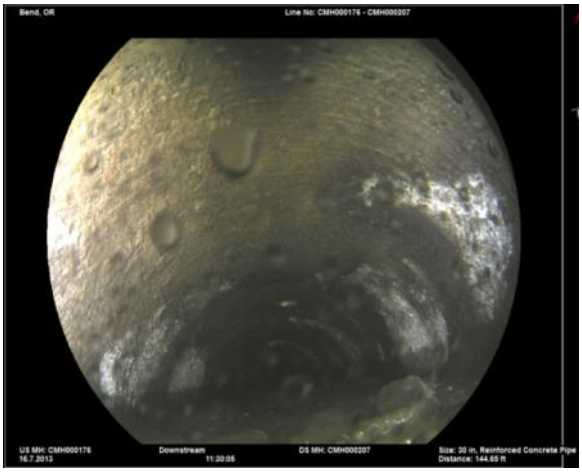

Figure 3-23. MH CMH000176 to CMH000207 (SRV)

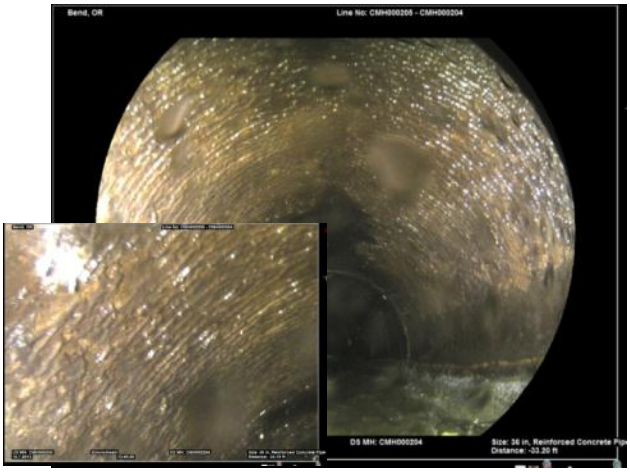

Figure 3-24. MH CMH000205 to CMH000204 SRV

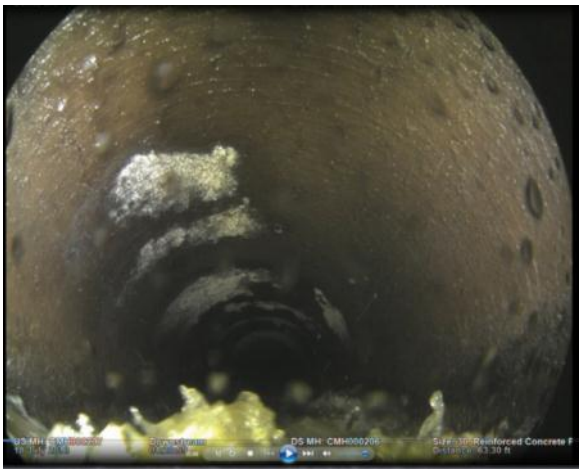

Figure 3-25. MH CMH000207 to CMH000206 (SRV)

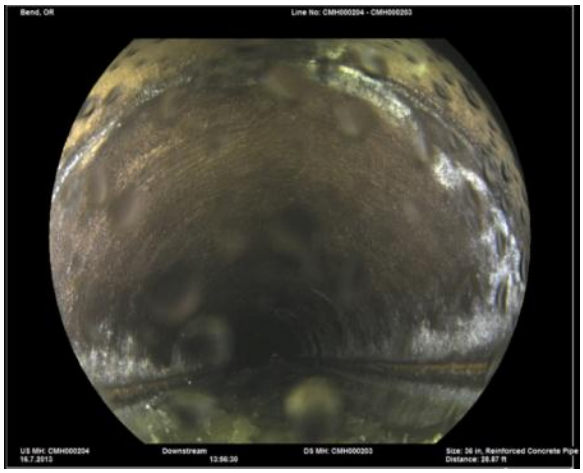

Figure 3-26. MH CMH000204 to CMH000203 SRV

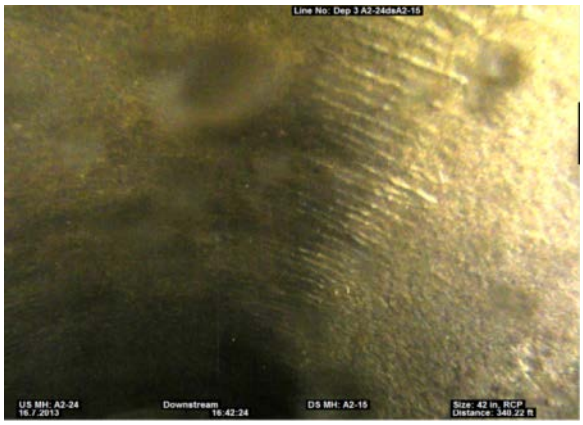

Figure 3-27. MH CMH000203 to CMH000201 SRV

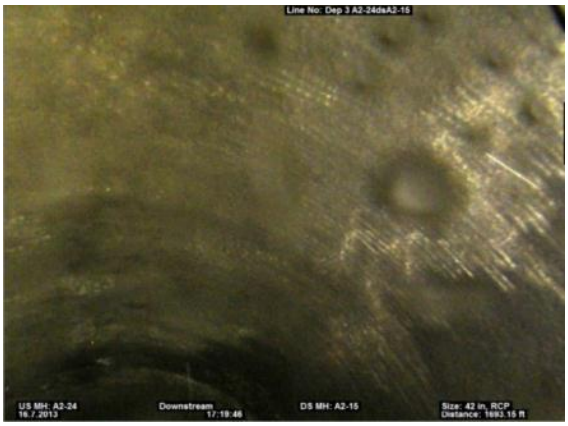

Figure 3-28. MH CMH000199 to CMH000198 SRV

Figure 3-29. MH CMH000201 to CMH000200 SRV

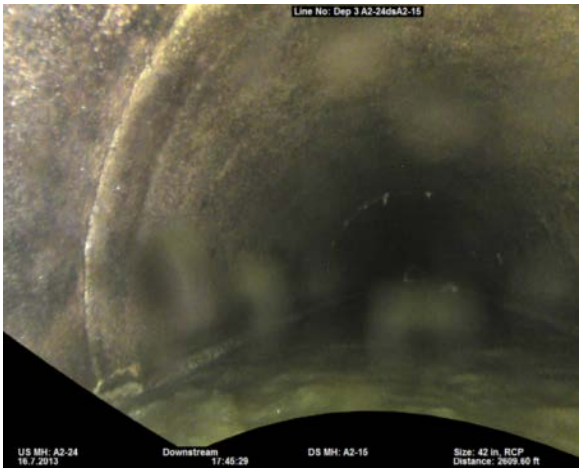

Figure 3-20. MH CMH000198 to CMH000196 CC

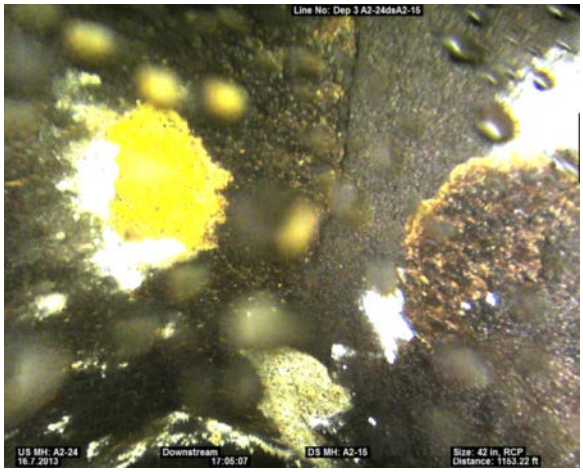

Figure 3-31. MH CMH000200 to CMH000199 SAV

Figure 3-32. MH CMH000196 to CMH000194 CL

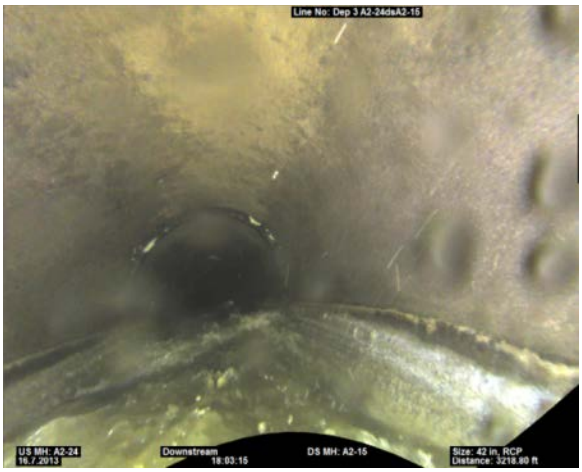

Figure 3-33. MH CMH000194 to CMH000193 (SRI)

Figure 3-34. MH CMH000191 to CMH000190 (SAV)

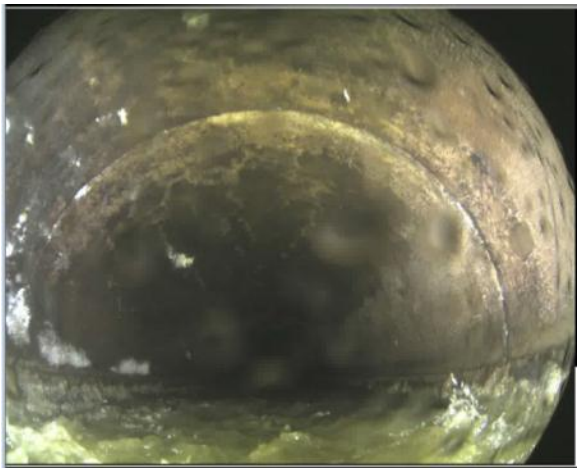

Figure 3-35. MH CMH000193 to CMH000192 (SAV)

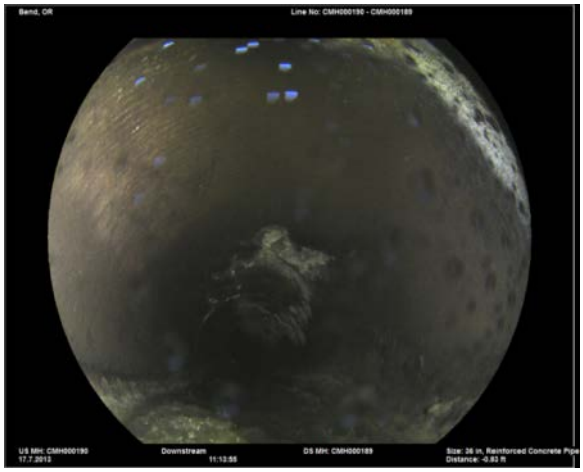

Figure 3-36. MH CMH000190 to CMH000189 (SRV)

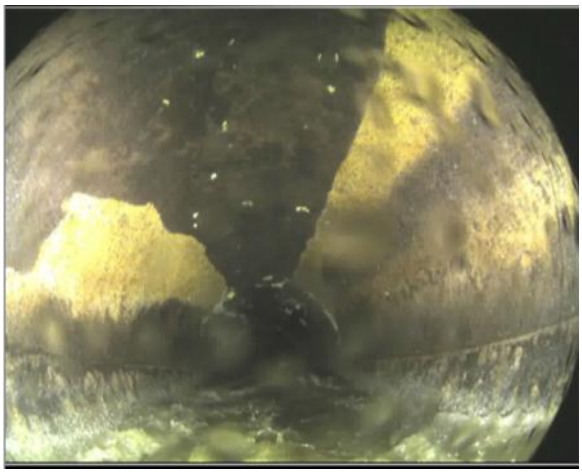

Figure 3-37. MH CMH000192 to CMH000191 (SAV)

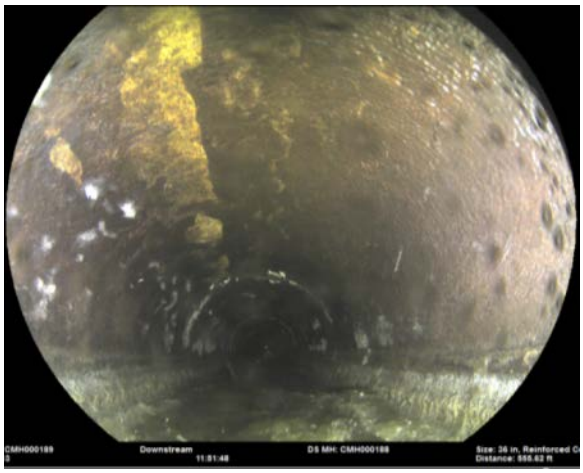

Figure 3-38. MH CMH000189 to CMH000188 SRV

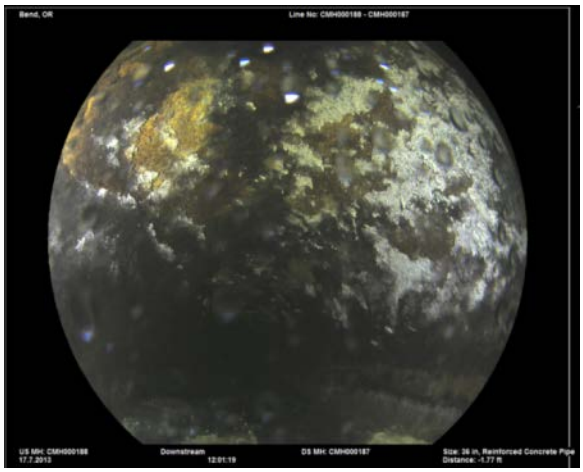

Figure 3-39. MH CMH000188 to CMH000187 SAV

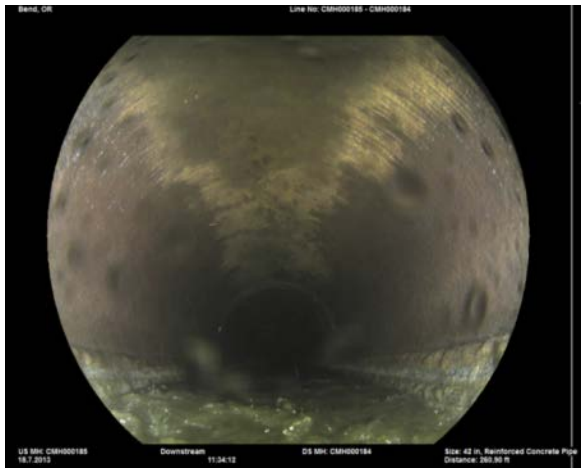

Figure 3-40. MH CMH000185 to CMH000184 (SRV)

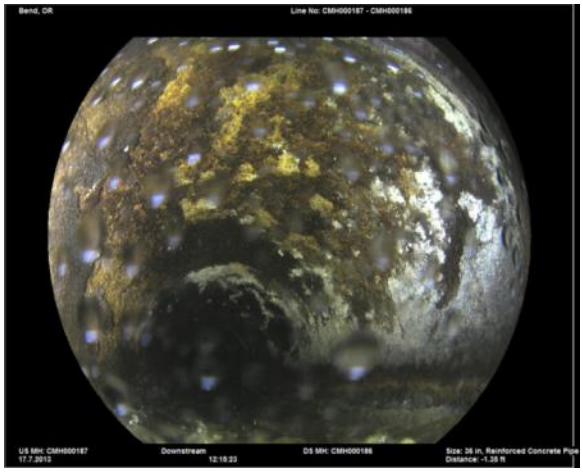

Figure 3-41. MH CMH000187 to CMH000186 SAV

Figure 3-42. MH CMH000184 to CMH000183 (SRV)

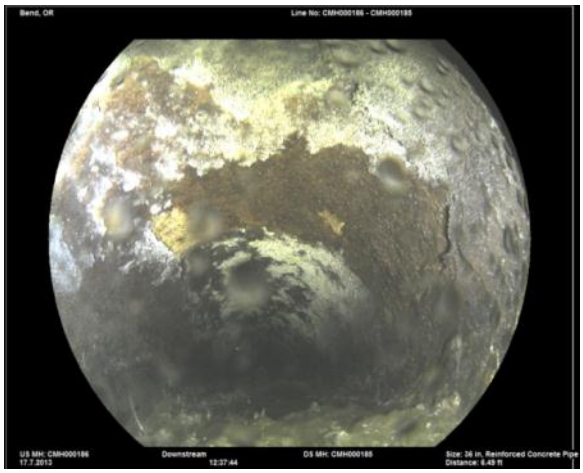

Figure 3-43. MH CMH000186 to CMH000185 SAV

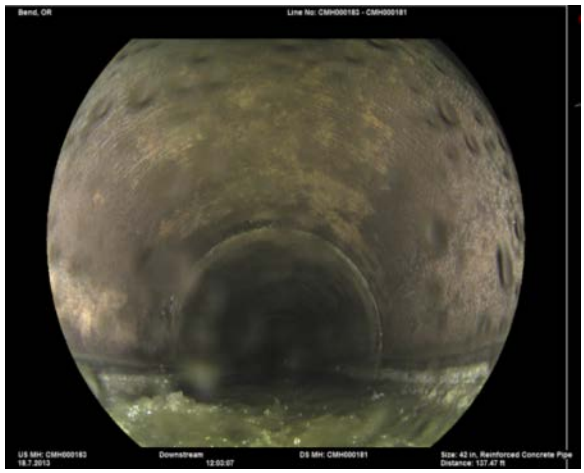

Figure 3-44. MH CMH000183 to CMH000181 (SRV)

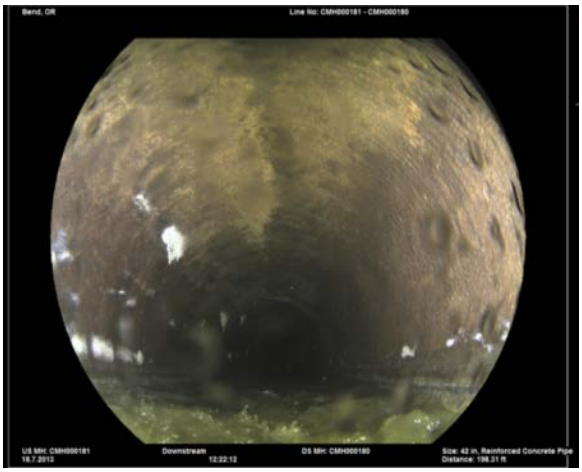

Figure 3-45. MH CMH000181 to CMH000180 (SRV)

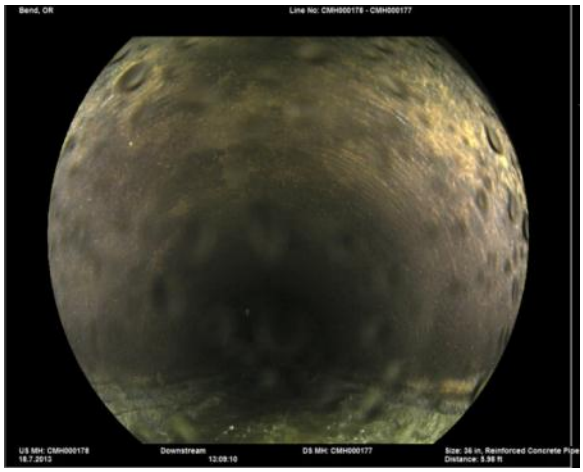

Figure 3-46. MH CMH000178 to CMH000177 (SRV)

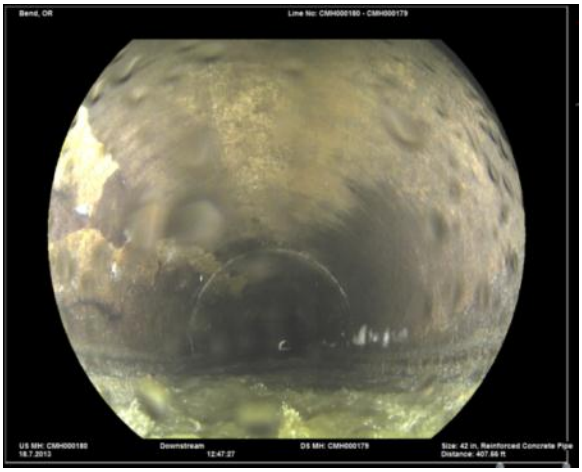

Figure 3-47. MH CMH000180 to CMH000179 (SRV)

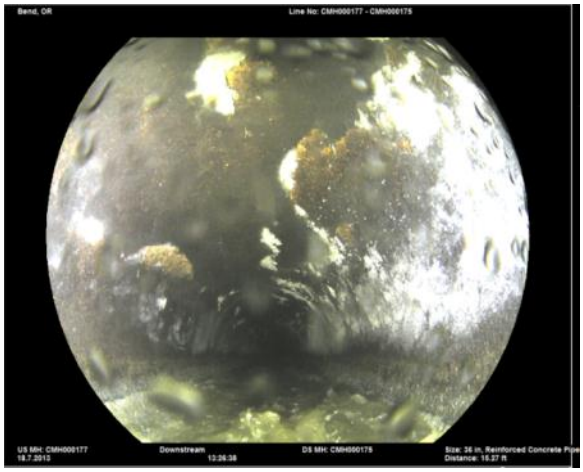

Figure 3-48. MH CMH000177 to CMH000175 (SAV)

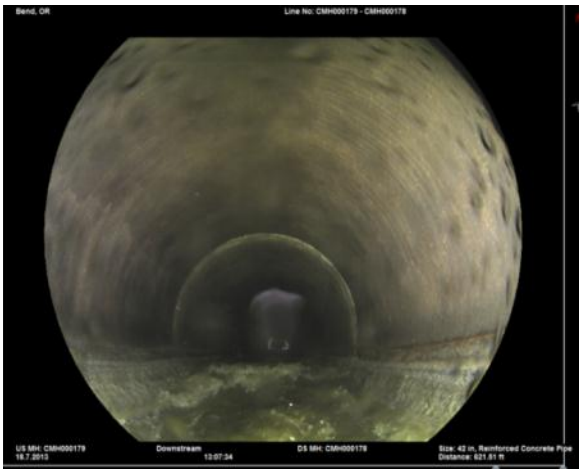

Figure 3-49. MH CMH000179 to CMH000178 (SRV)

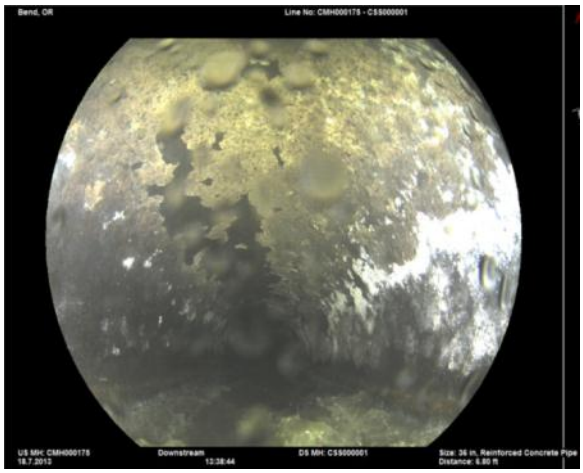

Figure 3-50. MH CMH000175 to CSS00001 (SAV)

Section 4

Corrosion Control

The primary cause for the defects found within the gravity portion of the Plant Interceptor (PI) is exposure of the pipe surface to corrosive air. Factors leading to the production and mitigation of this corrosive environment are discussed below.

4.1 Hydrogen Sulfide Production

The sulfate ion $(SO_4)^{2-}$ is one of the most prevalent anions occurring in natural waters. $(SO_4)^{2-}$ is biochemically reduced by bacteria residing in the so-called slime layer that forms along the wetted perimeter of a sanitary sewer pipe. Once reduced, sulfate is converted to hydrogen sulfide (H_2S), a highly corrosive compound.

When the dissolved oxygen level is below approximately 1.0 milligram per liter (mg/L), as it is in most municipal waste streams, sulfate reduction to liquid sulfide will occur. Sulfate is present in abundance in most municipal waste streams. Sulfate reduction is performed by bacteria residing in the slime layer that lies beneath the wastewater surface on the inside wall of the sewer pipe or wet well. Figure 4-1 illustrates this phenomenon (Figure 4-1 indicates sulfate reduction will occur at a DO less than 1.0 mg/L; newer information indicates this is an overly conservative number and sulfate reduction occurs even when DO is at 1.0 mg/L).

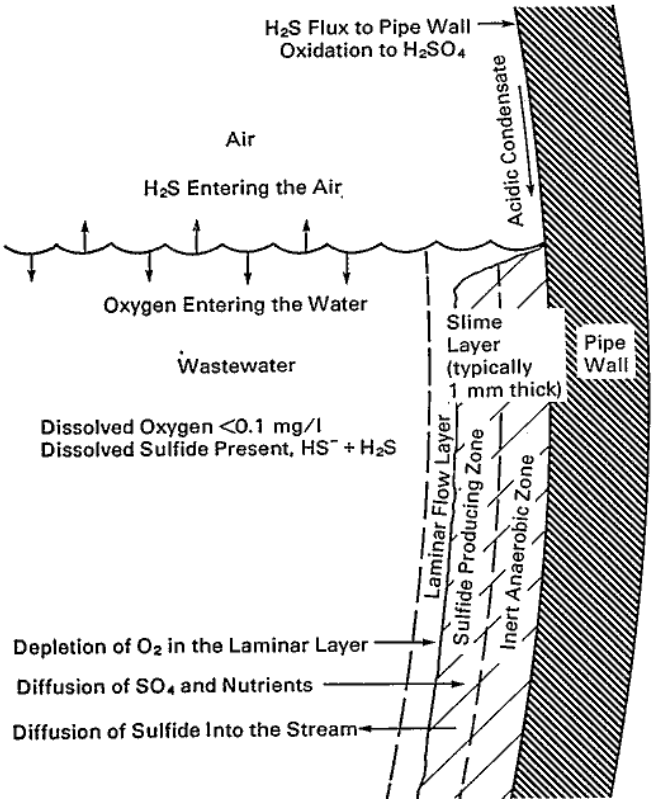

Figure 4-1. Formation of H_2S in the slime layer

The reduced sulfate exists as sulfide (S^{2-}), bi-sulfide (HS^-), and H_2S in varying concentrations, depending on the pH of the wastewater. For example, between a pH of 8 and 10, most of the reduced sulfate exists as S^{2-} and HS^-. At a pH equal to or below 7.1, the reduced sulfate exists as HS^- and H_2S. Figure 4-2 shows a chart of the percentage of each constituent as a function of wastewater pH.

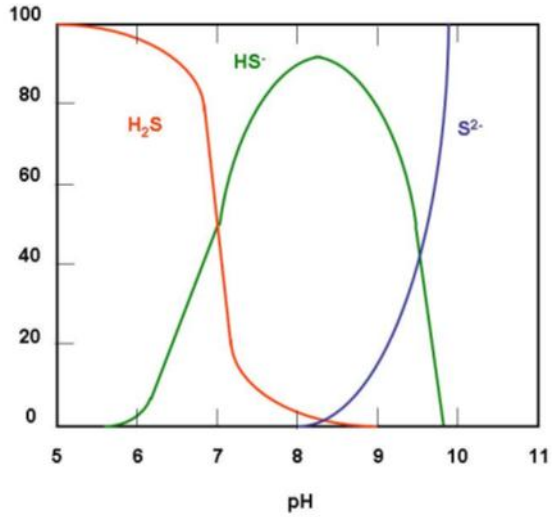

Figure 4-2. Percentage of each sulfur constituent as a function of pH

When H_2S is stripped from raw wastewater to the gas phase, it is oxidized to corrosion-inducing sulfuric acid (H_2SO_4) by bacteria, *Thiobacillus thiooxidans*, that reside in a very thin water layer on the exposed surfaces of pipes and structures. When these bacteria are deprived of either the moist surface or the gas phase H_2S from which they draw their energy, they fail to thrive and associated concrete corrosion on exposed surfaces can be significantly reduced.

Given this set of conditions, it then becomes possible to induce this reduction in concrete corrosion rates by reducing the amount of sulfide produced in the liquid phase and/or by drying the exposed concrete surfaces by means of forced-air ventilation. The following discussion provides a summary of liquid and gas phase modeling and analysis done towards these ends for the Bend Influent Trunk Sewer.

4.2 Liquid Phase Sulfide Control

A sulfide generation model was developed for the PI. This model is based on the physical characteristics of the Bend Influent Trunk Sewer and sulfide generation equations developed by Pomeroy and Parkhurst for sulfide generation in gravity sewer systems as documented in the U.S. Environmental Protection Agency's publication EPA/625/1-85/018, "Odor and Corrosion Control in Sanitary Sewerage Systems and Treatment Plants." The following wastewater characteristic input parameters were used to develop the model:

- Upstream [S^{2-}] at MH CMH000294 = 0.5 mg/L
- Average wastewater flow = 5.73 million gallons per day (mgd)
- Biochemical oxygen demand = 250 mg/L
- Wastewater temperature = 25 degrees Celsius
- Wastewater pH = 7.1

Under these conditions, the model predicted the following sulfide generation results:

- Resulting downstream [S_2-] at MH CMH000175 = 0.8 mg/L (60 percent increase from upstream to downstream)
- Resulting pounds of sulfide per day at 0.8 mg/L [S_2-] = 39.

This information was used to predict an average yearly cost for chemical feed to reduce the total sulfide concentration in the wastewater to non-detectable levels. Several chemicals were analyzed, including 60 percent calcium nitrate, 37 percent ferrous chloride and 39 percent ferric chloride. These chemicals were chosen for their proven effectiveness in similar applications and their relative safety. At this stage of analysis the average annual cost for the use of any one of these chemicals for this application is predicted to be approximately $200,000 per year. However with any liquid phase sulfide control measure, full-scale pilot testing would be necessary to verify the predicted chemical feed requirements. Such a system would be deployed in the upstream reaches of the influent sewer and carry a capital equipment cost of approximately $75,000.

4.3 Sewer Headspace Ventilation

Using the same sewer physical characteristic data, a second model was developed to predict the maximum expected airflow that is induced in the headspace by the flowing wastewater. The equations for this model are based on wastewater flow and corresponding induced dragged-headspace air velocity relationships observed and documented by Pescod and Price in “Major Factors in Sewer Ventilation,” (*Journal of the Water Pollution Control Federation*, April 1982). The following flow conditions were modeled to determine the predicted maximum induced headspace air flow:

- Average flow condition = 5.73 mgd
- 20 mgd
- 30 mgd

The maximum wastewater flow induced headspace airflow was predicted to be 650 cubic feet per minute (cfm). Applying a safety factor of 1.5 to this airflow value results in a forced air withdrawal ventilation requirement of approximately 1,000 cfm. Such a system, if coupled with an odor control device such as a biological scrubber or carbon adsorption system, typically carries capital equipment and annual operating costs of approximately $100,000 and $7,500, respectively.

To verify the effectiveness of a forced-air ventilation corrosion control solution along the entire alignment of the PI, a full-scale pilot test was implemented in the late summer of 2014. The test consisted of the deployment of a trailer-mounted 1,000-cfm fan that would withdraw air at the approximate midpoint of the sewer alignment, such as at manhole (MH) CMH 000194 and at the downstream end of the alignment, near the upstream end of the twin barrel siphons, at MH CMH000175. The purpose was to test the effectiveness of the fan at moving air through the headspace along the upstream half of the sewer from the two locations. The zone of influence of air withdrawal from each location was determined by differential air pressure responses to the air withdrawal by the fans. These responses were recorded by differential air pressure data loggers specially designed for the purpose and installed in manholes along the entire alignment. Clear air pressure reduction responses to fan ON/OFF conditions would indicate induced air movement in the headspace of the sewer that would result in dry pipe and manhole wall conditions in those sections of the sewer alignment. While no set of standards exist regarding the necessary air velocities or flow rates needed to dry the pipe, based on actual physical inspection projects where forced-air ventilation was being employed, 1000 cfm should be sufficient to dry out the pipe wall in the sewer head space.

Forced-air ventilation will not impact any aspect of the WRF, as the airflow will control corrosion in the exposed concrete in the gravity portion of the PI. The ventilation will not have any impact downstream of the siphons since the siphons are running full at all times, preventing the movement of air. Any corrosion occurring at the headworks or any other location at the WRF will need to be addressed separately.

4.3.1 Results and Recommendations

Based on the forced air ventilation tests results, the following conclusions were made:

- 1,000 cfm air withdrawal efforts resulted in significant air pressure reductions along the entire length of the PI.
- The withdrawal of air at manhole CMH000175 had a much greater overall pressure reduction effect along the alignment than the air withdrawal at manhole CMH000194. At CMH000194 the fan was pulling against the momentum of the flowing wastewater in the downstream direction, in addition to pulling air from the upstream reaches of the pipe. This resulted in less significant pressure reduction in the downstream reaches of the sewer. At manhole CMH000175 all of the air withdrawn by the fan was drawn from the upstream reaches of the sewer, resulting in lower overall negative pressures.
- Given the pressure reduction effects measured during the fan test, it is surmised that the maximum air velocity in the open headspace of the PI was increased by a factor of 6, up to approximately 600 feet per minute. Experience has shown that forcibly moving air at such velocities through the open headspace of a sewer such as the PI will be effective at controlling and reducing the rate of corrosion in the exposed concrete surfaces of the pipe wall

The following recommendations were made:

- Design and build a 1,000 cfm forced-air withdrawal facility at CMH000175 to withdraw air and slow the rate of corrosion. At a minimum, the purpose of this facility would be to move sufficient amounts of air to dry the exposed concrete pipe walls along the PI; however, this facility could also be designed and built as a dedicated odor control facility to help reduce historical odor complaints that have been recorded along the alignment of the PI.
    - The City should make the determination if an odor control facility is worth the cost to construct and maintain. The odor control facility's primary purpose would be to reduce customer complaints; an odor control facility will not impact the ability of the forced-air withdrawal facility from successfully controlling corrosion. If an odor control facility is desired, it is recommended that a biotrickling filter be designed and built; however, before proceeding with the design of any odor control facility along the PI, a routine H_2S data logging exercise, involving recording continuously monitored H_2S data at MH CMH000175, should be conducted to further understand the concentrations of H_2S that are stripped from solution along the PI alignment.

The full results and conceptual design layouts are presented in the Influent Fan Testing Results and Recommendations report, included in Appendix H.

Section 5

Rehabilitation Options

The City of Bend (City) has a variety of options for resolving the defects discovered within the Plant Interceptor (PI). Rehabilitation or replacement can be deferred, but Brown and Caldwell (BC) recommends implementing rehabilitation to address the most structurally compromised (i.e., Grade 4 and Grade 5) sewers, at a minimum. The following is a discussion of the viable alternatives for addressing the gravity sewer and siphon portions of the PI.

5.1 Gravity Rehabilitation Options

Small instances of Grade 5 defects were detected during BC's review of the 2005 inspection video and the 2007 Yeoman Interceptor CCTV Report, included in Appendix G. The gravity pipe has functioned as intended for approximately 8 years, but the structural defects are currently more extensive and it is obvious that the rate of corrosion is fairly significant.

Roughly 68 percent of the pipe segments found in the gravity sewer portion of the PI exhibited Grade 4 or 5 defects. Based on this observation and assuming that the pipe will continue to operate under open channel flow conditions except in rare instances, BC has developed five options for moving forward:

Option 1 Address Grades 4 and 5 segments

Option 2 Address Grade 5 segments and implement corrosion control

Option 3 Address Grade 4 and Grade 5 segments and implement corrosion control

Option 4 Rehabilitate the entire PI

Option 5 Replace the entire PI

With the advancement of trenchless rehabilitation options, there are no pipe reaches that have deteriorated beyond the capabilities of trenchless rehab, such as cured-in-place pipe (CIPP) or slip-lining.

The City's 2014 Collection System Master Plan (CSMP) has identified four segments of the PI that require upsizing:

- CMH000207 to CMH000205 (two segments), 900 LF of 30-inch RCP replaced with 36-inch, $542,000
- CMH000191 to CMH000189 (two segments), 800 LF of 36-inch RCP replaced with 42-inch, $488,000

All of the below options include these recommended upsized pipe segments as part of the rehabilitation costs. BC assumes that the CSMP costs include the manholes associated with these segments as well as using corrosion resistant pipe and manhole materials. BC assumes that no additional costs are required to make these new upsized segments and associated manholes corrosion resistant.

5.1.1 Option 1: Address Grades 4 and 5 Segments

As mentioned previously, the corrosion observed in 2005 has continued to worsen. Pipe reaches that appeared to be a structural condition Grade 3 have deteriorated to a Grade 4 or 5.

Grade 4 segments indicate localized sections of reinforcement visible that are most cost effective to be addressed by short sectional cured-in-place pipe (CIPP) lining instead of full manhole-to-manhole segmental lining. There are eight segments requiring 16 sectional liners covering defects totaling 82 linear feet (LF). Given the time and labor required for installation of each sectional liner, it generally is more cost-effective to rehabilitate the entire pipe reach with CIPP than it is to install more than three sectional CIPP liners within the same pipe reach, so using segmental liners in these eight segments is the more cost-effective option

For pipe reaches that are rated as Grade 5 or have extensive lengths of reinforcement, full-length segmental CIPP is recommended under this option. Fifteen pipe reaches totaling 6,526 LF would require full-length CIPP. The two manholes that have experienced corrosion and concrete degradation should be rehabilitated structurally using an interior fiber-reinforced cementitious lining. An additional 10 manholes should be coated with an epoxy coating to protect the existing concrete from further deterioration. The four segments (and associated manholes) requiring upsizing by the CSMP are included in Option 1. Figure 5-1 shows the components of the PI recommended for rehabilitation using sectional and full length CIPP. Full bypassing of the PI from the upstream-most manhole to the siphon junction structure is included in the capital costs. For budgetary purposes, bypassing will be parallel along the Main Canal access road and that road ramps will be used to cross roadways.

The total project cost for Option 1 would be approximately $4.5 million and is summarized in Table 5-1. However, this alternative does not address any sewers beyond Grade 4. Based on the rate of corrosion observed from 2005 to the current inspections, this option likely extends the life of the PI for 7 to 10 years, with a recommended reinspection of PI (including laser profiling or scanning to quantify the rate of deterioration) in 7 to 10 years.

Table 5-1. Option 1 Project Costs

Description	Cost, $
Rehabilitation capital cost	2,411,000
Contingency (20 percent)	482,000
Design and construction management (25 percent)	603,000
Upsizing project costs (per CSMP)	1,030,000
Total	4,526,000

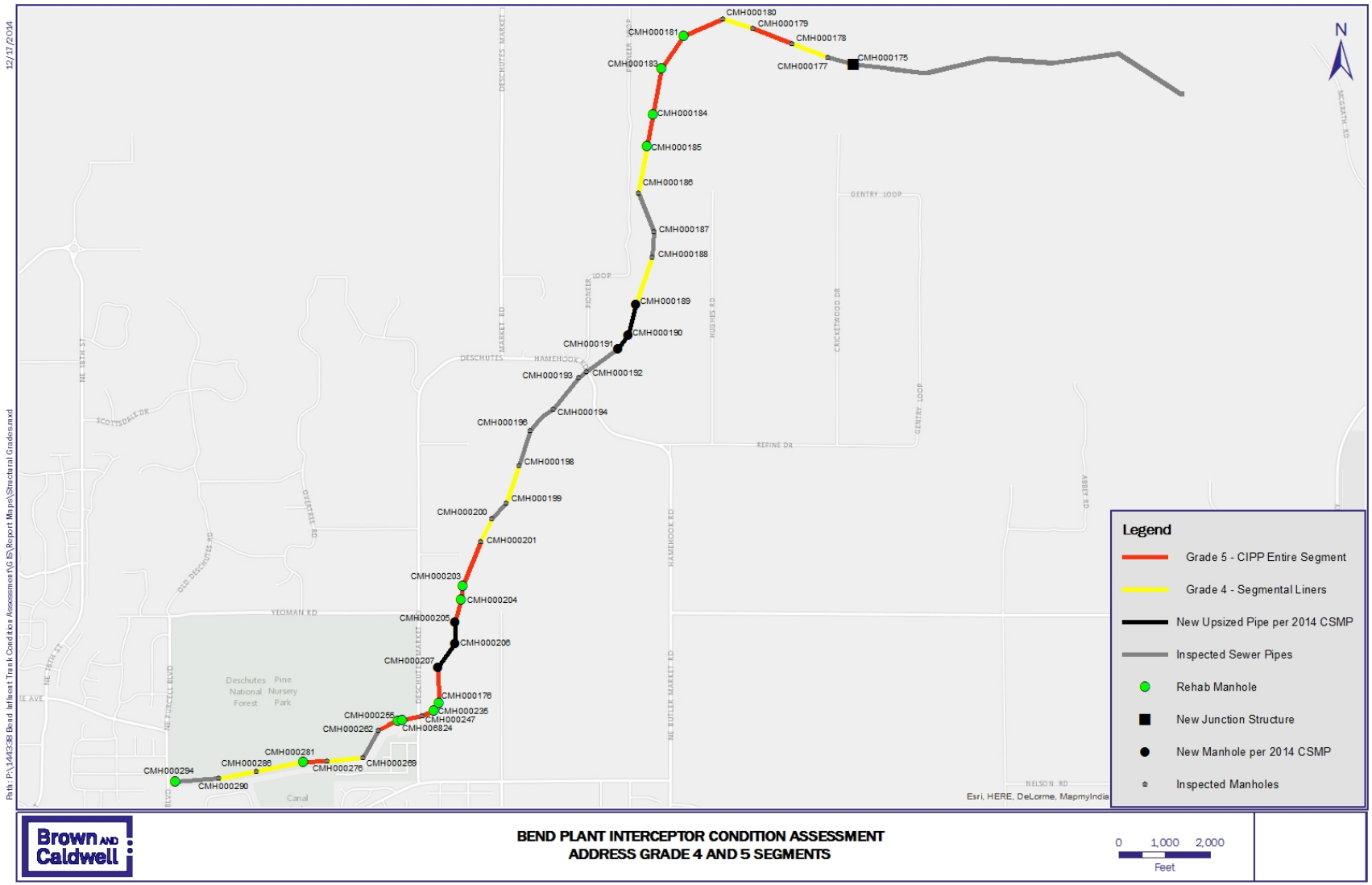

Figure 5-1. Address Grades 4 and 5 segment defects

5.1.2 Option 2: Address Grade 5 Segments and Implement Corrosion Control

A second option would be to repair all the Grade 5 defects and significantly slow the rate of corrosion through ventilation. This option would use CIPP on all Grade 5 sewer reaches. A total of 6,526 LF would be rehabilitated as well as two structurally compromised manholes. The corrosion control is assumed to be a forced-air ventilation system with a biotrickling filter as described in Section 4, which had an initial capital cost of $188,000 with an annual operating cost of $8,500. This option likely extends the life of the Grade 4 segments for approximately 10 to 15 years and extends the life of Grade 3 and below segments for approximately 20 to 30 years. The forced air ventilation system will also provide the added benefit of addressing odor issues. Full bypassing of the PI from the upstream-most manhole to the siphon junction structure is included in the capital costs. For budgetary purposes, bypassing will be parallel along the Main Canal access road and that road ramps will be used to cross roadways. Figure 5-2 shows the components of the PI recommended for rehabilitation using full-length CIPP.

The total project cost for Option 2 is approximately $4.3 million and is summarized in Table 5-2. The four segments (and associated manholes) requiring upsizing by the CSMP are included in Option 2.

Table 5-2. Option 2 Project Costs

Description	Cost, $
Capital cost	2,247,000
Contingency (20 percent)	449,000
Design and construction management (25 percent)	562,000
Upsizing project costs (per CSMP)	1,030,000
Total	4,288,000
Annual Operating Costs (forced-air ventilation, 25 years)	255,000

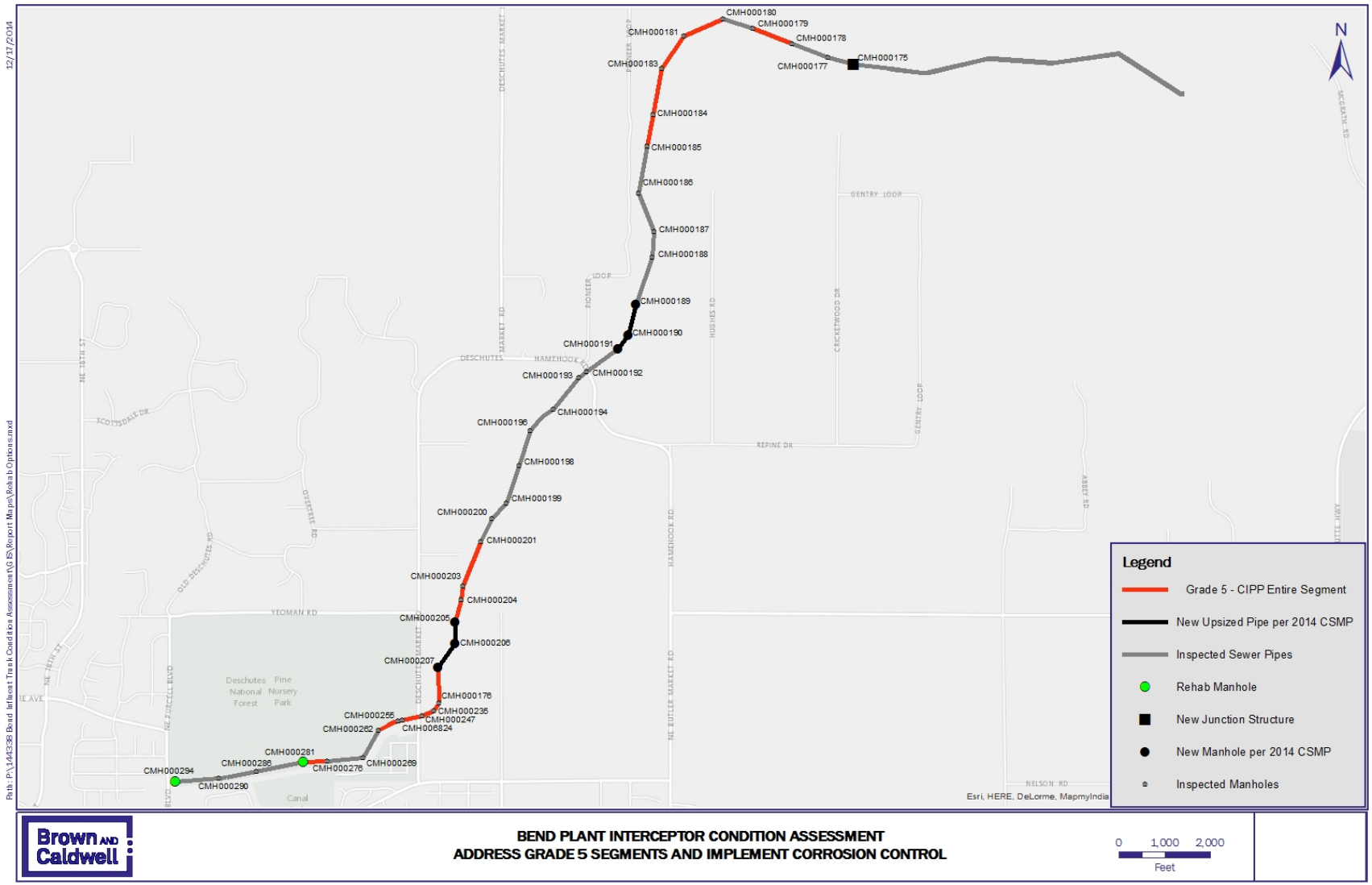

Figure 5-2. Address Grade 5 segment defects and implement corrosion control

5.1.3 Option 3: Address Grade 4 and 5 Segments and Implement Corrosion Control

A third option would be to repair all the Grade 4 and Grade 5 defects and significantly slow the rate of corrosion through forced-air ventilation, as described in Section 4. This option would be similar to Option 1, where eight Grade 4 segments are rehabilitated with 16 sectional liners covering defects totaling 82 LF and fifteen segments totaling 6,526 LF would receive full-length CIPP. The two manholes that have experienced corrosion and concrete degradation should be rehabilitated structurally using an interior fiber-reinforced cementitious lining. An additional 10 manholes should be coated with an epoxy coating to protect the existing concrete from further deterioration. Figure 5-3 shows the components of the PI recommended for rehabilitation using sectional and full-length CIPP.

The corrosion control is assumed to be a forced-air ventilation system with biotrickling filter as described in Section 4, which had an initial capital cost of $188,000 with an annual operating cost of $8,500. This option likely extends the life of the Grade 3 and below segments for approximately 20-30 years, with the CIPP rehabilitated portions having a design life of 50+ years. The forced air ventilation system will also provide the added benefit of addressing odor issues. Full bypassing of the PI from the upstream-most manhole to the siphon junction structure is included in the capital costs. For budgetary purposes, bypassing will be parallel along the Main Canal access road and that road ramps will be used to cross roadways.

The total project cost for Option 3 is approximately $4.8 million and is summarized in Table 5-3. The four segments requiring upsizing by the CSMP and associated manholes are included in Option 3.

Table 5-3. Option 3 Project Costs

Description	Cost
Capital cost	$2,599,000
Contingency (20 percent)	$520,000
Design and construction management (25 percent)	$650,000
Upsizing project costs (per CSMP)	$1,030,000
Total	$4,799,000
Annual Operating Costs (forced-air ventilation, 25 years)	$255,000

5.1.3.1 Option 3A – Address Grade 4 and 5 Segments using Full-Length CIPP and Implement Corrosion Control

A variation to Option 3 would be to fully rehabilitate all Grade 4 and Grade 5 defects and significantly slow the rate of corrosion through forced-air ventilation, as described in Section 4. All eight Grade 4 segments and all 15 Grade 5 segments totaling 12,148 LF would receive full-length CIPP. The two manholes that have experienced corrosion and concrete degradation should be rehabilitated structurally using an interior fiber-reinforced cementitious lining. An additional ten manholes should be coated with an epoxy coating to protect the existing concrete from further deterioration.

The corrosion control is assumed to be a forced-air ventilation system with biotrickling filter as described in Section 4, which had an initial capital cost of $188,000 and an annual operating cost of $8,500. This option likely extends the life of the Grade 3 and below segments for approximately 20 to 30 years, with the CIPP-rehabilitated portions having a design life in excess of 50 years. The forced air ventilation system will also provide the added benefit of addressing odor issues. Full bypassing of the PI from the upstream-most manhole to the siphon junction structure is included in

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the capital costs. For budgetary purposes, bypassing will be parallel along the Main Canal access road and that road ramps will be used to cross roadways. Figure 5-3 shows the components of the PI recommended for rehabilitation using full-length CIPP.

The total project cost for Option 3A is approximately $6.4 million and is summarized in Table 5-3A. The four segments requiring upsizing by the CSMP and associated manholes are included in Option 3A.

Table 5-3A. Option 3 Project Costs

Description	Cost, $
Capital cost	3,716,000
Contingency (20 percent)	743,000
Design and construction management (25 percent)	929,000
Upsizing project costs (per CSMP)	1,030,000
Total	6,418,000
Annual Operating Costs (forced-air ventilation, 25 years)	255,000

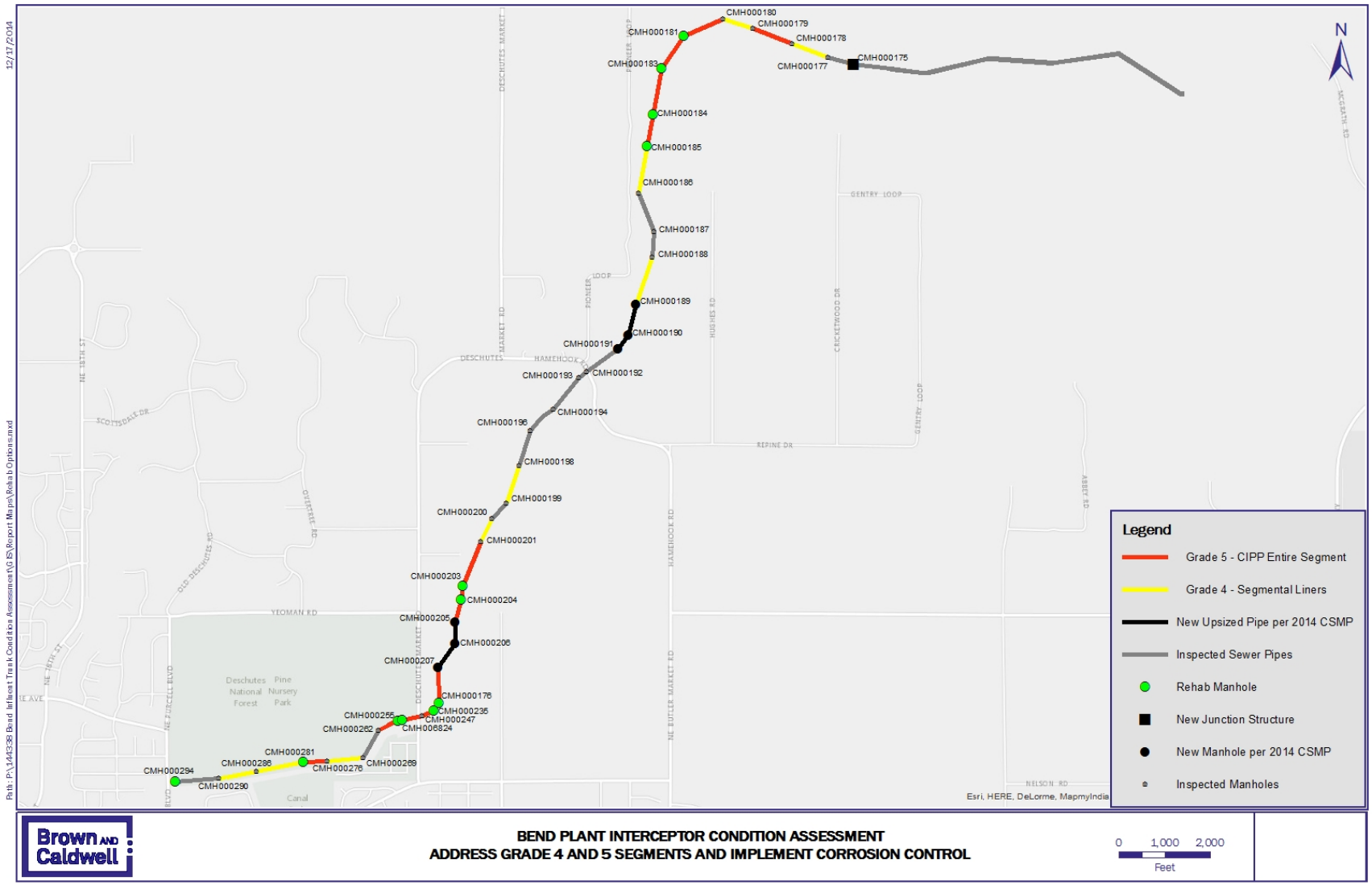

Figure 5-3. Address Grades 4 and 5 segment defects and implement corrosion control

5.1.4 Option 4: Rehabilitate the Entire PI

A fourth option would be to rehabilitate the entire gravity portion of the PI with CIPP and rehabilitate the manholes. The result of implementing this option would be a fully structural pipe that closely fits the existing PI and is fully corrosion-resistant. Thirty-six segments of the PI totaling 18,226 LF would be rehabilitated, with four segments upsized per the 2014 CSMP. Six new manholes will be replaced per the 2014 CSMP with the 33 remaining structures rehabilitated and coated with epoxy. The remaining useful life of the PI would be in excess of 50 years, assuming the hydraulic capacity needs of the City would continue to be served by the existing PI. Full bypassing of the PI from the upstream-most manhole to the siphon junction structure is included in the capital costs. For budgetary purposes, bypassing will be parallel along the Main Canal access road and that road ramps will be used to cross roadways. Figure 5-4 shows the entire length of the PI recommended for rehabilitation using full-length CIPP.

The four segments (and associated manholes) requiring upsizing by the CSMP are included in Option 4. The total project cost for Option 4 is approximately $8.7 million and is summarized in Table 5-4.

Table 5-4. Option 4 Project Costs

Description	Cost, $
Capital cost	5,291,000
Contingency (20 percent)	1,058,000
Design and construction management (25 percent)	1,323,000
Upsizing project costs (per CSMP)	1,030,000
Total	8,701,000

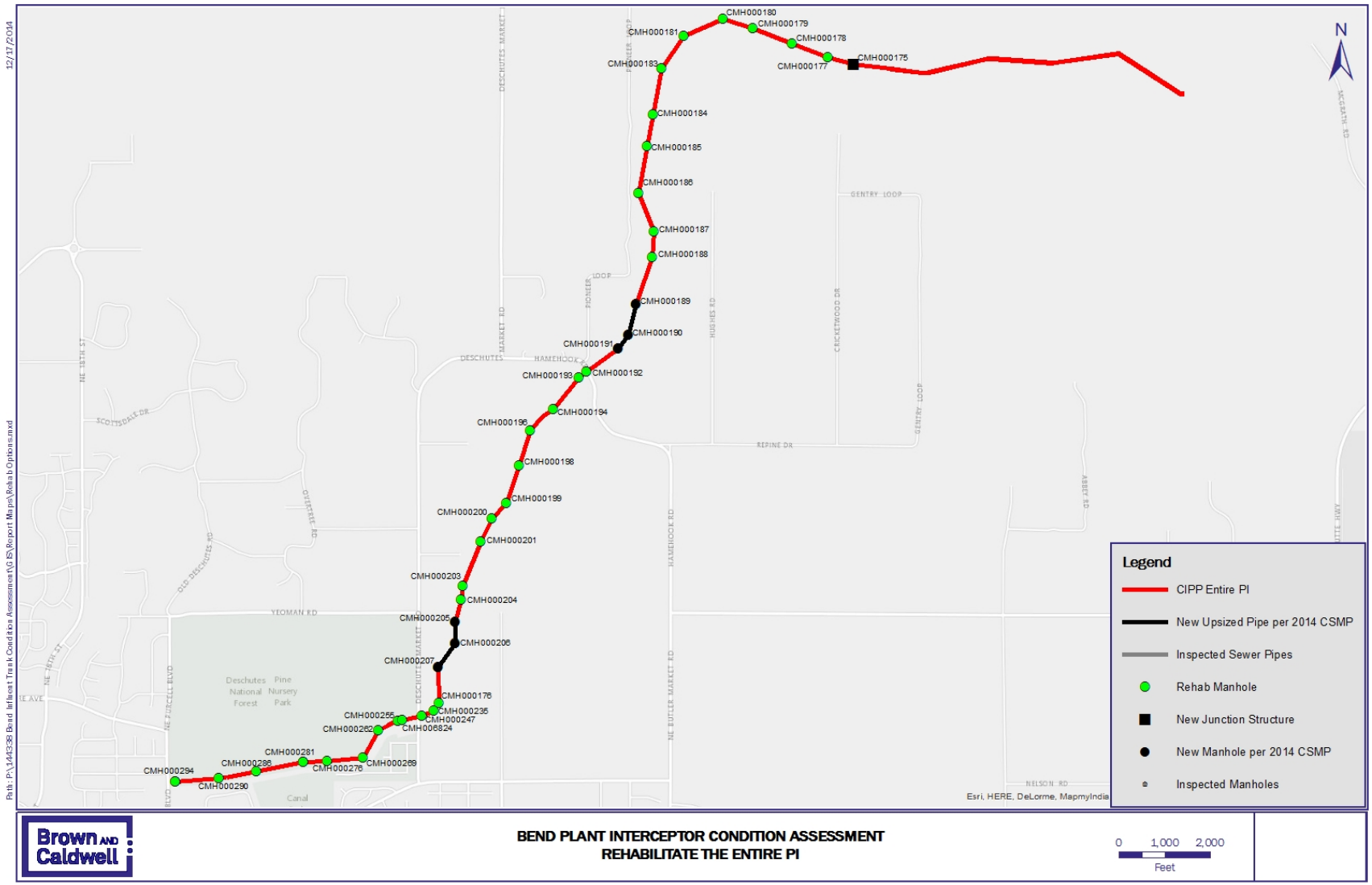

Figure 5-4. Rehabilitate the entire PI

5.1.5 Option 5: Replace the Entire PI

A fifth option would be to replace the entire gravity portion of the PI with a new corrosion-resistant pipe adequately sized for future growth. This option would be recommended if the current PI is undersized and cannot provide adequate wastewater conveyance in the near future. Figure 5-5 shows the entire length of the PI recommended for rehabilitation using full-length CIPP.

While the size and the cost of a replacement interceptor and siphon are not fully known, using costs from the City's 2007 Collection Sewer Master Plan (CSMP) and escalating to 2013 dollars indicates a capital cost of $14.6 million. Full bypassing of the PI from the upstream-most manhole to just downstream of the siphon junction structure was included in the CSMP costs. It is assumed that bypassing across the Main Canal is not required, and that the bypass discharge will take place immediately downstream of the siphon junction structure. Assuming this capital cost can be used for planning purposes, the total project cost for Option 5 is approximately $21.8 million and is summarized in Table 5-5.

Table 5-5: Option 5 Project Costs

Description	Cost, $
Capital cost	14,551,000
Contingency (20 percent)	2,910,000
Design and construction management (25 percent)	4,365,000
Total	21,826,000

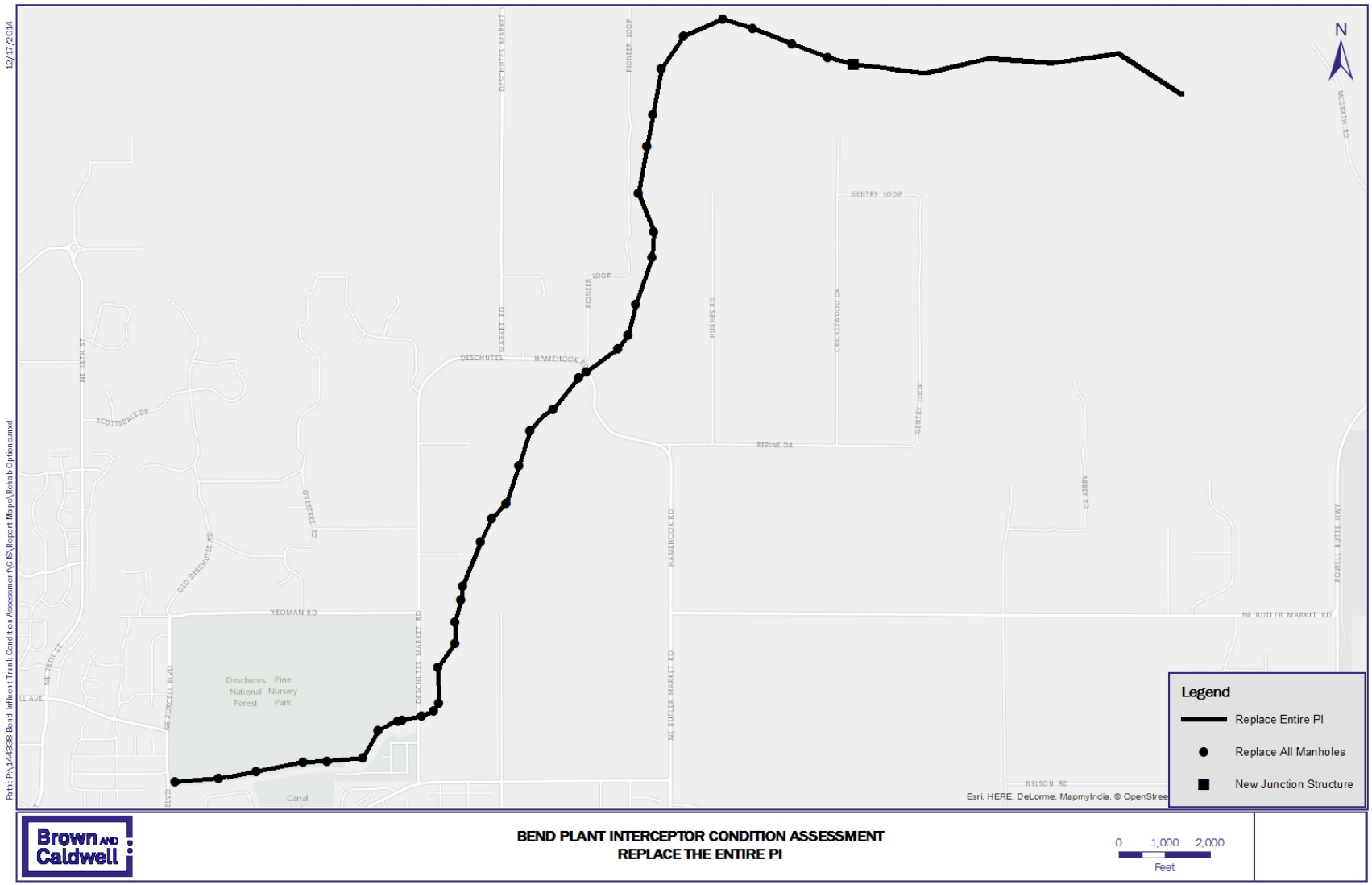

Figure 5-5. Replace the entire PI

5.2 Siphon Options

The sonar inspections determined that the siphon exhibited no gross structural issues. However, the presence of debris and grease accumulation has drastically reduced the hydraulic capacity of the pipes. Also, the lack of a full pipe in the lower portion of the 36-inch siphon barrel is a potential corrosion concern that should be explored more fully. Cleaning of the siphon is recommended. While expensive, the City could bypass the siphon by constructing a temporary pipe bridge across the Main Canal, construct an access structure near the low point of the siphons to dewater the siphon barrels, and clean and further inspect the siphon barrels to confirm there are no structural issues in the lower portion of the 36-inch siphon barrel.

Another option for cleaning would be to retain the services of a national cleaning firm with specialized equipment, such as Brenford Environmental Services. Brenford's Sewer Hog and Grit Gator system could be well suited for cleaning this difficult siphon. This closed-loop system has been used to clean pipes 18-inches in diameter and larger and is one of the largest and most powerful jetters in the nation, using high flow rates of up to 350 gallons per minute at pressures of up to 2,000 pounds per square inch. The Sewer Hog utilizes active flow in the lines as the water source and returns the filtered water back to the system. The high-pressure nozzle suspends materials and the high volume flow forces them down the sewer pipe to the downstream access point where a 6-inch submersible pump directs the debris and water up to the dewatering box. The sand and grit is captured in the dewatering box and water is returned to the sewer line mostly free of debris. In cases where hydrant water is not available, the decanted water is reused to power the jetter. Line segments up to 4,000 LF can be cleaned without repositioning the equipment, so two setups would be required for the PI, one at each end of the siphon. Figure 5-6 shows the Sewer Hog setup.

Figure 5-6. Brenford's Sewer Hog

After successful cleaning with the Sewer Hog and having use of the powerful jet nozzle that can easily propel a tag line through the siphon, the lower third of the 36-inch siphon barrel could be reinspected using sonar to confirm that no gross structural defects exist. While the sonar inspections did not detect any gross structural defects in the siphons that would be of concern during this high-pressure cleaning, there was significant debris in the siphons such that the entire pipe wall could not be reached with the sonar signal. The City should explore the risks of this cleaning operation with Brenford.

The budgetary cost for Brenford to clean the siphon barrels and have a subcontractor reinspect the lower third of the 36-inch siphon barrel is approximately $600,000. An estimate of the work was provided by Brenford and is included in Appendix H.

The current operational strategy of the upstream siphon junction box should be evaluated. With both siphon barrels fully opened, during lower flows the scouring velocity of the flow may not be constantly maintained, leading to the accumulation of grease and debris. Directing flows to the 21-inch barrel while utilizing the 36-inch barrel for diurnal peak and wet-weather flows may be feasible. Simple strategies such as constructing a regulating overflow weir with a trash rack between the barrels may be feasible but require more maintenance and would require City input. More complex strategies, such as installing actuating gate valves tied to the flow meters at the WRF, could be used to provide a more expensive solution with less maintenance. For the purposes of this condition assessment report, a replacement precast junction box with a cast-in-place regulating overflow weir and lined with epoxy is assumed with a budgetary cost of $85,000. This cost assumes full installation at the same time as other rehabilitation work.

Other management strategies of grease and debris should be considered at points upstream, including industrial pretreatment requirements, grease management, and installation of debris sumps.

5.3 Recommendations

Table 5-6 summarizes the options discussed above. Costs are capital costs only; annual operating costs are not included.

Table 5-6. Rehabilitation Options for PI

Option	Project cost, $	Remaining useful life, years
Option 1: Address Grades 4 and 5 segments	4,526,000	7 to 10
Option 2: Address Grade 5 segments and implement corrosion control	4,288,000	10 to 15 for Grade 4 20 to 30 for Grade 3 and below
Option 3: Address Grade 4 segments with short liners and Grade 5 segments with full CIPP and implement corrosion control	4,799,000	20-30
Option 3A: Address Grade 4/5 segments with full CIPP and implement corrosion control	6,418,000	30 to 40
Option 4: Rehabilitate the entire PI	8,701,000	50+
Option 5: Replace the entire PI	21,826,000	50+
Siphon cleaning and inspection	600,000	N/A
New siphon junction box	85,000	50+

The timing and scope for any rehabilitation or replacement work must coincide with a proper hydraulic analysis to determine the conveyance needs now and in the future. Based on the information provided in the City's CSMP, both the gravity and siphon portions of the PI have sufficient hydraulic capacity to serve the City for the next 20 years. BC recommends Option 3 in conjunction with cleaning of the siphon and the siphon junction box replacement. However, if adequate capacity is anticipated for well beyond the 20- to 30-year planning window, BC recommends Option 4 in conjunction with cleaning of the siphon and siphon junction box replacement.

Table 5-7 summarizes BC's recommendations that depend on the current updates to the City's CSMP.

Table 5-7. BC Recommendations Based on Hydraulic Requirements		
Hydraulic capacity need	Recommended option	Project cost, $
Adequate capacity for next 20 years	Option 3 + siphon cleaning + siphon junction box	5,484,000
Adequate capacity for foreseeable future	Option 4 + siphon cleaning + siphon junction box	9,386,000

Depending on the City's preference and timing of rehabilitation, the Grade 4 and Grade 5 segments of the PI should be inspected every 2 years. Grade 3 segments and below should be inspected in the next five years. Ideally laser data would be collected and compared to the laser data from this inspection to determine additional pipe wall loss and estimate the rate of deterioration.

Since there were very few operational defects, cleaning of the gravity portions of the PI is strongly discouraged. The cleaning operations are likely to worsen the already poor concrete in the sewer head space.

Section 6

Limitations

This document was prepared solely for the City of Bend, Oregon (City) in accordance with professional standards at the time the services were performed and in accordance with the contract between the City and Brown and Caldwell (BC) dated April 15, 2013. This document is governed by the specific scope of work authorized by the City; it is not intended to be relied upon by any other party except for regulatory authorities contemplated by the scope of work. We have relied on information or instructions provided by the City and other parties and, unless otherwise expressly indicated, have made no independent investigation as to the validity, completeness, or accuracy of such information.

Further, BC makes no warranties, express or implied, with respect to this document, except for those, if any, contained in the agreement pursuant to which the document was prepared. All data, drawings, documents, or information contained this report have been prepared exclusively for the person or entity to whom it was addressed and may not be relied upon by any other person or entity without the prior written consent of BC unless otherwise provided by the agreement pursuant to which these services were provided.

Appendix A: Pre-Inspection Presentations and Meeting Minutes

Appendix B: Inspection Technology Memorandum

Appendix C: Property Owner Handouts

Appendix D: Intertie Slab Removal, Storage, and Replacement Specification

Appendix E: RedZone Robotics Final Report

Appendix F: Manhole Inspection Reports

Appendix G: 2007 Yeoman Interceptor CCTV Report

Appendix H: Brenford Siphon Cleaning Quotation

Appendix I: Influent Fan Testing Results and Recommendations Report