Utilizing Nondestructive Testing for Large Ductile Iron Force Main and Air Release Valve Evaluation

Weston Haggen, Emily Staubus Williamson, Mark Burgess, Jeremy Waugh, Dan Glaser, and Joel Kelsey

What could you be doing to stay one step ahead of your existing infrastructure as it approaches the end of its useful life? Pinellas County (county) has taken a proactive approach to evaluate its force mains and air release valves (ARVs) following the failure of a large force main. The suspected cause of failure was corrosion from buildup of hydrogen sulfide (H_2S), resulting in the formation of sulfuric acid (H_2SO_4) and leading to corrosion and the eventual breakdown of the pipe's structural characteristics.

The county operates a manifolded wastewater force main system of many different sizes (ranging from 4 to 42 in. in diameter) and materials in two separate service areas. The north wastewater service area transmits flow to the William E. Dunn Water Reclamation Facility (WRF) as shown (Figure 1) and the south wastewater service area transmits flow to the South Cross Bayou Advanced WRF (Figure 2). Reiss Engineering, along with the county, conducted an evaluation of multiple force mains and their associated ARVs in the north wastewater service area of the county utilizing various technologies.

To evaluate the condition of the force mains and ARVs, the existing record information was compared to new field survey data, ground-penetrating radar (GPR), and subsurface utility engineering data to prepare an updated profile to determine high points and other locations that could be subject to

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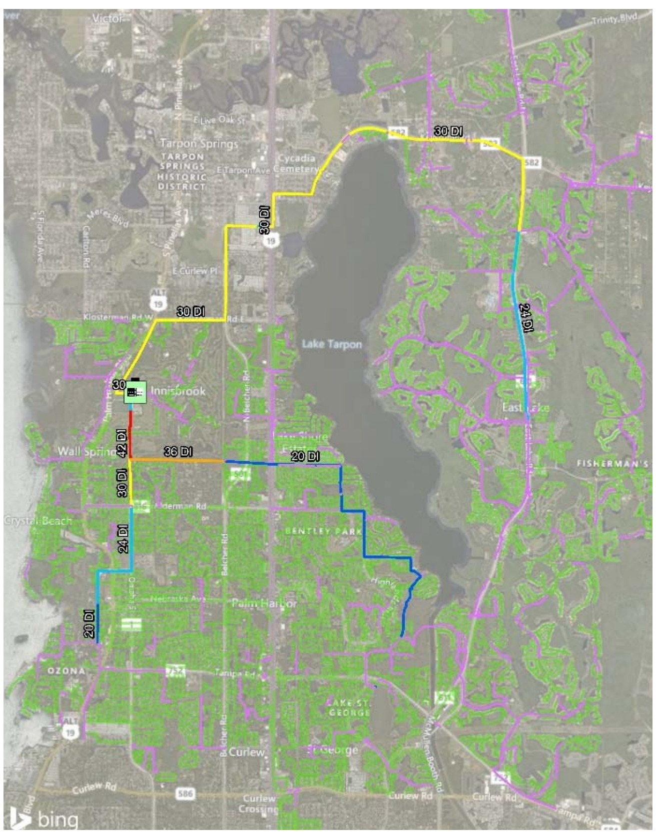

Figure 1. North Wastewater Service Area

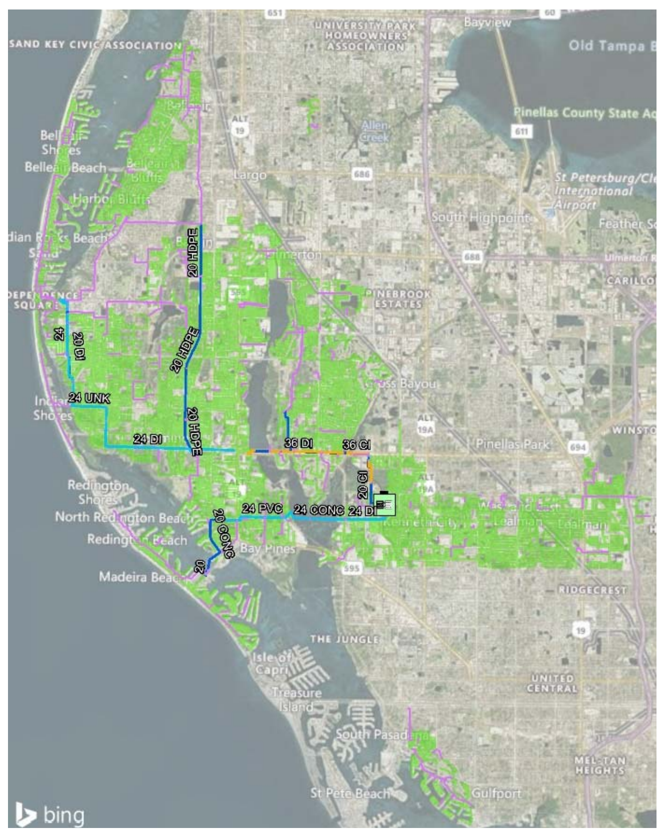

Figure 2. South Wastewater Service Area

Figure 3. Pipe Corrosion

Figure 4. Ground-Penetrating Radar Equipment

corrosion within the force mains. The current exterior condition and wall thickness of the force mains and ARVs were determined using ultrasonic thickness testing (UTT). At each UTT location, wall thickness was tested at targeted locations on the cross section of the pipe, with approximate angles of 0, 45, 90 (top of pipe), 135, and 180 degrees.

The evaluations found that the existing ARVs are located at surveyed high points of the force main, but are undersized compared to current industry standards. Visual observations indicated various force main deficiencies, including corrosion on the exterior of the force main, ARV pipe saddles, ARV piping, isolation valves, ARV bodies, and interior of the concrete ARV vault. Wall thickness measurements were completed at numerous locations on one of the force mains assessed with three locations determined to be at a critical level based on the tested wall thickness. Recommendations were ultimately made by categorizing the wall thickness at the tested locations and identifying an action category (repair, replace, or retest), which corresponded with the remaining wall thickness.

The county plans to continue using this method of pipeline assessment for all of its force mains and to continue testing vulnerable locations identified in initial assessments to determine if their condition further deteriorates.

This article details the high-point determination, testing methods, testing results, and recommendations made after assessment, with the goal to prevent further failures from occurring.

Assessment Following Force Main Failure

On Oct. 4, 2016, a 30-in. ductile iron (DI) force main located adjacent to a county pump station experienced a failure that caused a spill (Figure 3). The failure was believed to have been caused by a failed ARV that trapped H_2S within the DI force main, causing internal pipe corrosion. The spill was quickly contained and temporary high-density polyethylene (HDPE) piping was used to bypass the failed section to allow for replacement of the force main. Due to the failure, the county wanted to evaluate additional portions of the transmission main for similar potential issues caused by H_2S. This assessment utilized GPR and test holes to determine the horizontal and vertical profiles of the force main to identify high points. SmartBall, an inspection tool from Pure Technologies, was used to identify the presence of any gas pockets or leaks, which indicates locations that are vulnerable to corrosion, and UTT to identify the extent of any corrosion of the pipe wall.

Initial Force Main and Profile Determination

Force main assessments included a condensed vertical profile of the force main that was created initially using record and geographic information sustem (GIS) information provided by the county. A utility designation was completed along the force main to determine the alignment. The GPR was based on the initial condensed profile and was used to determine the depth of cover over the force main (Figure 4). A topographic survey was completed to collect the latitude, longitude, and force main depth. The high points of the force main were confirmed using GPR, air lancing (a thin tube with compressed air), and test holes. One of the primary factors for corrosion is the production and accumulation of H_2S, which is known to collect and become entrapped at high points in piping networks. The ARVs are typically placed at the highest points in a piping network to release the air at these locations; however, other incremental high points within the system can collect air and become susceptible to corrosion.

The GPR works by sending pulses of energy into the earth and reading the strength and the time it takes for a signal to be reflected back to the transmitter. Reflections

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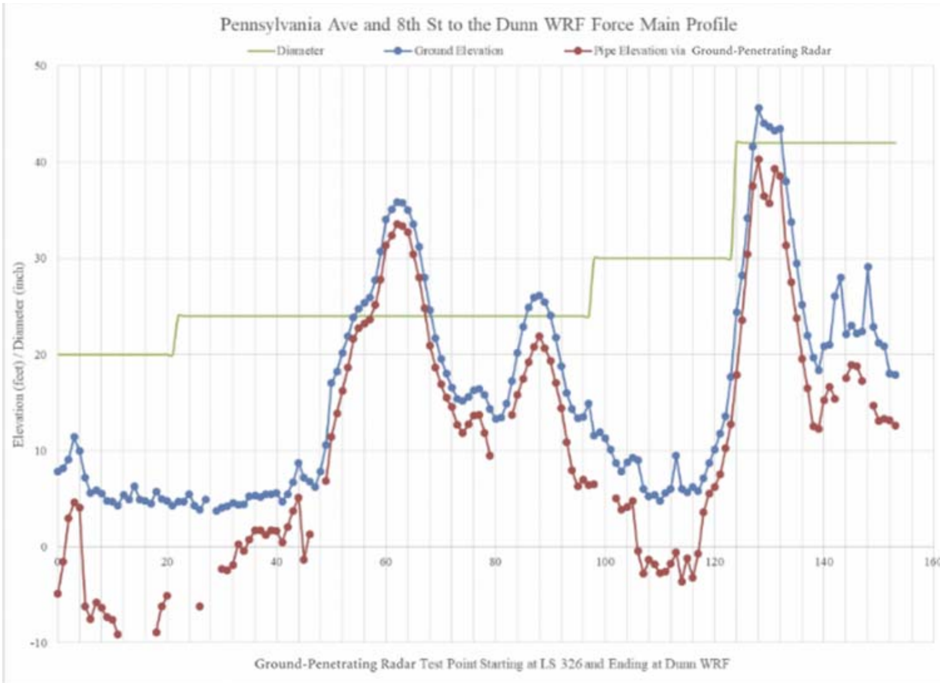

Figure 5. Force Main Profile

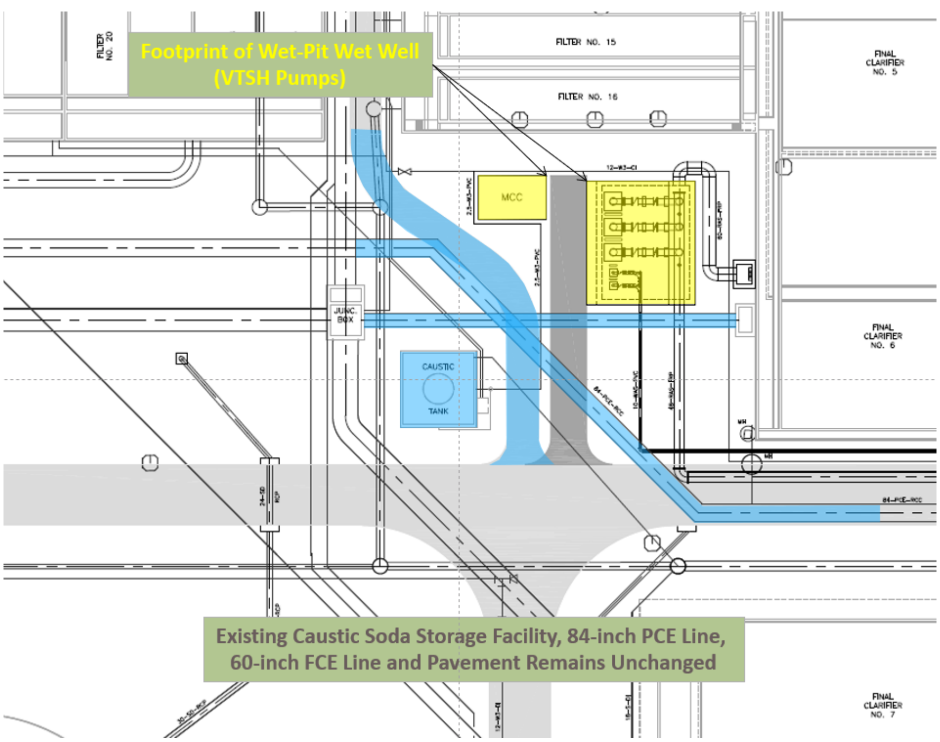

Figure 6. Gas Pocket Determination

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are produced whenever pulses encounter material with different electrical conduction properties; the strength of the reflection helps to identify the material below the surface. Metals reflect completely and do not allow any amount of signal to pass through, thus helping to identify the force main location. The time it takes to send the pulse and receive back a full reflection can also be used to approximate the depth at which the force main is located. The GPR was performed at approximately 500-ft intervals along the project route to determine the force main profile.

Additionally, the top-of-pipe elevation of the force main upstream and downstream at each ARV location was obtained. After the maintenance of traffic or lane closures was coordinated as required, air lancing was completed at approximately 1,000-ft intervals along the force main. If the air lancing location was within the road, the asphalt test-hole procedure was used. The surveyed field data were used to supplement the GPR data collected to better identify high points (or high segments of pipe) that could be subject to higher risk of internal corrosion, and to identify locations where minimal earth cover and surface improvements indicate that the pipe was easily excavated and exposed for inspection and UTT (Figure 5).

Gas Pocket and Leak Detection

The inspection tool used is a free-swimming gas pocket and leak detection device, which is inserted into a force main using a check valve or tap and is retrieved downstream of the insertion point, typically where the force main discharges to a gravity system or treatment facility (Figure 6). When traveling in a force main, the tool uses acoustic technology to detect anomalous acoustic activities associated with leaks or pockets of trapped gas in pressurized mains and requires a velocity of 1 to 4 ft per second (ft/s).

The investigation was utilized following the failure of the Penn Avenue to Dunn WRF force main, which resulted in a spill to quickly identify the existence of other potentially damaging gas pockets or leaks that may cause conditions that lead to corrosion and eventual breakdown of the pipe's structural characteristics. The tool was inserted at two locations via check valve at Pump Station 326 and Pump Station 300 on consecutive days and was retrieved at the Dunn WRF's headworks structure on both days.

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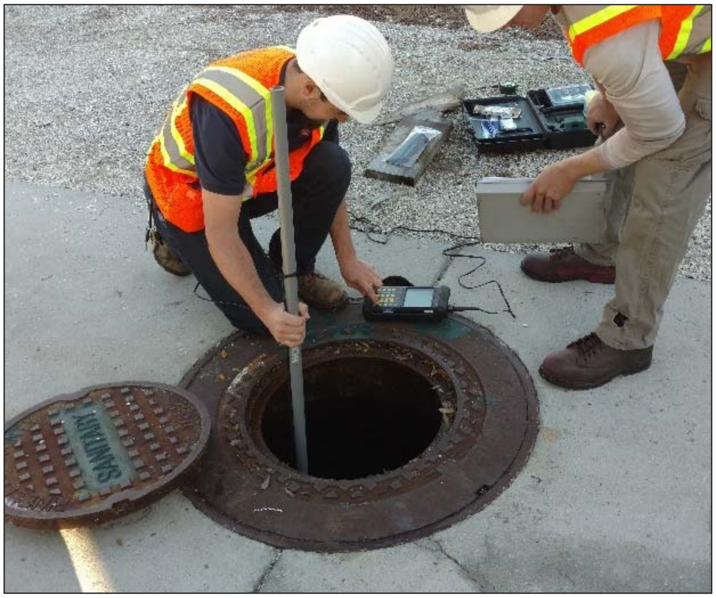

Figure 7. Ultrasonic Thickness Testing

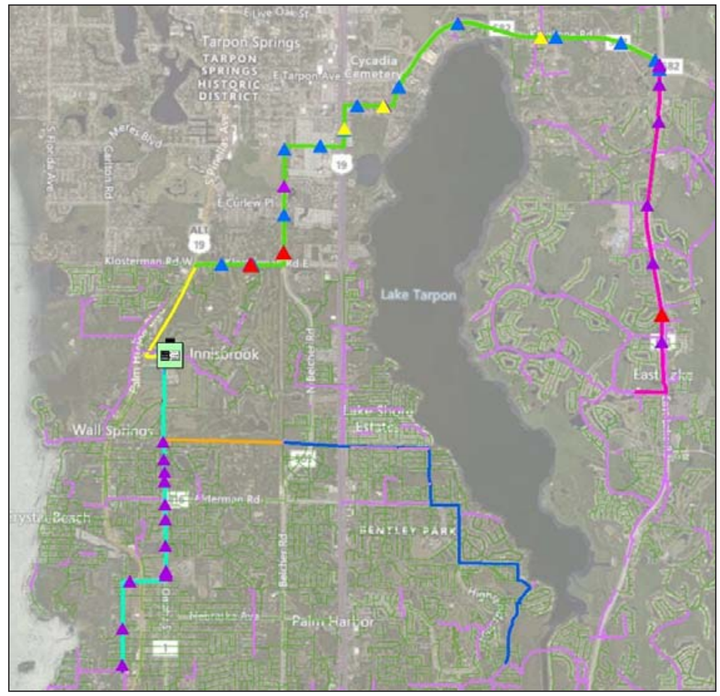

Figure 8. Ultrasonic Thickness Testing Results

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No leaks were detected during inspection. Eleven total gas pockets were detected and ranged in lengths of 15 to 100 ft. One gas pocket was located in the 24-in. force main, six gas pockets were located in the 42-in. force main, and other gas pockets were located in the 30-in. HDPE temporary force main bypass. By locating the gas pockets, the pipe wall thickness could be tested using UTT to determine if the gas pockets have caused pipe wall corrosion.

Ultrasonic Thickness Testing

The UTT is a nondestructive form of materials testing most commonly used to measure thickness and identify corrosion in various metals. The ultrasonic technology measures and displays the thickness of the metallic portion of the pipe, as well as its coating, using a "single backwall echo." An average/minimum mode setting on the ultrasonic equipment saves the average or minimum of several successive thickness measurements, and an overall pipe thickness is calculated based on these results.

To determine the extent of the corrosion, field investigations using nondestructive ultrasonic testing were performed at various locations along the project corridor (Figure 7). Initially, the overall condition of the pipe was visually inspected near the ARVs to determine the exterior condition of the force main and to identify the feasibility for UTT along the force main corridor.

At each test location, ultrasonic readings are conducted at the top of the pipe and along an array of angles located on a cross section of the pipe, with approximate angles of 0, 45, 90, 135, and 180 degrees, respectively (the top of the pipe being 90 degrees). An average thickness is obtained from the three measurements per position, and the lowest average thickness was used to measure the percent remaining based on DI pipe thickness class. In order to accurately calculate the quantity (or percentage) of pipe wall remaining at the test location, the original thickness of the pipe must be known. Since the original installed DI pipe classes (and thickness) are unknown, a DI pipe thickness of Class 54 (ANSI/AWWA Standard C151/A21.51) was assumed based on UTT results and prior studies.

Remaining thickness was also compared to ANSI/AWWA Standard C150/A21.50, with standard thickness for pressure classes. This defined the minimum thickness required to meet a specific pressure class. The results of all assessments are shown in Figure 8 and detailed further.

Penn Avenue to Dunn Water Reclamation Facility Force Main

For the Penn Avenue to Dunn WRF force main assessment, approximately 14,500 lin ft (LF), which is shown in light blue in Figure 8, of field ultrasonic testing locations were selected based on the location of gas pockets, as well as based upon visual inspection of ARVs on the force main to evaluate the exterior condition of the force main. High-point locations were also identified and influenced the final selection of the UTT.

The northernmost 42-in.-diameter portion of the force main was not evaluated due to concern that it was not in adequate condition to perform the testing without causing undue stress, which could cause a failure. The county ultimately elected to replace the entire force main with a smaller pipe, since the main was oversized, which was confirmed by the velocity of the inspection tool. After eliminating the 42-in. main from the UTT assessment, 13 locations were selected as follows:

- Two locations on the 20-in. force main, both in ARV manholes.
- Seven locations on the 24-in. force main, with four in ARV manholes and three requiring excavation.
- Four locations on the 30-in. force main, all requiring excavation.

30-In. Keystone Road to Klosterman Road Force Main

For the Keystone Road to Klosterman Road force main assessment (shown in green in Figure 8), approximately 30,525 LF of field ultrasonic testing locations were based on ARV locations and high points along the 30-in. force main. Fifty-three UTT locations were selected based on analyses of the vertical profile as follows:

- Fourteen ARV vaults were tested. Two ARVs locations were not tested: one could not be located, and the other one was on a polyvinyl chloride (PVC) main adjacent to the 30-in. main.

- Thirty locations, upstream and downstream of the ARV locations, were tested. Exact locations were selected based on a field investigation at each ARV and based on field obstructions. One UTT location was not tested due to soft sand, and excavations were unsuccessful at this location.
- Nine additional locations were selected based on ARV ultrasonic testing readings and the survey profile results. The results confirmed that ARVs are located at all significant high points, and no additional high points were identified based on the GPR and air lacing spacing. Therefore, the nine additional UTT locations were strategically placed around four ARVs, with concerning wall thickness remaining.

24- and 30-In. East Lake Road Force Main

For the East Lake Road force main assessment, approximently 16,000 LF of field ultrasonic testing locations were selected based on ARV locations and high points along the 24- and 30-in. force main on East Lake Road (shown in pink in Figure 8).

Nineteen UTT locations were selected based on analyses of the vertical profile as follows:

- Five ARV vaults were tested. This includes one ARV that was previously tested as part of the Keystone Road force main assessment.
- Eight locations upstream and downstream of the ARV locations.
- Seven additional locations are proposed to be tested based on record drawings and field survey results.

Assessment Results

Penn to Dunn Water Reclamation Facility Force Main

The force main assessment of the Penn Avenue to Dunn WRF force main used the tool technology to determine locations of trapped gas in combination with UTT to find the extent of corrosion at vulnerable locations, including high points and ARVs. The GPR and test holes showed that there are existing ARVs at all major high points on the force main.

As previously discussed, UTT was not used on this force main due to concerns regarding the current integrity and possibilities of failure. Both ARVs on the 42-in. force main had excessive exterior corrosion within the manhole. All

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Figure 9. Wall Thickness Results

Table 1. Summary of Ultrasonic Thickness Testing: Penn Avenue to Dunn Water Reclamation Facility Force Main

Pressure Class (psi)	20-in. Nominal Thickness (in.)	24- in. Nominal Thickness (in.)	30- in. Nominal Thickness (in.)	% Wall Thickness Remaining	Number of UTT
0-50	0.00-0.23	0.00-0.24	0.00-0.27	0-49%	**0**
51-100	0.24-0.26	0.25-0.27	0.27-0.30	50-55%	**0**
101-150	0.27-0.28	0.28-0.31	0.31-0.34	56-62%	**0**
151-250	0.29-0.33	0.32-0.37	0.35-0.42	63-76%	**1**
>250	0.34-0.38	0.38-0.43	0.43-0.49	77-100%	**12**

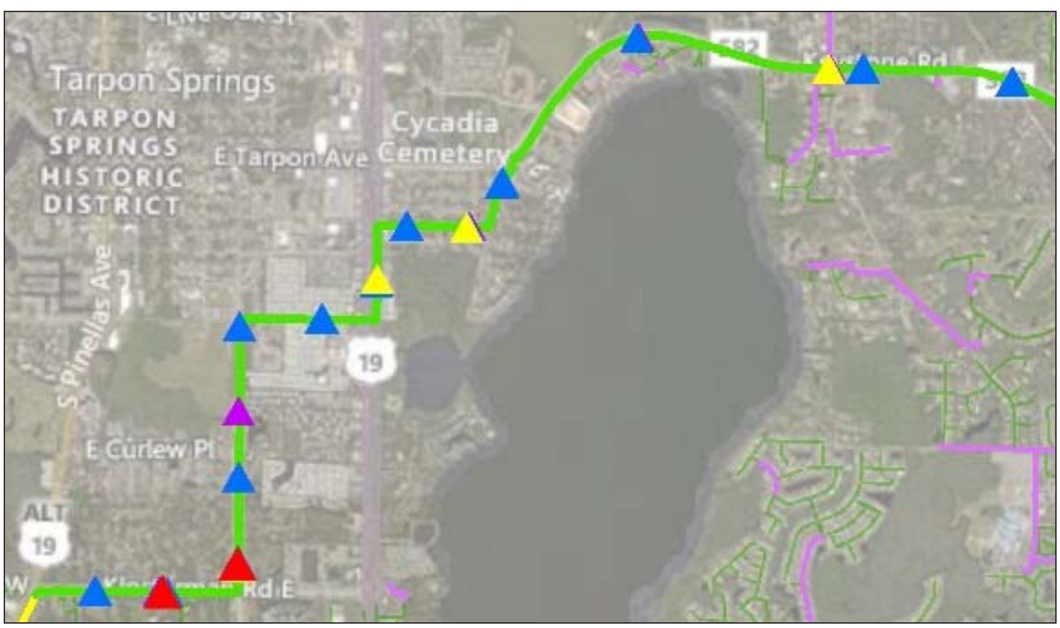

Figure 10. Keystone Road Results

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UTT locations on the 20-, 24-, and 30-in. portion of the force main had remaining wall thicknesses above 70 percent, with a range of 0.379 to 0.590 in., indicating that they are in good condition (Figure 9). Table 1 indicates that 12 of the tested locations have a pressure rating of above 250 pounds per sq in. (psi).

30-In. Keystone Road to Klosterman Road Force Main

The force main assessment provided the opportunity to evaluate locations vulnerable to corrosion. The original plan was amended as necessary through the duration of testing due to unfound ARVs and those located on mains adjacent to the subject 30-in. force main. The assessment found that all ARVs on the force main were 2-in. inlet ARVs, which do not meet the current industry standards for the minimum size for a 30-in. ARV. The ARVs were located at all significant high points of the transmission main, and no additional high points were identified, based on the GPR and air lance spacing.

The results of the UTT, shown on the map in Figure 10, show that three of the UTT locations are in critical condition, as the pipe section loss results in a pipe with a calculated (interpolated) pressure class of approximately 50 psi or less (0.153- to 0.239-in. remaining thickness) detailed in Figures 11 and 12. Five of the UTT locations are in a calculated pressure class between 101 and 150 psi (0.313- to 0.327-in. remaining thickness). Twenty-nine of the UTT locations are in a calculated pressure class between 151 and 250 psi, and the remaining UTT locations are in a pressure class greater than 250 psi, as summarized in Table 2. The pressure class was determined from the remaining wall thickness compared to ANSI/AWWA Standard C150/A21.50.

24- and 30-In. East Lake Road Force Main

The third force main assessment, currently underway on the 24- and 30-in. force mains on East Lake Road (Figure 13), connects upstream to the previously assessed section of the 30-in. force main. The force main has five ARVs, with the northernmost ARV tested with the previous project.

The same previously used methodology for force main profile determination and high-point elevation identification was utilized for the assessment. This profile determination was hindered by the presence of an

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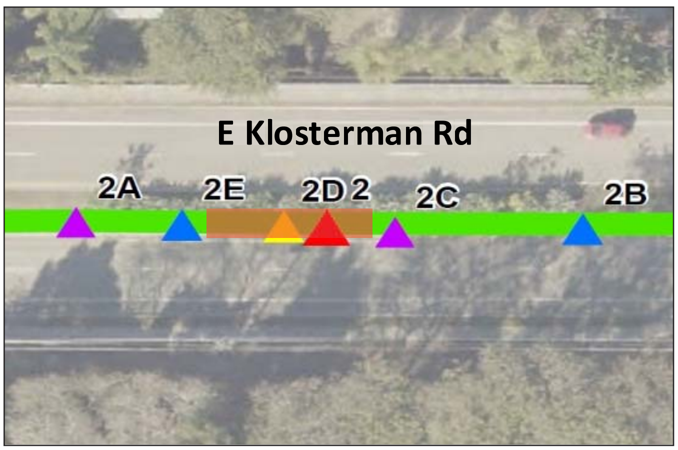

Figure 11. East Klosterman Road Results

Figure 12. Disston Avenue Results

Table 2. Summary of Ultrasonic Thickness Testing: Keystone Road to Klosterman Road Force Main

Nominal Thickness (in.)	Pressure Class (psi)	% Wall Thickness Remaining	Number of UTT
0.00 - 0.27	0-50	0-49%	**3**
0.28 - 0.30	51-100	50-55%	**0**
0.31 - 0.34	101-150	56-62%	**5**
0.35 - 0.42	151-250	63-76%	**29**
0.43 - 0.49	>250	77-100%	**16**

Figure 13. East Lake Road Results

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unusually high groundwater table for the time of year (January/February 2019), which experienced record amounts of rain for these two months. The corridor where the force main is located is within swampy areas. Survey crews experienced difficulty locating the force main depth due to the groundwater levels, affecting GPR readings. Additionally, survey crews experienced trouble during test-hole excavation to visually confirm force main depth due to the groundwater levels. During the excavation activities, a small submersible pump was placed inside the excavated hole to pump out excess water. The submersible pump would only allow for the excavated pit to remain dry for less than a minute before soil would begin to cave in, and the water levels would rise faster than the sump pump was able to pump it out.

Eight locations have been tested to date using the UTT procedure, including all five ARV locations and three additional locations selected using preliminary survey data of the force main elevation and record drawings provided by the county. Six of the eight locations had a good remaining wall thickness and a pressure rating of above 300 psi, and one of the locations had a pressure rating of 250 to 300 psi (Table 3). One location (specifically at an ARV) had low readings, with a remaining wall thickness of less than 50 percent and a pressure rating of less than 100 psi. This location will have additional testing performed upstream and downstream of the ARV to determine the extent of any corrosion beyond the initially tested location. If the extent of corrosion is large, replacement of the section of pipe will be recommended.

Recommendations Made Following Assessments

After the assessments, the following recommendations were made based on the information obtained, indicating that some sections of the force main piping do not have adequate pipe wall thickness.

1. Existing ARVs within the county's force main network should be assessed based on their working condition, and repaired or replaced to ensure proper function and release of entrapped air.
2. The 42-in. portion of the Penn Avenue to Dunn WRF force main, which was untested with UTT, was recommended for replacement based on its condition following completion of the initial study and was ultimately replaced.
3. The UTT locations, which were limited by high groundwater, should be dewatered and inspected during the dry season.
4. The force main sections with critical UTT results along East Klosterman Road and South Disston Avenue (Figures 14 and 15) should be evaluated for immediate repair or replacement, with approximately 40 LF for each pipe section.
5. The remaining UTT locations should be monitored based on the information in Table 4 to confirm that the locations tested in this project are not degrading. The county sanitary model should be reviewed to determine the working and surge pressures that are likely to occur at the locations evaluated during this study, and the results compared to the equivalent pressure ratings set forth herein.

Table 3. Summary of Ultrasonic Thickness Testing: East Lake Road Force Main

Nominal Thickness (in.)	Pressure Class (psi)	% Wall Thickness Remaining	Number of UTT
0.00 - 0.27	0-50	0-49%	**1**
0.28 - 0.30	51-100	50-55%	**0**
0.31 - 0.34	101-150	56-62%	**0**
0.35 - 0.42	151-250	63-76%	**0**
0.43 - 0.49	>250	77-100%	**7**

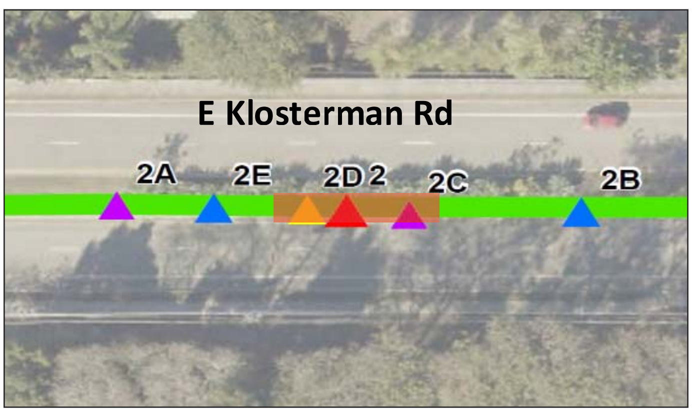

Figure 14. Klosterman Rd Results

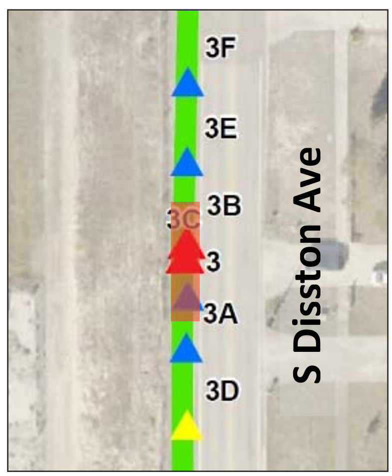

Figure 15. Disston Avenue Results

Table 4. Summary of Action for Three Assessed Force Mains

Nominal Thickness (in.)	Pressure Class (psi)	% Wall Thickness Remaining	Number of UTT
0.00 - 0.27	0-50	0-49%	**1**
0.28 - 0.30	51-100	50-55%	**0**
0.31 - 0.34	101-150	56-62%	**0**
0.35 - 0.42	151-250	63-76%	**0**
0.43 - 0.49	>250	77-100%	**7**

6. Additionally, ARVs should be assessed based on the size of the force main and upsized, where appropriate, to preempt excessive air entrapment, which is the primary source of internal corrosion within DI piping. Over the past few years, numerous municipalities, including the county, have changed their standards regarding the sizing of ARVs, and it's generally no longer typical to use only a 2-in. ARV. The ARVs are now sized based on the diameter of the force main, since the potential air pocket that can form within the crown of the piping is typically larger on these large-diameter force mains.

Replacement of Pipe at Locations With Reduced Wall Thickness Remaining

As previously discussed, it was originally recommended that the 42-in. force main flowing to Dunn WRF was in poor condition and vulnerable to failure. The county has recently completed a project that sliplined the original 42-in. force main to rehabilitate and replace the main using the original pipe.

Following the assessment of the 30-in. force main, the county immediately moved to initiate the design to replace two sections with increased wall deterioration (at East Klosterman Road and South Disston Avenue as previously recommended), in addition to redesigning five other locations to upsize the saddle and ARV, and in addition to relocating the ARV to be above ground.

The county's updated standard, shown in Figure 16, requires the tee/saddle of the mounted ARV to be half the nominal size of the force main it's located on (i.e., a 30-in. force main would require at least a 16-in. saddle for an ARV). This upsized tee, as compared to previous standards, will allow for air to be captured (as much as possible) in the ARV infrastructure and exit, rather than potentially moving past it. The county's updated standard also requires that additional valving be incorporated, with a valve being located on the saddle of the force main, prior to the offset elbow and at the base of the inlet.

The county's general maintenance division additionally wanted to relocate all ARVs above ground, where possible, to allow for ease of access for maintenance activities. Due to the location of the force main within the roadway, above ground ARVs are offset using 4-in. piping. Some adjustment changes were made to the county standard due to the shallow elevation of the force main at high points.

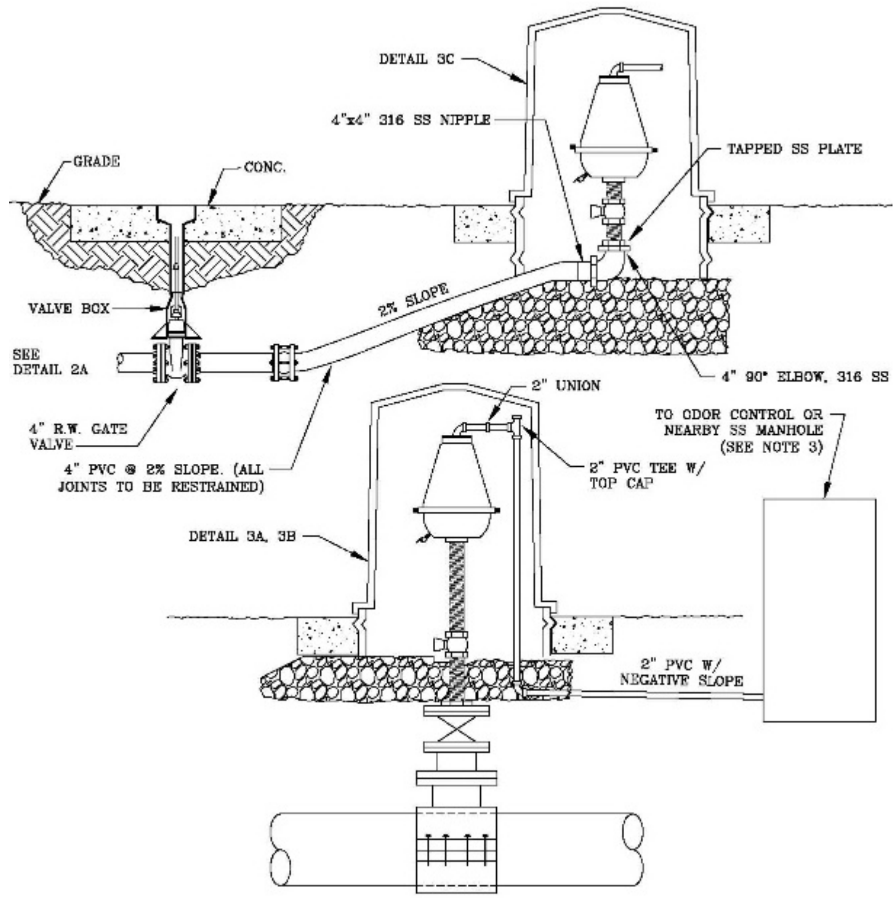

Figure 16. New Standard Air Release Valve Detail

Construction of these replacements took place in 2019. Careful planning and coordination with the county will be necessary for the work, as the large saddles require tapping by a specialty contractor. Wet tapping may be utilized to prevent any interruptions to service, in addition to any necessary bypassing for the construction to replace the deteriorated pipe sections.

Conclusions and Recommendations

The process used to assess the force mains, inclusive of force main profile determination, high-point identification, gas pocket identification, and UTT testing for pipe wall corrosion quantification, has been successful through multiple different force main assessments in identifying vulnerable areas of the force main. The county was able to determine the condition of multiple force mains and immediately address critical locations where pressure rating was reduced to less than 50 psi.

The county plans on continuing the use of this method of pipeline assessment for all of its force mains to address—and continue to test—vulnerable locations identified in initial assessments to determine if deterioration continues. This method may allow the county to plan rehabilitations in a timely manner and always remain ahead of the curve in knowing the condition of its infrastructure.