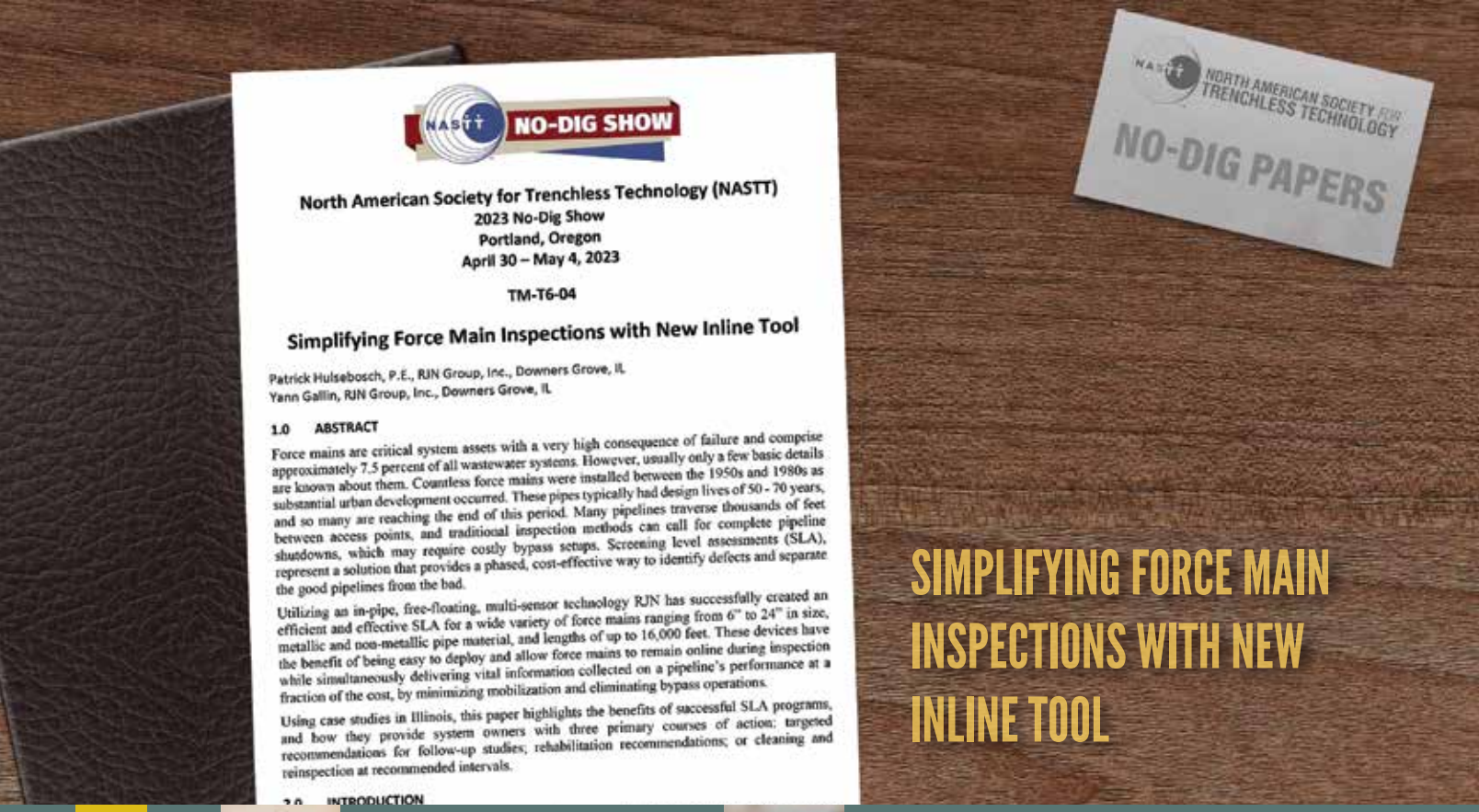

SIMPLIFYING FORCE MAIN INSPECTIONS WITH NEW INLINE TOOL

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1. ABSTRACT

Force mains are critical system assets with a very high consequence of failure and comprise approximately 7.5 percent of all wastewater systems. However, usually only a few basic details are known about them. Countless force mains were installed between the 1950s and 1980s as substantial urban development occurred. These pipes typically had design lives of 50 - 70 years, and so many are reaching the end of this period. Many pipelines traverse thousands of feet between access points, and traditional inspection methods can call for complete pipeline shutdowns, which may require costly bypass setups. Screening level assessments (SLA), represent a solution that provides a phased, cost-effective way to identify defects and separate the good pipelines from the bad.

Utilizing an in-pipe, free-floating, multi-sensor technology RJN has successfully created an efficient and effective SLA for a wide variety of force mains ranging from 6 to 24 inches in size, metallic and non-metallic pipe material, and lengths of up to 16,000 feet.

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These devices have the benefit of being easy to deploy and allow force mains to remain online during inspection while simultaneously delivering vital information collected on a pipeline's performance at a fraction of the cost, by minimizing mobilization and eliminating bypass operations.

Using case studies in Illinois, this paper highlights the benefits of successful SLA programs, and how they provide system owners with three primary courses of action: targeted recommendations for follow-up studies; rehabilitation recommendations; or cleaning and reinspection at recommended intervals.

2. INTRODUCTION

Force mains are an integral asset in a gravity sewer system that convey wastewater under pressure to a discharge point and comprise just 7.5 percent of all wastewater pipes (EPA, 2010). Force mains provide solutions for challenging topography that cannot support a gravity-reliant system, significantly reducing the size and depth of sewers, and decreasing the overall costs of sewer system construction and maintenance by avoiding deeper excavations. Despite these advantages, force mains have proven to be challenging to maintain, inspect, and repair. Force mains often cannot be taken out of service for any significant period of time because any extended downtime would result in surcharging issues in the upstream tributary system. As a result, routine inspections or maintenance can be difficult and costly.

Figure 1: In-Line Screening Pipers® Device

Since force mains are pressurized, they typically run a higher risk of failure than their gravity counterparts. Despite this increased risk, force mains usually have a limited number of access points for inspection or maintenance. Additionally, typical inspection and maintenance


Figure 2: Broken Air Release Valve due to H_2S Damage

technologies are not applicable to force mains. Televising is not feasible as force mains are designed to run at full capacity and consistent visibility in wastewater is near impossible. Flushing or jetting a force main is not as effective as it is in gravity lines because deposit buildup in force mains can be hardened. Because of these limitations, force mains are often not included in regular assessment and maintenance programs and municipalities react to force main failures instead of being proactive to prevent force main failures.

Inspection technologies have improved with time and tools available that can extract actionable data at an affordable price. RJN, utilizing INGU's free-floating Pipers® devices as seen in Figure 1, has developed a screening level assessment that doesn't require a force main to be shut off to collect vital information on a pipeline's condition.

3. FORCE MAIN RISKS

When inspecting force mains, it is important to know their common modes of failures. Force mains can vary in material and the failure mechanisms differ in each. Understanding each force main and its high-risk locations is vital in assessing a force main's risk of imminent failure.

3.1 Internal Corrosion

Approximately 64 percent of force mains are ferrous material such as cast iron, ductile iron, and steel. The highest cause of failure in these force mains is internal corrosion caused by hydrogen sulfide (H_2S) gases (EPA, 2010). H_2S is formed under anaerobic (septic) conditions when bacteria produce sulfides that then combine with hydrogen. High retention times at pump stations and low velocity flow, resulting in long travel times, can increase the amount of hydrogen sulfide in wastewater which can then form into gas pockets at high elevation points along the force main. Proper installation and maintenance of air release valves (ARVs) can help mitigate gas pockets and subsequent hydrogen sulfide damage at high elevation locations.

3.2 Structure Deterioration

Depending on the profile of a force main, it may have one or multiple structures along its path. High points in force mains trap air, which reduces hydraulic capacity, causes non-uniform flow, and creates the potential for sulfide corrosion. ARVs, as aforementioned, are installed if high points in the alignment of force mains cannot be avoided, while blowoffs are installed at low points. All structures and valves must be diligently inspected and maintained as they are integral components of an efficient force main.

As seen in Figure 2, if not properly maintained, these structures can be the source of failure on a force main. For example, the ARV in Figure 2 was on a PVC force main but a local stream had submerged the structure with infiltration. As a result, the ARV became inoperable and sulfide corrosion slowly deteriorated the metallic piping and valve. In the end, one of few only metallic components of the entire PVC force main was the source of the failure.

3.3 Low Scouring Velocity

The minimum self-cleaning velocity for a force main is two (2) feet per second. Below this minimum velocity, deposits can build up on a force main which will restrict capacity and can be a risk for abrasion over time. The profile of a force main will reveal low points that are at risk of significant deposit buildup if a self-cleaning velocity is not achieved. In addition, as wastewater flows through gravity and force main pipes, heavier particles can accumulate forming a solid deposit. Depending on the type of particles, this results in a flow regime with a sliding bed or a stationary bed. A sliding bed can cause abrasion of the pipe's invert as seen in Figure 3. Conversely, a stationary bed reduces the cross-sectional area available in the pipe effectively reducing the hydraulic capacity. Both types of solid deposits can cause long-term force main problems to occur if left unaddressed. Finally, gas pocket formation is more likely to occur in slower velocities.

These three factors contribute to the majority of the different ways a force main can fail. Reducing and highlighting these risks is the goal force main management programs. Evaluating consequence of failure guides which pipelines to inspect and what techniques to use. Condition assessment determines likelihood of failure. Together, consequence and likelihood of failure create a clear picture of risk that informs short- and long-term management decisions.

Figure 3: Pipe Invert Abrasion

3.4 Other

Force mains can fail due to a multitude of other reasons. If a force main is not cathodically protected, external corrosion can cause breaks via weathering of exposed pipe, stray currents, and corrosive soils. External loading due to road crossings, utility crossings, and previous repairs can also lead to eventual failure. Lastly, pressure surges caused by sudden changes in the flow's velocity often occur during pump start-ups or shutdowns or as the result of sudden expulsion of air from the system. Pressure surges can affect the integrity of the pipe over time and if the surge is in excess of the pipe's pressure rating, it can result in a catastrophic failure of the pipe.

4. PLANNING AND PREPARATION

4.1 Desktop Study

The first phase in the SLA is gathering and reviewing all available data for a force main. This includes type of material, diameter, lengths, pump curves, pump run times, force main plan and profiles, and design and/or record drawings of the lift station. The objective of this phase is preparing for a preliminary site visit. All available data is used to develop an understanding of the force main operations including an estimate of travel times.

Potential launch and retrieval points and any structures on the force main will be noted after studying the plans.

Pumps have to be running throughout the entire duration of a deployment to ensure accurate data. Pipers® are a free-floating device meaning their arrival speed is directly correlated to the flow speed and therefore highly predictable. Thus, once travel time times have been estimated, it is essential to follow-up with system owners and inquire if there is sufficient flow to the lift station for the pumps to run continuously. Knowing the travel time also helps with the retrieval process as well.

Figure 4: Lift Station Check Valves - Insertion Points

4.2 Preliminary Site Visit

The primary goal of a preliminary site visit is to increase the likelihood of a smooth deployment of the inspection devices. The fundamental tasks of a preliminary site visit are as follows:

- *Confirmation of Sufficient Volume* - Determine if extended pump shut-down times will provide enough volume in the upstream tributary system for a deployment or if nearby hydrants/vacuum trucks need to be used to provide supplemental flow.
- *Calculating Precise Travel Times* – Perform timed dye test runs to precisely calculate confirm travel times and flows to ensure retrieval success.
- *Confirmation of Deployment Procedures* – Assess the lift station function, insertion points as seen in Figure 4, and visiting the discharge manhole, if applicable, to plan for retrieval.
- *Accessibility of the Force Main* – Document areas and structures, such as ARVs or cleanout structures, where the force main is accessible and their respective conditions.

A preliminary site visit will provide a tangible deployment work plan consisting of the insertion and retrieval points as well as all the necessary velocity and travel time calculations. These travel time calculations are imperative for both the retrieval process, with regards to timing, and for determining how much flow is needed for the duration of each deployment. If the upstream tributary system cannot support enough volume without risk of basement backups, then supplemental flow must be brought in, such as nearby fire hydrants or vactor trucks.

5. DEPLOYMENT

For the deployment, once sufficient volume is confirmed and the retrieval set-up is ready, dye and the activated device will be inserted into the designated insertion point. Together with the preliminary site visit travel times, the dye will help crews at the retrieval point know when to expect the device and be prepared.
Two successful deployments are recommended to determine what is repeatable in each run. Repeatability is important for verifying possible defects or gas pockets. If something can be produced in both deployments under the same exact conditions in a relatively short amount of time, it can be assumed the results are not random.

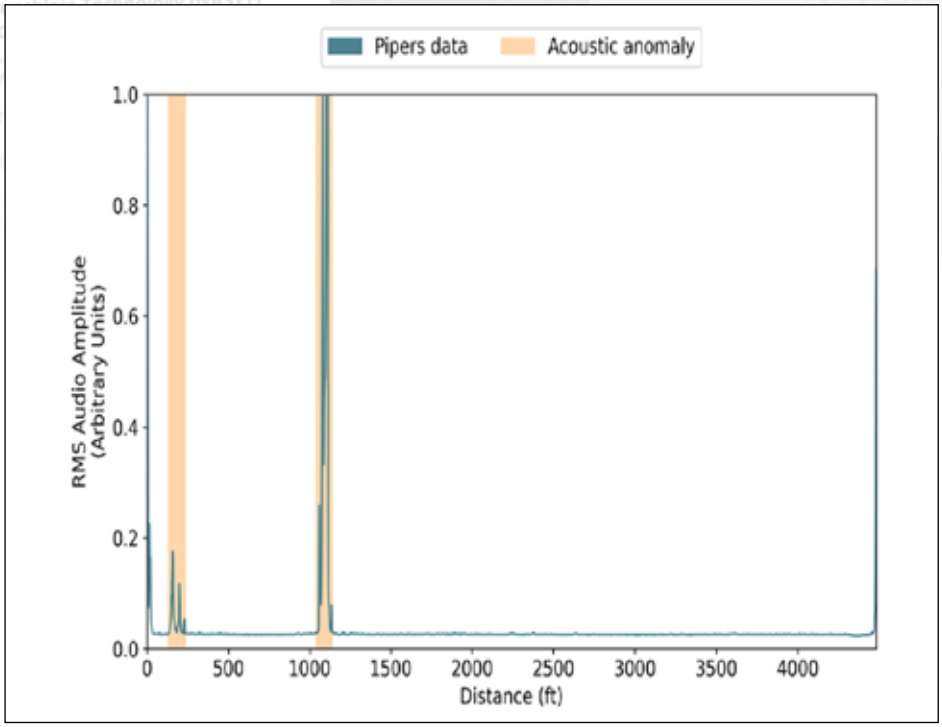

Figure 5: Acoustic Amplitude Analysis

6. SCREENING LEVEL ASSESSMENT DATA ANALYSIS

The three sets of data collected in an SLA is acoustic data, a pressure survey, and a magnetic flux analysis. A breakdown of these three sets of data and how they can be interpreted and analyzed are below.

6.1 Acoustic Data

Acoustic data can detect sounds caused by air pockets, pumps, and other noise sources in the pipeline.

Air pockets are usually louder than the background noise in the pipeline and can be confirmed by the specific spectral signature at its location. Acoustic anomalies should always be compared to a force main's profile. Acoustic anomalies with large amplitudes, such as the one in Figure 5, that align with localized high points should be considered when budgeting next steps.
Any other background noises that do not produce enough amplitude to be considered an air pocket are referred to as acoustic anomalies. Acoustic anomalies are short sections where air is entrapped. The acoustic data could be picking up noise where the flow gets slightly more turbulent at a bend, a valve, or sudden change in the force main's profile. For that reason, these

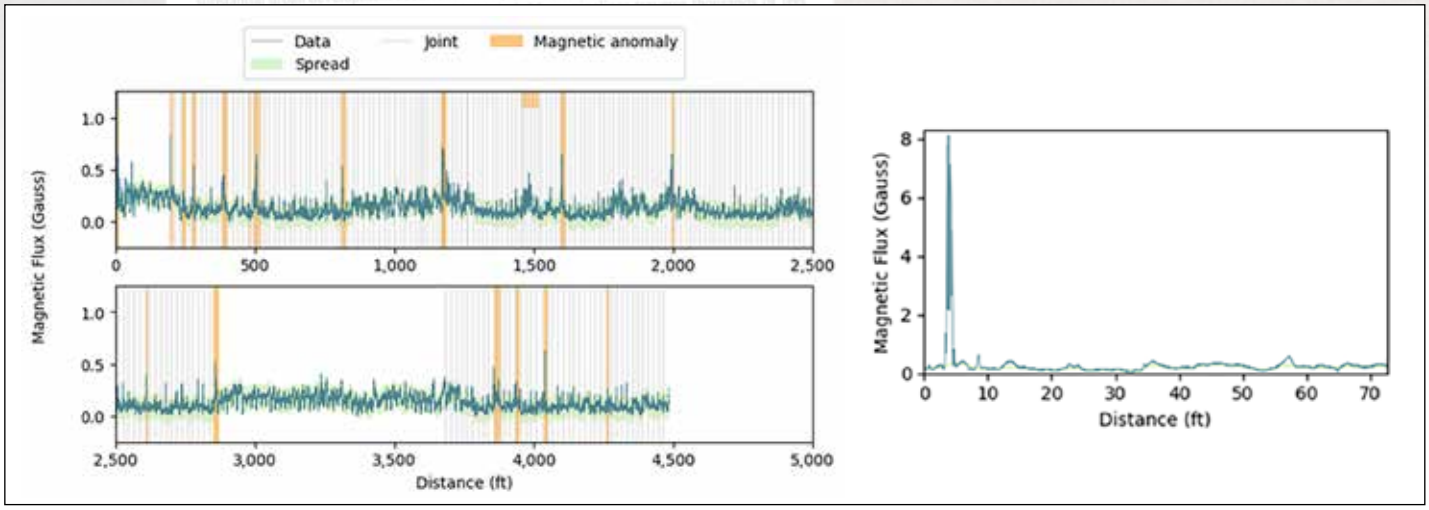

Figure 6: Magnetic Flux Analysis (Left); Flow Meter Identified as Anomaly (Right)

anomalies should be monitored to ensure they do not develop into air pockets over time as more air gets trapped.

All existing ARVs should be inspected and rehabilitated if needed. Additional ARVs should be installed at localized high points or at acoustic anomaly locations if an ARV is not already present. Ferrous force mains with larger acoustic anomalies at higher points should be considered for further inspection and even rehabilitation. Depending on the size and age of a force main, it may make more economical sense to partially rehabilitate an older, smaller force main than to put more money towards further inspection. Conversely, further inspection such as a broadband electromagnetic (BEM) inspection may be warranted on larger force mains where rehabilitation

would require extensive bypass operations and significant cost.

6.2 Pressure Monitoring Survey

SLAs will also collect pressure data throughout the force main based on the hydraulic grade line (HGL). The HGL is calculated based on the measured pressure and the force main elevation which accounts for the effects of hydrostatic pressure. The HGL is an indication of the amount of frictional pressure loss throughout the force main, where regions of the HGL with a steeper slope experience more flow friction suggesting increased internal surface roughness and/or diameter restrictions. These diameter restrictions can indicate buildup such as tuberculation in ferrous force mains and grease in PVC force mains. These buildups can vary in size depending on the profile of the force main and the scouring velocity.

Table 1: City of Naperville Inspected Force Main Features

Lift Station	Force Main Size (inches)	Force Main Length (feet)	Force Main Material	No. of Air Valves	Year Installed
Cinnamon Creek	6	2,261	DIP	1	1976
Hobson Oaks	4	770	DIP	0	1987
Rivermist	4	476	DIP	0	1987
Riverwoods	6	1,633	DIP	0	1988
Country Lakes	10	1,094	PVC	1	1998

Force Main	Cleaning Rating	Condition Rating	Overall Rating	Recommendations	Follow-Up Investigation?	Minor Improvement/Upgrades	Budgetary Cost Estimates
Hobson Oaks	4	4	4	1. Force Main Rehabilitation - Partial Replacement, Full Replacement, or Trenchless Rehabilitation 2. Restoring Hydraulic Capacity - Pigging the 4" DIP force main	Yes		1. Partial Replacement (150 LF) - $95,050 2. Full Replacement - $348,205 3. Trenchless Rehabilitation - $333,000 4. Pigging - $50,000 5. Monitoring and Inspection Program - $43,000
Rivermist	5	5	5	1. Force Main Rehabilitation - Partial Replacement, Full Replacement, or Trenchless Rehabilitation 2. Restoring Hydraulic Capacity - Pigging the 4" DIP force main	Yes		1. Partial Replacement (390 LF) - $178,930 2. Full Replacement - $240,250 3. Trenchless Rehabilitation - $234,250 4. Pigging - $50,000 5. Monitoring and Inspection Program - $43,000
Riverwoods	2	2	2	1. Restoring Hydraulic Capacity - Pigging the 4" DIP force main	Yes	1. Installation of Air Release Valve and Structure at Localized High Point.	1. Pigging - $50,000 2. Monitoring and Inspection Program - $43,000 3. Air Release Manhole and Valve - $25,000
Country Lakes	2	1	1	1. Restoring Hydraulic Capacity - Pigging the 10" PVC force main	Yes	1. Installation of Cleanout and Blowoff Valves and Structures at Low Point. 2. Valve Vault Manhole Replacement	1. Pigging - $50,000 2. Monitoring and Inspection Program - $43,000 3. Cleanout and Blowoff Manholes and Valves - $40,000 4. Valve Vault Manhole Replacement - $60,000

Table 2: 2022 Naperville Force Main Programs Recommendations Summary

The 2022 force main program featured three DIP force mains ranging from 4" to 6" in diameter and one 10" PVC force main. All force mains were nearing their design life and had suffered no breaks in their histories. The SLA provided insight to the City on the condition of these force mains and the recommendations are summarized in Table 2. The cleaning and condition ratings are as follows:

Cleaning Ratings

1. 0% to 10% Diameter Restriction
2. 10% to 20% Diameter Restriction
3. 20% to 30% Diameter Restriction
4. 30% to 35% Diameter Restriction
5. 35% or Greater Diameter Restriction

Condition Ratings

1. Zero Anomalies
2. Low Risk Anomalies
3. Low Risk Anomalies, Structure Deterioration
4. Medium to High-Risk Anomalies
5. Numerous High-Risk Anomalies

Force mains with large sections of diameter restrictions due to deposits should be pigged to restore hydraulic capacity. Pigging structures should be installed as well as cleanout structures at low points in the force main's profile, for future maintenance.

There are two types of pigging operations: ice pigging and conventional pigging. Ice pigging is recommended for smaller diameter pipes as it provides all the advantages of solid conventional pigging but none of the risks involved. It has 100 times the scouring power of flushing and will flow like a liquid through obstructions such as changes in diameter, bend, and valves, and it can be inserted and ejected from the pipe using small diameter fittings. If an ice pig does become stuck it can be left to melt and flushed out after a few hours. Ice pigging yields a high-quality clean comparable to more intrusive methods. However, ice pigging is only suitable for diameters smaller than 14 inches. For pipes with diameters larger than 14 inches, conventional mechanical pigging is recommended. In order to navigate turns, multiple access pits and pigging structures may need to be installed along the line.

6.3 Magnetic Flux

The last set of data collected during SLAs is the magnetic flux analysis. The magnetic flux can provide insights along the pipeline and is intended to identify bends, areas of potential deterioration, material changes, air release valves, flow meters, cleanout structures, and additional metallic fittings along the force main. As seen in Figure 6, magnetic anomalies are identified where spikes occur between joints. The gray bands represent joints, the green band indicates the characteristic spread in the magnetic flux, and the orange highlights indicate magnetic outliers that fall outside the characteristic spread. As an overall condition assessment, pipelines with wider spread in the magnetic flux are expected to be in worse condition compared to those with narrower spread and smoother magnetic flux.
Magnetic flux data should be plotted along the profile of a force main to determine if any large anomalies occur at high-risk locations or locations where an acoustic anomaly was located. Similarly, to acoustic anomalies, the size of the force main should dictate whether rehabilitation or further inspection is warranted for a magnetic flux anomaly. Large magnetic anomalies located at high-risk locations in larger diameter metallic pipes should be further inspected in a second phase. Conversely, replacement may be a more feasible option on smaller diameter force mains.

Depending on the results from these phase two assessments, force main rehabilitation may need to be prioritized. Force mains can be rehabilitated via partial replacement, full replacement, and trenchless pressure lining. Each force main is unique and each method's advantages and disadvantages are compared. For example, partial replacement of pipe will create new sections of pipe that have a fresh design life of 50 years but other original sections of the force main may still be deteriorating and susceptible to a break in the future. For full open-cut replacement, it offers a new design life of 50 years to an entire force main but has drawbacks with regards to traffic control, resident disruption, restoration efforts, and expensive costs.

7. CASE STUDIES

7.1 Naperville, IL

The City of Naperville has taken a proactive approach and has performed five (5) force main inspections and plan to inspect the remaining eighteen (18) force mains over the next four years.

Figure 7: Submerged Air Release Valve

Following a successful pilot force main deployment in 2021 of the City's Cinnamon Creek force main, four additional force mains were chosen for SLAs in 2022. These four (4) force mains were the Country Lakes, Hobson Oaks, Rivermist, and Riverwoods force mains and their features are listed in Table 1.

In all five (5) force mains, the SLAs produced actionable data for the City. In total six (6) acoustic anomalies were identified and two force mains were found to be running below full capacity. Partial replacement was recommended for the Cinnamon Creek force main at road crossings with large magnetic flux anomalies. An ARV was located at this location but was inoperable for an unknown number of years before 2006. The large magnetic anomalies potentially represent wall loss due to an old gas pocket. Due to the smaller 6-inch diameter and advanced age, 200 LF of 6-inch DIP was recommended to be removed and replaced from the Cinnamon Creek force main.

The overall ratings were determined based upon the cleaning and condition ratings to identify force mains that require more attention than others. The condition rating, which considers a force main's age, past breaks, and anomalies, is weighted heavier than the cleaning rating.
The Hobson Oaks and Rivermist force mains were both DIP force mains that exhibited signs of corrosion and concern for failure. The Hobson Oaks force main was found to have a low scouring velocity and potential tuberculation buildup restricting the diameter by up to 32.5 percent in some sections of pipe. Two acoustic anomalies and numerous magnetic flux anomalies were identified along the pipe. The Rivermist force main was found to not be running at full capacity and potential tuberculation buildup restricted the diameter by 37.5 percent in some sections. Given the smaller sizes and lengths of both force mains, trenchless rehabilitation was recommended for both the Hobson Oaks

and Rivermist force mains. Pressure lining reduces the bypass times and cost, environmental footprint, traffic control, and public disruption all while restoring the integrity of the force main and resetting their design lives to 50 years.

The Riverwoods and Country Lakes force mains exhibited signs of force mains operating as they were intended. The Riverwoods DIP force main had one smaller acoustic anomaly at a localized high point where an ARV was recommended to be installed at. The Country Lakes force main was also found to be running below full capacity. There is probably too much air entrapped in the force main for a single air release valve to remove prior to the next pump cycle turning on. However, since Country Lakes is PVC, H_2S corrosion is not an issue as it is with iron force mains, but hydraulic capacity is still a concern.

Additional ARVs as well as pigging structures were recommended to be installed on the line. Both force mains were recommended for continued monitoring and inspection. Magnetic flux anomalies can be monitored and evaluated more thoroughly with multiple SLAs. Just as consecutive deployments on the same pipe during one deployment provides accuracy for the magnetic flux analysis, multiple deployments over a multi-year span paints a much clearer picture on these actual anomalies and their significance.

7.2 Glenbard Wastewater Authority, IL

In June 2022, an SLA was performed on the Glenbard Wastewater Authority's (Authority) 10-inch PVC Valley View force main which travels underneath and then parallel to Illinois Route 53 (I-53). I-53 is scheduled to undergo construction for the addition of a bike path along the force main's route. This portion of the force main is DIP within a steel casing.

Figure 8: October 2022 ARV #1 Break

Replacement of this section would be especially significant due to the cost of traffic control and construction to replace or repair a force main underneath a major road. The Authority decided to proactively perform an internal inspection of the force main to determine its condition and if any rehabilitation could be done while construction was underway and access to the force main was available.

The Valley View force main was predominantly PVC but still had two sections of DIP and three metallic ARVs and their associated structures along its route which are susceptible to H2S corrosion. The SLA revealed little concern with the DIP sections of force main but all three ARVs were found to be inundated with infiltration and damaged by corrosion. The force main is located within the floodway of the East Branch DuPage River. These ARVs are placed at high points along the force main so that trapped air can escape. Submerged ARVs can lead to deterioration, causing them to not function properly and leave this air trapped. These ARVs, their adjacent DI piping, and their structures were recommended to be rehabilitated and replaced. In addition, ice pigging was recommended to remove buildup along the force main.

In October 2022, the Valley Force Main suffered a break at the first ARV along its line. As seen in Figure 8, the failure occurred at the ARV piping where corrosion had caused severe wall loss. The Authority was proactive in its inspection but it is difficult to estimate the true remaining life of the pipeline if no rehabilitation were to occur. A break or leak could be months or years away. Being proactive for force main maintenance, rather than reactive, is highly recommended when considering a budget. An emergency force main repair can be incredibly expensive.

8. CONCLUSIONS

Force main conditions are not necessarily uniform throughout the length of the entire pipeline. SLAs provide insight to owners on potential options for their force mains and helps plan a budget. Pipeline characteristics evaluated individually, especially age, is not an accurate method for determining the pipeline condition. Force mains can break at any time so proactive management and budget planning is crucial. Assessing a force main is a highly specialized service, but that does not mean it has to be a massive effort or require an exorbitant budget. Using the appropriate pre-planning assessment strategies and coupling those efforts with the most advantageous technologies will deliver actionable information. The results of a successful SLA provide system owners with three primary courses of action: targeted recommendations for follow-up studies, rehabilitation recommendations, or conditions warrant no further action.

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