IMPLEMENTING ADVANCED TECHNOLOGIES AND ASSET MANAGEMENT

To Help Prioritize and Rehabilitate Critical Pressurized Pipeline Infrastructure

1. ABSTRACT

Pressurized pipeline infrastructure (both water and wastewater) throughout the US is reaching a critical stage of critical condition. The outlook of this infrastructure as recently described in ASCE's 2021 Report Card (and statewide individual report cards in each successive years) shows that the trend line of system deterioration is getting worse for both water and sewer conveyance systems. This trend will, quite frankly, not change direction in a positive manner, unless a number of critical steps are undertaken. The report is quite clear that the only feasible way to address this rapidly increasing rate of pressurize pipelines for both water and sewer infrastructure deterioration is through asset management and the will of elected offices to fund these programs. Specifically, it states that "Asset management provides utility managers and decision-makers with critical information on capital infrastructure assets and timing of investments. Some key steps for asset management include making an inventory of critical assets; evaluating their condition and performance; developing plans to maintain, repair, and replace assets; and funding these activities".

The hardest ones are also those that need to address the systems that are pressurized 24/7/365 with no room for holidays and time off. To turn this corner and establish better and more reliable information on the actual condition of these buried and essential pressurized assets, several recent (and, frankly, pretty cool) advances in performing both external and internal inspection and assessment of pressurized pipelines, wastewater force mains, valves, hydrants, and other ancillary facilities has moved the level of understating condition and remaining useful life (RUL) to new levels. With these technologies and established protocols for determining their associated risks, cities and utilities are starting to bring this all together under effective asset management (AM) planning so that the three pillars of AM can be managed: sustainability, reliability, and efficiency. We can turn this around and do with confidence.

2. KEY WORDS

Pressurized pipe, inspection, assessment, asset management, remaining-useful-life (RUL), risk, prioritization, technology, costs, budget.

3. INTRODUCTION

There are many challenges associated with pressurized pipeline assessment and prioritization for follow-up renewal. Wastewater force mains and water transmission and distribution systems (combined are referenced herein as pressurized conveyance infrastructure) are inherently challenging to inspect and assess. The challenge is elevated when one needs to take this limited inspection data and evaluate these systems and their relative condition associated with structural integrity, hydraulic performance, reliability, and remaining service life. And do this pipe-by-pipe. This begins with the simple challenge that this critical infrastructure is, for the most part, buried.

The fact that pressurized municipal pipeline infrastructure is buried, and their condition is unknown means that other site-specific challenges can include the following:

- Access is often very, very limited (yes, quite limited indeed).
- Location of buried pressurized pipeline infrastructure is generally vague or uncertain.
- Typically, there is generally minimal (or absolutely no) history of O&M inspections, preventative maintenance, or even emergency repairs (break history).
- They represent a wide range of age, diameter, and materials, and methods of construction (if even known by the utility).
- They are always pressurized, often exceeding 100 psi (higher if surges/transients occur).
- They are the quintessential 24/7/365 systems with little or no tolerance or time allowance for temporary shutdown or bypass.
- There are significant public health issues associated with internal entry and

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inspection.

•Impediments such as debris, tuberculation, and fittings are usually the "rule" instead of the "exception".

•Obstructions such as inoperable (or partially closed) valves, fittings, and protrusions are routine.

•Currently, there are no industry-accepted condition and code-based standards that can be applied to both the wastewater and water infrastructure (although a recent publication by the Water Research Foundation titled "Potable Water Pipeline Defect Condition Rating" and the recently developed and soon-to-be-published PACP codes for pressure pipe are the first efforts made, in that regard).

The other challenge is that many of these buried and pressurized systems are already in critical condition, with a bleak forecast for their continued decline as they continue to race past their remaining useful service life. As an example, Figure 1 shows the historical trendline of the average age of these buried pipeline assets in the US, by decade, as reported by the EPA in their 2007 Gap Analysis. Data for the current decade, as reported by several municipalities and water utilities, represents more than one million miles of pressurized conveyance systems.

The average life span (and thus its remaining useful life) of a single pressure pipe asset depends on several variables including its original design criteria, materials and methods of construction, soil pH, operating pressure (including transients), seismology, supporting foundation, and preventative maintenance. Design engineers often use 50 years as the average life expectancy for most pipe types. However, there are water distribution systems (and a few wastewater force mains), currently in service, that exceed 100 years.

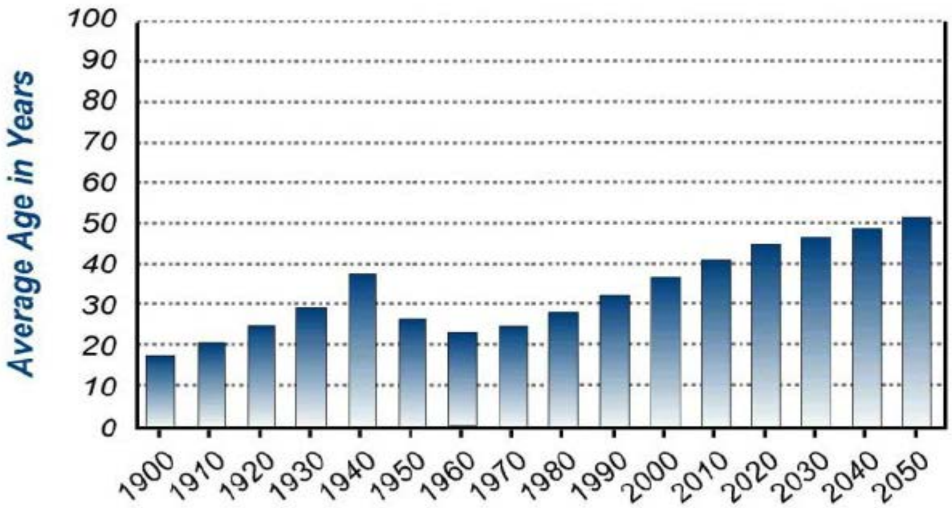

FIGURE 1. AVERAGE AGE OF BURIED PIPELINE INFRASTRUCTURE BY DECADE

The fact is, we currently do not have good data analytics to determine an overall remaining useful life of the nation's 2.2 million feet of pressure pipe infrastructure that has now surpassed 40 years of supplying drinking water to US consumers. Whether the actual life expectancy is 50, 60, or 70 years, we as an industry need to agree that the remaining useful life of a typical water conveyance asset is approaching zero, and that is certainly something to be concerned about.

The problem with pressure pipelines is one of being a double-edged sword. These systems are not only aging dramatically, but the estimated costs to upgrade and improve this critical national infrastructure is also increasing at astonishing levels. In their recent report to Congress, the EPA determined that the nation's water utilities in particular will need $313 billion in water distribution infrastructure investments over the next 20 years. This same survey by EPA found that water utilities planned to spend an estimated $78 billion over the next 20 years to satisfy that need. This demonstrates a shortfall of a whopping $235 billion in funding for needed improvements during the next 20 years.

In its updated 2021 report titled "Report Card for America's Infrastructure Report Card", ASCE made several compelling arguments that urgent funding is needed to avoid a "water infrastructure crisis". A few highlights from this report include:

Drinking water infrastructure overall grade score: C-.

Wastewater infrastructure overall grade score: D+.

260,000 water main breaks per year with increasing frequency (one every two minutes).

$1.0 trillion needed to maintain and expand service during the next 25 years.

More than 6 billion gallons of treated water lost every day through system leaks.

Whether the estimated need for pressure pipeline conveyance system improvements is $300 billion over the next 20 years, $1.0 trillion over the next 25 years, or some something in between, the critical needs must be met first before the longer-term challenges are prioritized. Digging ourselves out of this hole (or sinkhole) will require a large inspection technology toolbox that includes smart data analytics and good business management solutions. But before reviewing these technologies, some groundwork is needed to figure out what/where/when these new inspection tools are used. And the understanding of asset management is a good place to begin.

A GOOD START BEGINS WITH THE DEVELOPMENT OF A SENSIBLE ASSET MANAGEMENT SYSTEM

To address these serious, if not alarming, conditions, municipalities and water utilities should consider the need to implement asset management as a good starting point. There are many definitions for asset management that spans the financial, medical, construction, and energy sectors, but we believe a good definition, and one that we have used frequently, for publicly owned utilities could be the following:

Asset management is any system that monitors and maintains things of value to an entity or group. It may apply to both tangible assets such as buried utility infrastructure and to intangible assets such as human capital, intellectual property, goodwill, and financial assets.

To understand the value of asset management to help avert a national environmental and water crisis, one needs to also understand the trade-off between "capital" and "operating" expenditures. In addition, the actual cost of providing safe water supply and drinking water may be misunderstood to the average utility customer (rate payer), as much of the infrastructure is hidden from view One could argue that pressure pipeline infrastructure is even more hidden than typical wastewater collection (gravity) system infrastructure. Studies have shown that the typical water utility has 5-10 times more value in its assets than its annual operating income. It is the experience of every municipality and water utility that their customers expect on-demand, high quality water without interruption of its pressure pipeline infrastructure. Maintaining that level of service requires the utility to continually reinvest in the replacement and rehabilitation of those pressure pipeline assets that have reached the end of their useful life. Kicking this "reinvestment can" down the road will only result in increasing costs of (a) operation and maintenance and (b) emergency repairs due to system failures.

Well-managed utilities also implement asset management programs to help them make prudent and economically justified decisions regarding capital investments of their most critical assets. The age of pipe alone is not always the appropriate indicator of the need for that pipe to be rehabilitated or replaced. Through asset management, utilities can document the condition and failure history of their piping network and other assets. Over time, these utilities can reliably predict the likely remaining useful life of their vast and sprawling pressure pipeline assets. In some cases, utilities will find that they need to replace pipe sooner than age would suggest, while in other cases, they will find that pipe can be expected to provide many more years of service despite its age.

lines serving a hospital or other critical infrastructure may be managed to a lower risk of failure than will a pipeline serving a commercial area.

The most recent survey by EPA, citied previously, also shows that many utilities are only in the very early stages of developing an asset management program, as evidenced by the reliance of most survey respondents on the survey's baseline pipe replacement rate. That baseline rate of 0.5 percent per year, or 10 percent over 20 years, reflects the current documented rate of replacement of pipe within the water and wastewater industry. A 0.5 percent per year replacement rate is highly unlikely for a water asset service life of 200 years. So, we know for certain that a 0.5 percent replacement metric is a poor starting place.

Asset management provides managers and those responsible for proper governance with the kind of information on their needs, timing, and priorities to implement capital and preventative maintenance projects and programs. The beginning steps for asset management is to create a database of the condition and operation of the entire system, to a level by which such informed decisions can be made. The first projects that can subsequently be peeled off from the priority list are those whose asset management scores are in the "critical" range. The overarching principal of using asset management for any municipal pipe

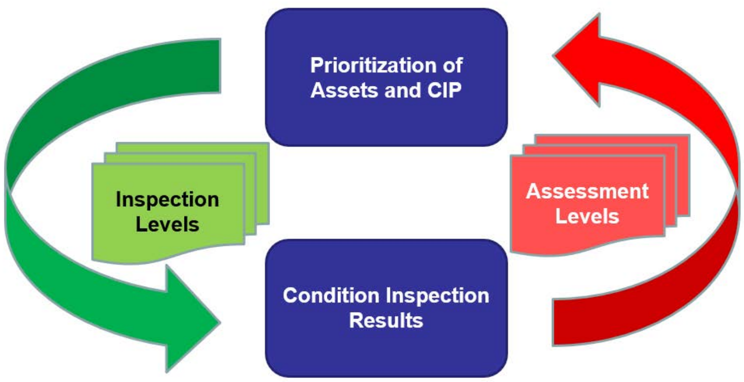

FIGURE 2. THE ASSET MANAGEMENT CYCLE FOR PRESSURE PIPE INFRASTRUCTURE

As a result of implementing asset management, some utilities are documenting larger capital investment needs than they had previously anticipated. Others are finding that there is greater remaining useful life in their assets than they had previously assumed. Deciding when to replace a given pressure pipeline asset ultimately depends upon a utility's target level of service and the risk the utility accepts of that section of pipe failing. The target level of service for the entire utility may incorporate differing levels of failure risk for different components of their distribution system. As an example, pipe-

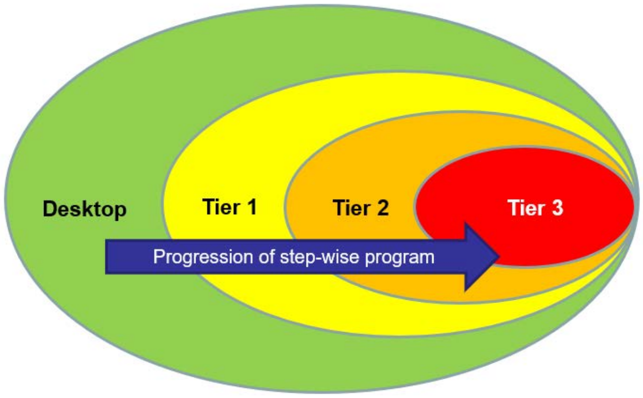

FIGURE 3. EXAMPLE TIERED (STEPWISE) APPROACH FOR PRESSURE PIPE INFRASTRUCTURE ASSET MANAGEMENT

line utility is to have enough condition data of each asset so that a municipality or water utility can decide on a repair, rehabilitate, or replace solution to that pipe, valve, or hydrant immediately before it fails or results in an unplanned or emergency repair. The combination of (a) system knowledge, (b) a big inspection toolbox, and (c) dependable prediction diagnostics are needed to successfully manage a water utility. The cyclical process of asset management to optimize the cost and time for inspection, assessment, and capital improvement is shown in Figure 2

The main point of Figure 2 is to encourage a municipality or water utility to optimize, as much as possible, the overall cost of improving the condition and operation of the pressure pipeline system by developing a large inspection toolbox and to know when to grab a specific tool or inspection technology to get to a better prioritized list of all assets, based on their respective asset score. For those municipalities and utilities that have moved in this direction, the outcomes have been promising as they have observed a general decrease in the frequency of main breaks/emergency repairs and improved hydraulic performance. The success of implementing such a cycle also requires the commitment of utilities to properly fund such a program and stay on-target year-to-year. Also, inherent in the implementation of asset management, is the reality that some pressure pipeline assets will fail before they rise to the top for further action. Positive outcomes are often measured in years rather than months.

With each pass through the diagnostic cycle shown in Figure 2, the utility may determine that more advanced inspection tools (in a higher level or tier) maybe be needed to reach a point where the pipeline utility is confident in reliability of the overall asset score (a combination of likelihood-of-failure or LOF and consequence-of-failure or COF) and is sufficient for its proper place in the overall priority of all assets and position within the traditional risk matrix. The choice to implement a higher-tier diagnostic technology can also be the need for additional condition information of a high-risk asset to select an appropriate capital repair or maintenance activity. Figure 3 shows how these levels, as they increase in unit costs, also apply to a smaller and more focused pool (or footprint) of assets. Regarding asset management for pressure pipeline infrastructure, it normally begins with the organization and prioritization of all assets using desktop data (no inspections). Utilities are encouraged to perform a robust data mining of its pressure pipeline assets and organize it in a manner that will produce an initial priority list to begin the inspection process.

The next challenge is to determine

Desktop	Tier 1	Tier 2	Tier 3
GIS Mapping	Pressure Monitoring	Transient Analysis	Electromagnetic
Asset Inventory	Predictive Modeling	Internal Pipe Inspection	Radiography
Work Order History	Hydraulic Modeling	Wall Thickness (external)	Destructive Testing
Master Plan	Leak Detection (external)	Corrosion Testing	GPR and PPR
Record Drawings	Soil Corrosivity	Leak Detection (internal)	Material Science
	Water Chemistry	Pot Holing/Coupon	Remote Field Technology
	Sound Wave	Phenolphthalein Test	Ultrasonic Inspection

FIGURE 4. INSPECTION AND ASSESSMENT TECHNOLOGIES VS. TIER LEVEL

Likelihood of Failure (LOF)	Consequence of Failure (COF) 1	2	3	4	5
1	L	L	L	M	M
2	L	M	M	A	A
3	L	M	A	A	A
4	M	M	A	H	H
5	M	A	H	H	C

FIGURE 5. EXAMPLE DATA FLOW FROM INSPECTION TO ASSET RISK SCORING

what defines each inspection level and what inspection technologies or tools belong within each level.

INSPECTION LEVELS/TIERS AND CORRESPONDING INPSECTION TECHNOLOGIES

The good news for engineers, cities, water utilities and municipalities is that the development of technologies to test, inspect, and assess the condition of buried pressure pipeline infrastructure has advanced in very recent years. Prior to this, there were only a few dependable (and enormously expensive) inspection tools and technologies to inspect the internal condition of pressure pipelines under live flow conditions (as there has been for gravity wastewater and storm water systems for the past several years). The only means to determine the internal condition of a particular pressure pipe asset, in recent years, was to perform a temporary shut-down, access the pipeline by removing one or more sections of pipeline, valves or fittings, perform limited inspections, reassemble the systems, perform disinfection, and put the system back into service. For external condition inspection and assessment, this meant that extraordinary efforts were required to excavate it and either perform a visual inspection of a small portion or extract pipe coupons for further laboratory analysis (and a patch or other appropriate repair). Because of this, very little actual internal (and external) inspections have been performed under any type of routine or preventative maintenance planning by utilities both large and small.

However, these expensive and very disruptive inspection and assessment protocols are slowly being replaced as the pressure pipeline technology industry is gradually developing advanced and robotic systems that can be cost-effectively introduced into targeted (high priority) water mains and other pressure pipe assets under live flow, even without the need for destructive, pre-inspection entry access. The introduction of these new inspection technologies has been made possible as the science of HDCCTV, infrared, electromagnetics, sonar, acoustics, remote field eddy, magnetic flux, pipe penetrating radar, and radiography has advanced globally, thus creating new and better ways of performing detailed condition assessments of pressure pipeline infrastructure.

As with gravity wastewater systems, the toolbox is getting larger and more complex. As new technologies are introduced to the commercial sector, the utility and the consulting communities have the added challenge of vetting these tools to determine where they belong in the overall scheme of their strategic usefulness in creating meaningful information regarding pressure pipeline assets (both water and wastewater). As the market for a particular type of technology enters a period of maturation, it essentially moves through a process beginning with prototype and development, to trial testing, and finally full-scale commercialization. As a word of caution, each of these technologies comes with a price. The challenge is to determine when one moves to the next tier or inspection level for a particular group of pressure pipe assets. Usually, this is an analysis that combines risk and cost-benefit. This is where the adaptation of an asset management plan can help a city, municipality or water utility integrate these technology tools into a particular inspection tier or level so that they leverage each one (even the ones that may, perhaps, still be in a wait-and-see trail period) at the right time and the right place. To that end, Figure 4 shows an example of how a water utility can create their own bucket list for multiple levels or tiers of inspection after the initial desk-top prioritization list has been developed.

In this case, the tiers are separated by two major factors; (a) cost of access and (b) cost of technology. For example, all the technologies listed under Tier 1 require very little preparation work in terms of creating direct access or making modifications to the existing pressure pipeline infrastructure. Depending on the number of technologies pulled from the toolbox to assess the existing pressure pipeline system, the LOF and COF scores from the initial desk-top results are updated to reflect more specific operational and condition information. The information can then be entered (or re-entered) into the risk matrix (an example matrix is shown in Figure 5).

As one moves strategically across the tiers from the initial desktop analysis to higher assessment levels (i.e., selecting a particular tool or technology at a particular cycle or time), the cost (commonly expressed as a unit price such as $/LF or $/asset) then becomes a major consideration. Unlike sanitary sewers, however, the unit cost for each tier can vary significantly. In fact, for live-main internal inspections, unlike sanitary sewers, most of the cost can be encountered in the actual internal inspection and data capture. This can include planning, preparation, mobilization, access, safety, disinfection, sampling (pre- and post-inspection), excavation and trench safety, traffic control, and public notification. In certain situations, more than 75% of the cost to inspect and assess a particularly challenging water pipeline can be encountered by the utility or their contractor before the actual inspection begins.

The final goal when combining LOF and COF scores with a progressive/cyclical and step-wise inspection strategy is to come to a well-informed decision on what to do with each-and-every pressurized pipeline asset within the water or wastewater distribution conveyance enterprise, which for larger utilities can represent tens of thousands of individual pipelines, valves, hydrants, and other appurtenances. This well-informed decision also needs to include a solid estimate of the asset's remaining useful life (RUL) which, when used properly, can make the job of scheduling and financing both short-term and long-term capital and O&M budgets easier and more manageable.

Given that there are several site conditions that influence the overall cost of performing work under each of the above levels or tiers, the graph shown in Figure 6 shows planning-level unit prices that can be anticipated for each level. It should be noted that the variation in unit pricing increases as one moves into a higher level. This is due to an increasing number of variables such as (a) project location, (b) pipe diameter, (c) access, (d) operating pressures, (e) pipe material type, (f) internal pipe conditions, (g) bends and fittings that must be negotiated, and (h) contiguous assets to be inspected. As an example, for large-diameter pressure pipe assets (such as those comprised of PCCP) with difficult and remote access, it is not uncommon to expect inspection and condition assessment results to exceed $100/LF and mobilization/set-up costs of $30,000 or more.

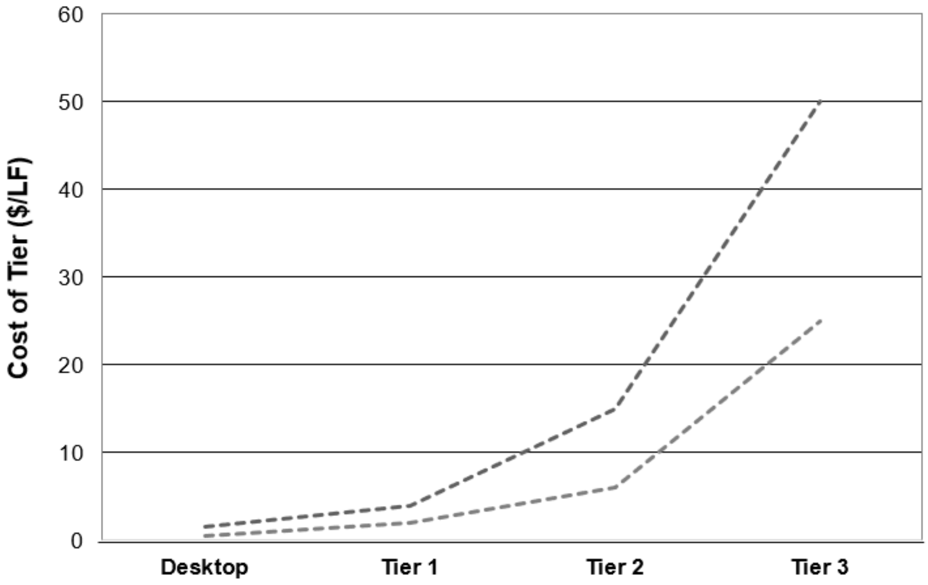

FIGURE 6. PLANNING LEVEL COSTS VS. INSPECTION TIER

INSPECTION TECHNOLOGY FOR PRESSURE PIPE INFRASTRUCTURE

Despite the many challenges over the years of getting good condition information associated with pressurized pipeline infrastructure, the encouraging news for both water and wastewater utilities is that technology to gain critical condition-related information has evolved rapidly during the past five years to meet the unique difficulties associated with primarily both external and internal inspections of pressure pipeline infrastructure. Advances for both external and internal (live-main) inspections, long-term transient monitoring, remote wall thickness measurement, and corrosion monitoring have meant that utilities and their engineers can now be looking ahead to selecting appropriate technologies from a robust toolbox.

External inspection using remote

sensing and diagnostic tools is still limited to non-invasive technologies such as acoustic leak locators, ground-penetrating radar, transient monitoring, and point-specific ultrasonic testing. Each offers limited evidence of the overall condition of the pipeline. They can be classified as either a Tier 1 or Tier 2 technology, depending on the asset's size, material, location, and depth.

Rather, the more significant and recent advances have been for those technologies that permit the utility to gather actual internal condition of a pressure pipeline asset (both water and wastewater) under live-flow conditions. This breakthrough has occurred at several levels of assets including nearly all diameters, materials, operating pressures, and flow. The significant challenge, however, remains that of access without taking the system down for it. A growing number of successful inspections of live-flow conditions have been reported by several cities, and utilities. Access has been successfully accomplished via hydrants (including equipment access through a wide range of hydrant manufacturers), air-release valves, hot-taps (as small as 2-inches), and other accessible fittings including those at pump stations and treatment facilities. The list of vendors and suppliers of internal live-flow inspection systems is growing steadily in industry maturation and reliability.

To demonstrate the current range of such technologies, Table 1 summarizes many of these new and developing alternatives (author's opinion, only, and may be different for one or more of the companies listed) available to the utility, depending on its need to determine the condition, asset score, and overall priority of a pressure pipeline asset or group of assets. Although the technologies listed are not exhaustive nor the information comprehensive, it does offer a good starting point.

TABLE 1. EXAMPLE INTERNAL INSPECTION/ASSESSMENT TECHNOLOGIES FOR PRESSURE PIPE INFRASTRUCTURE

Company	Tier	Pipe Material	Visual Inspections	Leak Detection	Wire Breaks	GPS/Locate	Pipe Wall	Access - Structure	Access - Hot Tap	Access - Hydrant	Tethered	Free Swimming
PURE TECHNOLOGIES A XYLEM BRAND (WWW.PURETECHLTD.COM)												
▪ PipeDiver®	3	PCCP/metallic			√	√		√	√		√	
▪ Smartball®	2	All		√		√	√		√			√
▪ Sahara®	2	All	√	√		√			√		√	
▪ Pure Robotics®	3	PCCP/metallic	√		√	√	√	√	√		√	
RUSSELL NDE AND PICA (WWW.PICACORP.COM)												
▪ See Snake	3	Metallic		√		√	√		√	√	√	√
▪ HydraScope	2	Metallic										
▪ Nautilus	2	All		√					√			√
▪ EMIT	3	Lined pipe					√		√		√	
▪ HydraSnake	2	Metallic					√	√			√	
▪ Pipers (Ignu)	2	All		√		√			√			√
AQUAM (AQUAMCORP.COM)												
▪ Investigator™	2	All	√	√		√			√	√	√	
▪ LDS 1000™	3	All	√	√		√			√	√	√	
▪ Bullet™	2	All	√	√					√		√	√
▪ Amplus™	3	All	√	√		√	√		√		√	
▪ Pipescan+™	3	Metal, plastic	√	√		√	√		√		√	
▪ Periscope Cam™	2	All	√						√			
MTA (RJN.COM)												
▪ Pipe-Inspector	2	All	√	√					√			√
PIPA UK (WWW.PIPA-UK.COM)												
▪ Flowrider™	2	All	√	√					√		√	
▪ Hydrocam™	2	All	√								√	
▪ Pipepod US™	2	All		√					√		√	

The technologies listed in Table 1 are only those for which the author has identified from project-related experiences as well as various market-driven venues, publications, and technical conferences. It may not be exhaustive, as the introduction of more technologies occurs on an almost annual basis. They do, however, represent a list that is current as of the published date of this manuscript. The reader is encouraged to explore the several chapters in the recent AWWA publication titled "Condition Assessment of Water Mains". In this manual there are several chapters that describe the various established and advanced inspection and assessment technologies that are available for their use in the process of assessing condition and asset scoring.

Each of the internal inspection and assessment technologies listed in Table 1 have unique features that are suited for specific boundary conditions such as point-of-access, internal operating pressure, minimum/maximum velocities, length of anticipated deployment, and physical parameters of the pipeline asset. Because many of these technologies have limited history, utilities are encouraged to perform their own product research, contact selected vendors, ask the opinions of other utilities that have used such technologies, and even arrange for on-site demonstrations. As a word of caution, it has been the experience of many utilities that most costs associated with the inspection of a pressure pipelines can be associated with the project's planning, site-preparation, access, and safety/public health (often as much as 70-80% of the total project cost). Once in the pipeline, these technologies can gather an impressive amount of information associated with the structural, hydraulic, and operational conditions of the pipe.

CONCLUSIONS

Significant advancements are being made for both the external and internal inspection and condition assessment of pressure pipeline infrastructure. These technological advancements parallel the need for utilities to create reliable condition scores as part of their on-going asset management program. The combination of good inspection technologies, smart asset management strategies, and useful planning tools will help utilities plan, improve, and maintain their vast and complex network of buried pressure pipe infrastructure while reducing emergency repairs and unplanned capital improvements. By doing so, they will gain better skills in maintaining their role of trusted stewardship to their 24/7/365 customers.

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