BAMI-I

2023

Biannual Journal H1 2023

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BURIED ASSET MANAGEMENT INSTITUTE - INTERNATIONAL

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Founded in 1976, Waggoner has become more than an engineering firm. Our solutions are developed through a culture of integrity, service, and creativity for the benefit of our clients.

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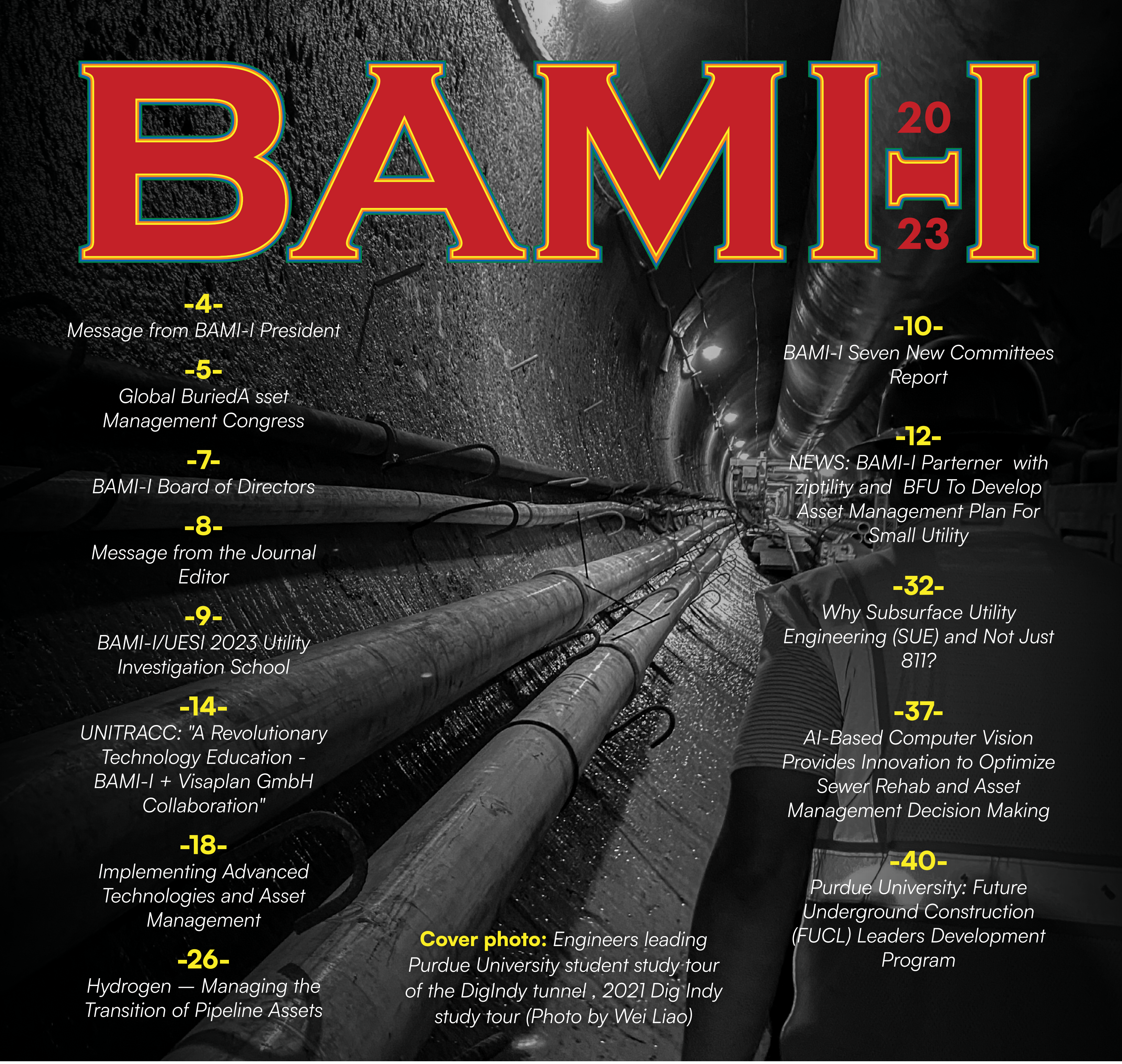
BAMI-I 2023



Cover photo: *Engineers leading Purdue University student study tour of the DigIndy tunnel , 2021 Dig Indy study tour (Photo by Wei Liao)*

Buried Asset Management Institute - International

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MESSAGE FROM BAMI-I PRESIDENT

Dr. Tom Iseley

Ph.D., P.E., Dist. M. ASCE, PWAM, BAMI-I President

BAMI-I Paving the Way in Water Asset Management with New Leadersip

It was January 2003 when I first met with Mr. Jack Ravan, Commissioner of Atlanta's Department of Watershed Management (DWM), to discuss how to accomplish Mayor Shirley Franklin's vision of moving the City's water program passed the $4.0 billion Federal Consent Decree to being first-in-class. That was 20 years ago. I agreed to assist as a senior advisor to the Commissioner.

We realized that having access to the best technical solutions and pipeline condition assessment technology was would not be sufficient without incorporating these in a comprehensive risk-based asset management program. Water asset management was not well understood during that time frame. We were fortunate to have a champion in EPA who had served as the author of the GAP Report and realized that a component of meeting this gap had to involved water utilities developing and applying best business practices. Mr. Steve Allbee traveled to several countries to learn more about asset management. Afterwards, he conducted numerous asset management workshops. We were fortunate to have him conduct 2 for us in Atlanta.

Realizing that about 70-80% of the challenge of meeting the $4.0 billion Federal Consent Decree had to do with the underground conveyance network. This was the driver for establishing the Buried Asset Management Group within the DWM. This Group became known as the Buried Asset Management Institute early on when academic researchers from 5 major universities spent 2-days with us in Atlanta to learn about our challenges and share how their research programs could assist. If the growing national and international interest, The Institute became the Buried Asset Management Institute-International in 2004 when it was established as a 501(c)3 non-profit organization. BAMI-I was selected for an EPA research grant in 2006 which was completed in 2008 which led to the 1st online course being offered in 2010.

So, after 20 years, what is the status of BAMI-I and what can be anticipated in the future. Through mostly volunteer efforts from global subject matter experts in the underground infrastructure industry, most of the past 20 years was devoted to developing 4 online courses which cover the full range of water asset management from the introduction through developing and implementing a program to who to fund a sustainable program.

BAMI-I is excited about the future. BAMI-I has always been an organization of professionals dedicated to advancing the science and practice of water asset management. All education and training materials and programs have been developed by the industry and for the industry. At the demand of industry, BAMI-I has responded and moved to the next dimension. BAMI-I has formed a partnership with Purdue University's Construction Engineering and Management program to provide administrative assistance. The BAMI-I Board of Directors' Executive Committee approved unanimously to utilize the services of Ms. Wei Liao as the Executive Director beginning March 1, 2023. Wei is uniquely qualified to move BAMI-I to the next dimension. She has a MSCE degree with 14 years of underground infrastructure design and construction experience before joining my program at the Trenchless Technology Center prior to transferring to Purdue with me where she serves as a lead research engineer. She is PWAM certified and holds NASSCO certification in PACP, MACP and LACP. In this edition of the BAMI-I Journal you will learn of the initiatives which she is directing. If you are not a member of BAMI-I, don't be left out, get onboard and help Wei accomplish what our water industry needs to meet current and future challenges.

2023 GLOBAL BURIED ASSET MANAGEMENT CONGRESS

SEPTEMBER 29 - OCTOBER 1, 2023/CHICAGO, ILLINOIS, USA

Hosted by: Buried Asset Management Institute - International (BAMI-I) & Construction Engineering and Management, Purdue University

Buried assets: out of sight but not out of mind through advancing the science and practice of asset management

GBAMC will bring together regulators, law and regulation makers, owners, contractors, products & service providers, professionals, and researchers from around the world to discuss advanced technologies, asset management practices, issues and challenges, and forward-looking perspectives on buried assets. GBAMC will enlist subject matter experts from government, academia and industry to present and discuss various aspects of managing buried assets.

UTILITIES/SECTOR:

- Water & Wastewater
- Oil & Gas
- Renewable Energy
- Electricity
- Communication

FOR WHOM:

All persons working/ interested in Water & Wastewater, Oil & Gas, Renewable Energy, Electricity, Communication sectors. Including but not limited to regulators, law and regulation makers, owners, engineers, contractors, manufacturers, suppliers, educators, researchers, students, and professionals.

TOPICS (ALL SIDES RELATED TO ASSET MANAGEMENT):

- Asset Management
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- Pipeline Condition Assessment
- New Installation
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- Trenchless Technologies
- Financial Management
- Research and Education
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Buried Asset Management Institute - International (BAMI-I) is a non-profit corporation whose main purpose is to educate and assist those interested in applying best buried asset management practices to extend the life and efficiency of their assets by developing standards/guidelines, developing and offering certification courses, and building a platform for the delivery and exchange of information, etc.

BAMI-I focus on underground infrastructure including water and wastewater systems, oil and gas pipeline, electric cable, renewal energy pipeline, communication, etc.

BAMI-I's mission is to serve as center of excellence to unite industry, government and academia to develop and advance underground infrastructure asset management principles and practices through education, research and service. BAMI-I's vision is to be one of the most valuable buried asset management centers in the world.

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AQUABRELLA

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- Measures wall thickness, subsidence, pipe ovality, deformations, joint defects, corrosion, leaching, sulfate attack and plots XYZ locations

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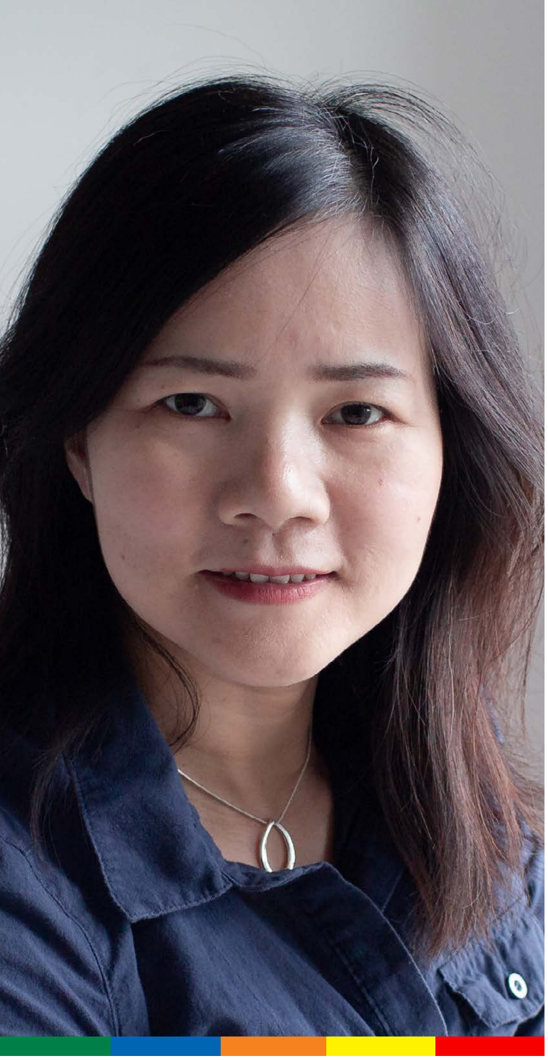
2023 ELECTED BOARD OF DIRECTORS



MESSAGE FROM THE JOURNAL EDITOR

Ms. Wei Liao

PWAM

Today, the concept of infrastructure asset management is widely recognized as a way to make infrastructure sustainable and resilient. However, there are still challenges in getting started and making an asset management plan a living document. One challenge is figuring out how to begin - there is no one-size-fits-all solution as each asset is unique in terms of scale, composition, materials, age, and operating conditions. This requires a tailored approach for each asset management plan, which can be resource-intensive including personnel and equipment and funding. To address this challenge, training and education have become a top priority. Another challenge is ensuring that the asset management plan is a living document that is constantly updated and understood by all members of the organization. This requires constant education and engagement from all levels of the organization

BAMI-I, as a non-profit organization, aims to provide value to its members through access to education and growth opportunities. BAMI-I's earliest CTAM course provided asset management professional certification. The first step in asset management is to create an inventory of assets and to locate and map them. BAMI-I's current successful Utility Investigation School program can provide the professional needs of Location and Mapping. The upcoming UNITRACC course in cooperation with Visaplan GmbH is the technical training for trenchless technology. More training programs need to be developed to meet the need of education in asset management. BAMI-I also provides education through publications, seminars, and conferences, such as BAMI-I 1st Global Buried Asset Management Congress (GBAMC). GBAMC will bring together industry leaders and experts to share their knowledge and insights, and to engage with a wider community in finding solutions to all challenges we meet in underground. The goal is to provide education and training that not only benefits careers, but also has practical applications in other areas of life.

Recently, we have made significant strides in our efforts to promote the BAMI-I mission. We have expanded our reach and impact by collaborating with other organizations and experts in the industry and have developed new programs and initiatives to support the growth and development of asset management professionals. We are working on using Purdue's media platform to publish articles in an open way. This way, the voices of all authors can easily reach every corner of the world. The future of BAMI-I journal will be focused on authority and cutting edge. Please stay tuned.

Exploring the unknown and taking risks is essential for growth and development. While it may be challenging, it is also exciting and fulfilling. The journey of starting something new is often slow and may encounter obstacles, but with determination and focus on the right path, success can be achieved.

We hope that you will find all the articles in BAMI-I journal engaging and informative, and that they will inspire you to continue pushing the boundaries of what is possible. Thank you for your interest in BAMI-I journal and we look forward to your contributions in the future.

BAMI-I/UESI 2023 UTILITY INVESTIGATION SCHOOLS

UIS-16th

March 13-17, 2023

Strakville, MS

MISSISSIPPI STATE UNIVERSITY (MSU)

Early registration ends Feb 3

UIS-17th

May 8-12, 2023

Pittsburgh, PA

Early registration ends April 7

UIS-18th

May 15-19, 2023

Brooklyn, New York

NYU TANDON SCHOOL OF ENGINEERING

Early registration ends April 14

8:00 am — 5:00 pm daily

REGISTRATION FEE: **$1,995** EARLY REGISTRATION $1,895 Additional 10% discount for 3 or more attendees from same company.

FOR MORE INFORMATION, CONTACT:

Saleh Behbahani, sbehbaha@purdue.edu or Leonard Ingram, leonard@engconco.com, (334) 872-1012

The Buried Asset Management Institute — International (BAMI-I) & the Mississippi State University (MSU), **New York University (NYU)** in conjunction with the **ASCE'S Utility Engineering and Surveying Institute** (UESI) have teamed to conduct the 16th and 17th and 18th ASCE UESI / BAMI-I UIS Schools in 2023. These short courses will give practitioners the knowledge and tools to provide competent utility investigations in accordance with accepted national standards (ASCE 38) and to defend against claims through this knowledge and its documentation.

In addition to the classroom lectures, practical sessions will be held where participants will be offered hands-on experience with the GPR, PCL, and etc. These two 5-day schools will be taught by the foremost experts in the geophysics and subsurface utility engineering field.

These 5-day schools have been designed for:

- Engineers and surveyors and project managers providing

  deliverables that include results and depictions of utility investigations.

- Consulting engineers, Employees of utility companies, state DOTs and local highway agencies, regulatory agencies, local governments, etc.

- Design engineers for infrastructure projects with significant expected utility congestion

Course Director

Tom Iseley, Ph.D., P.E., Dist. M. ASCE, PWAM Professor of Engineering Practice
Beavers Heavy Construction Distinguished Fellow Purdue University

Email: diseley@purdue.edu

Phone: (404) 386-5667

Course Developer & Primary Instructor

Jim Anspach, PG(r), Dist. M. ASCE ASCE/UESI President 2018
Member-EJCDC, TRB Utility Committee Chair ASCE -38

A.A. Prof. of Utility Engineering
IOWA State University
Civil, Construction and Environmental Engineering J.H. Anspach Consulting
Email: jim@jhanspach.com

BAMI-I ESTABLISHED SEVEN NEW COMMITTEES AND APPOINTED COMMITTEE CHAIRS TO LEAD EACH COMMITTEE

2023 will mark BAMI-I's 20th Anniversary and at this important point we plan to launch new initiatives to take BAMI-I to the next level. Establishment of seven Committees is one of the most important initiatives. The asset management program encompasses all aspects from technology to management to finance. It will take everyone involved to understand and embrace the asset management culture in order to work in concert to achieve its ultimate goals. The seven new committees will expand BAMI-I's participatory community and help to integrate asset management concepts throughout the infrastructure lifecycle which from the planning stage to the end of the useful life. We believe that the integration of asset management concepts into underground infrastructure industry products and services and operations will provide long-term advantages. In BAMI- I, companies, organizations and individuals will be able to strengthen their dominant position in the industry and interact with their peers, expand their brand presence, and more.

These committees and chairs have been approved at the 2022 BAMI-I Board of Directors/Member- ship Annual Meeting. In the past half of year, the committee chairs focused on membership recruitment and strategies development and assistance with other BAMI-I initiatives. We conducted 4 committee chair meetings to report on progress and related discussions. The establishment of these seven committees was a major milestone in the development of BAMI-I, and the committee chairs and their members became important assets to BAMI-I. We thank all those involved for their generous dedication.

Listed here are the seven Committees with the Chair for each committee.

PIPELINE CONDITION ASSESSMENT COMMITTEE (PCA)

SCOPE: Identifying PCA technologies and establishing a protocol for selecting how to develop a PCA program to comply with an asset management plan.

CO-CHAIR
Jerry Weimer
Jerry Weimer Consulting ,LLC

CO-CHAIR
Susan Dakak, PWAM
President of Smart Views, LLC

FINANCIAL MANAGEMENT COMMITTEE (FM)

SCOPE: Develop the protocol for establishing the life-cycle-costing criteria and procedures for determining the economic value of buried assets including the remaining useful life required in a risk-based asset management program.

CHAIR
Shah Rahman, MBA, M.ASCE
Water Practice Leader in North Texas for KCI Technologies, Inc.

TT- RENEWABLE ENERGY INFRASTRUCTURE COMMITTEE (TT-REI)

SCOPE: Focus on existing and innovative technologies for gathering, distribution, transmission, and storage of renewable energies, such as H2, RNG, CO2, NG/H2 hybrids and Ammonia. Committee shall lead the standardization, compliance, testing, risk management, development, implementation, and commercialization of all relevant technologies.

CHAIR

Kent Weisenberg

The Managing Partner and Chief Technology Officer for BrainDrip

OIL AND GAS COMMITTEE (O&G)

SCOPE: Determining the operational risks and potential failure consequences of OG pipelines, pipe galleries, and equipment and providing asset management plans based on inspection and evaluation.

CHAIR

Dr. Hongfang Lu

Associate professor at Southeast University

UTILITY INVESTIGATION COMMITTEE (UI)

SCOPE: Establishing a risk-based utility locating program utilizing ASCE 38-22 to develop an accurate inventory and mapping system to comply with an asset management plan

CHAIR

Joseph Murphy, PE

VP Utilities Division at Lina T. Ramey & Associates, Inc. (LTRA)

EDUCATION & RESEARCH COMMITTEE (R&E)

SCOPE: Identify education and training needs including workforce development. This will also include how best to utilize and promote CTAM and the Journal and future initiatives such as a Global Asset Management Congress, etc. This committee will follow ASCE's leadership in preparing the underground construction 2070.

CHAIR

Dr. Andy Chae

Associate professor at Central Connecticut State University.

TRENCHLESS TECHNOLOGY COMMITTEE (TT)

SCOPE: Identify and describe how TT can be utilized to provide the required technical solutions to accomplish the objectives of a utilities operational and management program with a focus on the decision process.

CHAIR

Mark G. Wade, P.E.

President and a Senior Pipeline Technologist in BlueWater Solutions Group.

NEWS: BAMI-I PARTNERED WITH ZIPTILITY AND BFU TO DEVELOP ASSET MANAGEMENT PLAN FOR SMALL UTILITY

The beginning of 2023, Buried Asset Management Institute — International (BAMI-I), Ziptility, Inc., Bynum Fanyo Utilities (BFU) and the Town of Switz City, Indiana plan to work together to develop an Asset Management Plan (AMP) for the town's drinking water and wastewater system.

Drinking water and wastewater system assets deteriorate with time. At some point they reach the end of their useful life. As this deterioration continues, emergencies increase requiring reactive management measures. These measures tend to be much more expensive than if prevented utilizing proactive management measures. Every utility has a responsibility to provide a level of service to their customers which include a sufficient quantity of safe drinking water and an effective wastewater service with minimum interruptions at the right rate. This requires developing and implementing a comprehensive risk-based asset management (AM) program. According to Senate Bill 272, in order to obtain a loan, grant, or other financial assistance from the Indiana Finance Authority (IFA) after June 30, 2023: Utilities must demonstrate that it has developed an asset management program, as defined in the guidelines of the Authority; and an estimate of the life cycle management costs, as defined in the guidelines of the Authority.

The problem is that many small utilities lack the water AM knowledge, workforce and resources to develop their own programs. They need assistance and help. BAMI-I has an AM certification program to support small utilities, and Ziptility provides operations and asset management software for small utility teams, BFU is a small utility operations provider. BAMI-I representative Tom Iseley and Wei Liao along with Ziptility representatives Adam Hershberger, Jesse Kurth and BFU's owner Jeff Farmer, agreed that they would choose the Town of Switz City to collaborate on the development of their asset management program with the goal of making the program a reference model for asset management for small utilities in Indiana.

The city of Switz City, with a population of less than 400, has a water and sewerage system in place. All parties had met several times at a Switz City town council to discuss the implementation of an asset management plan (AMP) for the system. George E. Kurz was enlisted to conduct an inflow and infiltration (I/I) analysis using operational report data provided by the operator. He estimated the cost of I/I, cost of sewer rehabilitation, and payback period. The next step is to conduct data collection and site surveys as per the IFA Asset Management Guidelines and to develop a development plan.

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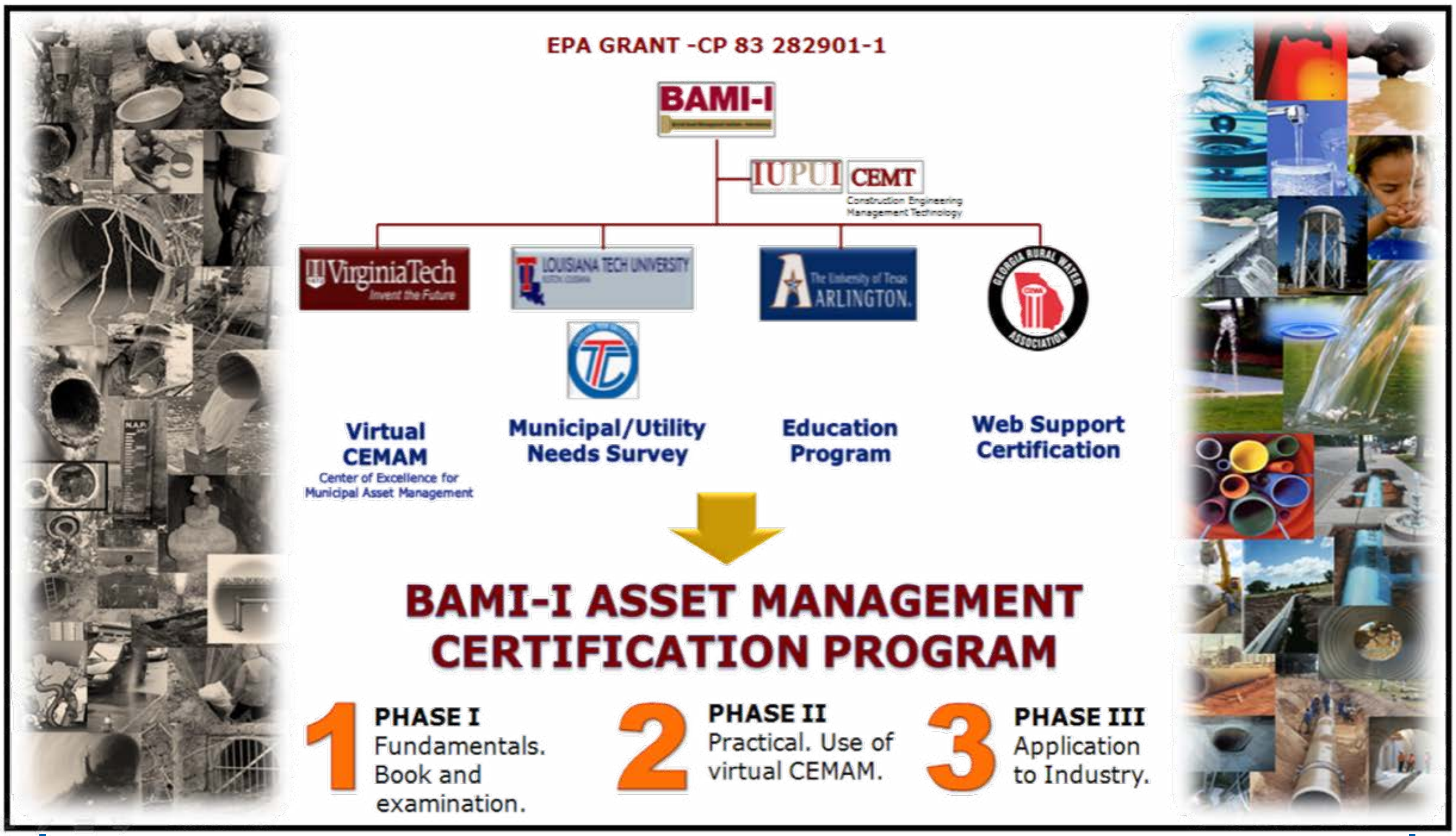
1 CTAM-100 – Overview of Asset Management
2 CTAM-200 – Developing an Asset Management Program
3 CTAM-300 – Managing an Asset Management Program
4 CTAM-400 – Financing an Asset Management Program



The CTAM program was developed by BAMI-I (Buried Asset Management Institute International) in conjunction with the Trenchless Technology Center at Louisiana Tech and Indiana University-Purdue University at Indianapolis, in partnership with UIM: Water Utility Infrastructure Management, and is hosted by the Construction Engineering and Management Department at Purdue University.

Visit Website: www.bami-i.com for more information, contact:

Saleh Behbahani
sbehbaha@purdue.edu

UNITRACC: "A REVOLUTIONARY TECHNOLOGY EDUCATION BAMI-I + VISAPLAN GMBH COLLABORATION"

With the transition into the new millennium, the need for increased flexibility and effective access to engineering knowledge with practical applications on pipeline planning, design and construction, operation, management, rehabilitation, etc. are necessary. This need inspired Prof. Dr.-Ing. Stein & Partner GmbH (https://stein.de/) and visaplan GmbH. Stein & Partner to pioneer the development and application of online options. These two organizations were instrumental in initiating, accompanying and shaping the development of maintenance in the water sector and trenchless technologies based on lessons learned from R&D (Research & Development) projects, expert reports, studies, standardization work and numerous engineering projects. This know-how was published in a wide range of technical books and was therefore available.

At the time, Visaplan was a leader in the field of technical 3D visualisation and in the development of didactic concepts for CBT applications.

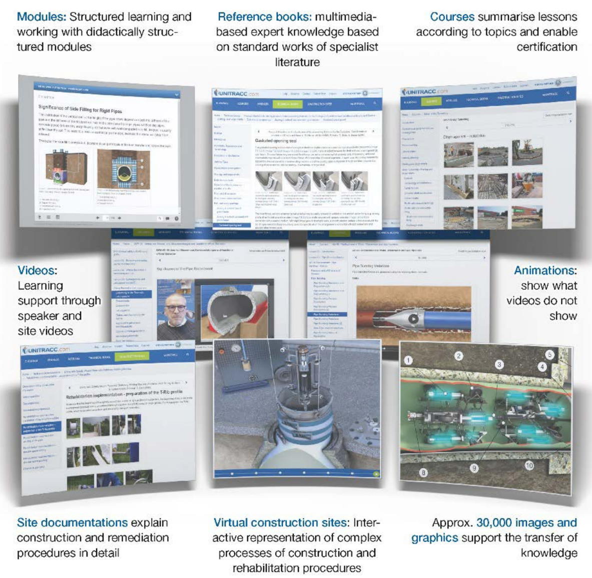
Extensive funding from the Federal Government of Germany provided the financial means to develop UNITRACC with the know-how of both companies. In 2003, the Underground Infrastructure Training and Competence Centre (UNITRACC) went online. Shortly afterwards, UNITRACC received several awards, including the European E-Learning Award.

Since then, the content of UNITRACC has been continuously developed and expanded, especially with practical experience and current developments in the sector. The know-how comes from the team of experts at STEIN Ingenieure (https://www.stein-ingenieure.com/), which consists of planners, structural engineers, geotechnical engineers, hydraulic engineers and environmental engineers, many of whom are involved in committees for the standards and regulations.

Today, UNITRACC provides highly specialised engineering knowledge in the fields of planning, construction, operation & maintenance, rehabilitation and management of water infrastructure networks. All contents are didactically prepared and

elaborately visualised so that UNITRACC supports intuitive learning. Due to the various ways of conveying the technical knowledge in the form of technical books, construction site documentation, modules and courses, UNITRACC is more than just an e-learning platform. We see UNITRACC as a knowledge platform that helps engineers and technicians 24/7 to solve the complex, daily tasks efficiently and with pleasure.

With more than 30,000 graphics and visualisations, more than 50 lessons, UNITRACC is currently the world's largest knowledge platform in this field.



Internationally, UNITRACC strives to cooperate with partners. As each country has its own national standards and regulations, but also quality requirements or planning approaches, individual adaptations of the contents are necessary. One such partner is BAMI-I.

Buried Asset Management Institute-International (BAMI-I) is a non-profit corporation whose main purpose is to educate and assist those interested in applying best buried asset management practices to extend the life and efficiency of their assets by developing standards/guidelines, developing and offering certification courses, and establishing a platform for information transfer and exchange, etc. BAMI-I focuses on subsurface infrastructure, including water and wastewater systems, oil and gas pipelines, power cables, renewable energy pipelines, etc. BAMI-I was founded by Dr. Tom Iseley, who has served as chairman of the Institute since its inception; he retired from the Trenchless Technology Center he founded and was appointed Professor of Practice at Purdue University. He established Purdue Underground Infrastructure Team which not only has a strong research orientation, but also has a strong educational component. UIT offers courses at Purdue in Asset Management for underground infrastructure, High Tech Entrepreneurship, and Underground Space Development. UIT's main mission is to advance the underground infrastructure industry, and expand Purdue's presence in the field of underground engineering and construction, to encourage more of the younger generation to get involved. UIT provides strong support to BAMI-I, where Wei Liao is a board member and serves as editor of the BAMI-I Journal. Saleh Behbahani is the administrator of the BAMI-I related courses. BAMI-I is our partner for the distribution of UNITRACC services in the USA.

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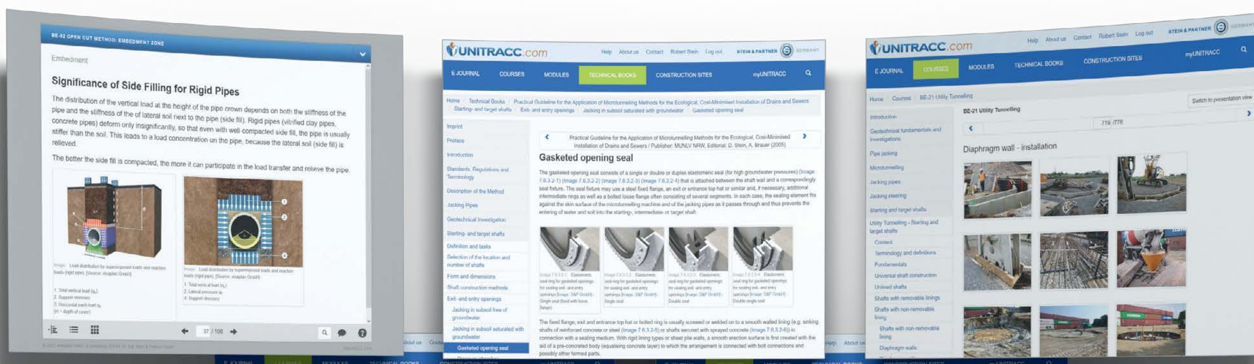

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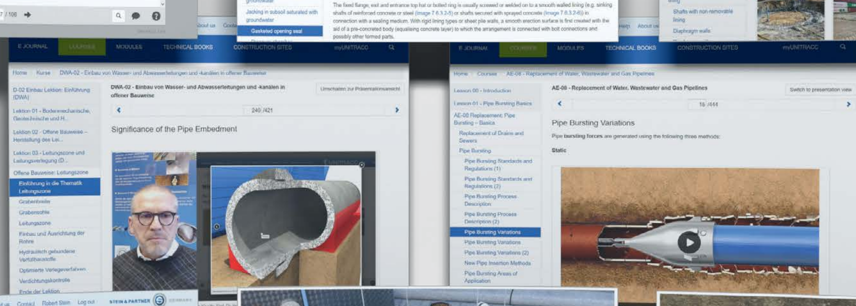

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Course: Trench Protection and Pipe Installation (Free of charge)

The most common method utilized worldwide for pipeline installation is the open cut method. This is especially true for gravity pipelines. While, at first glance, the open cut method seems to be a „simple“ construction method, it becomes highly complex when used in urban areas and at large depths.

This course is structured in two parts:

- The first part is focused on important technical knowledge on securing the trench and making it a safe work zone. It presents t many options available in this regard.
- The second part is focused on the correct pipeline installation techniques including backfilling of the trench and the removal of the shoring.

Course Contents

PART I: Trench Protection

- Pipeline Trench Construction
- Trench -without Support System
- Trench -with Support System
- Trench Shoring Systems
- Trench Shoring Installation
- Trench Shoring Installation Methods
- Trench Drainage

PART II: Pipe Installation

- Pipe Installation and Alignment
- Lifting Systems
- Jointing
- Trench Backfilling and Compaction
- Pipeline Embedment and Installation
- Removal of Shoring
- Hydraulically Bound Backfill (Flowable Fill)
- Optimised Installation Methods
- Compaction Test

The net learning time is approx. 3 days. After completing the course, a certificate of participation from the BAMI-I and Prof. Dr.-Ing. Stein & Partner can be requested

This course is available free of charge.

Questions?

Contact us!

info@unitracc.com

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

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.

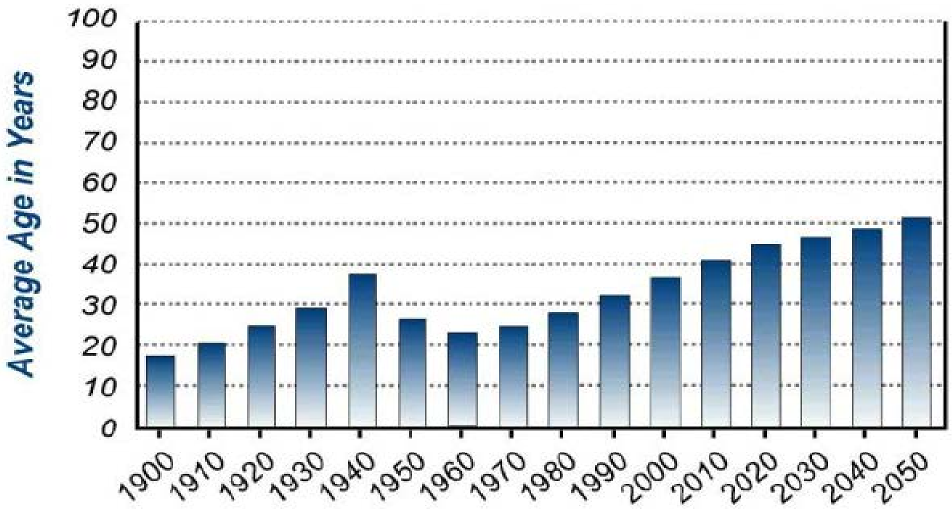

FIGURE 1. AVERAGE AGE OF BURIED PIPELINE INFRASTRUCTURE BY DECADE

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.

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.

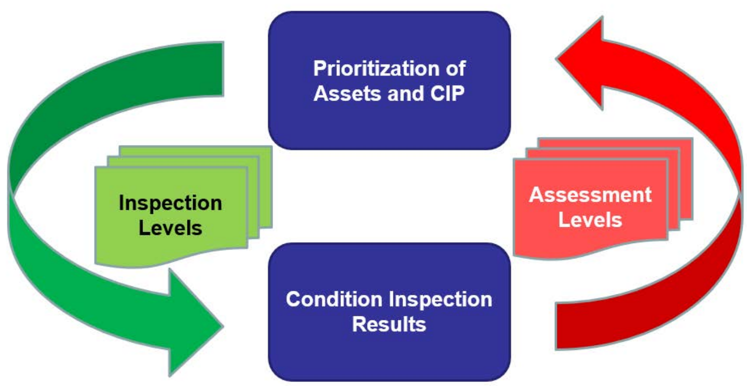

FIGURE 2. THE ASSET MANAGEMENT CYCLE FOR PRESSURE PIPE INFRASTRUCTURE

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, pipelines 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

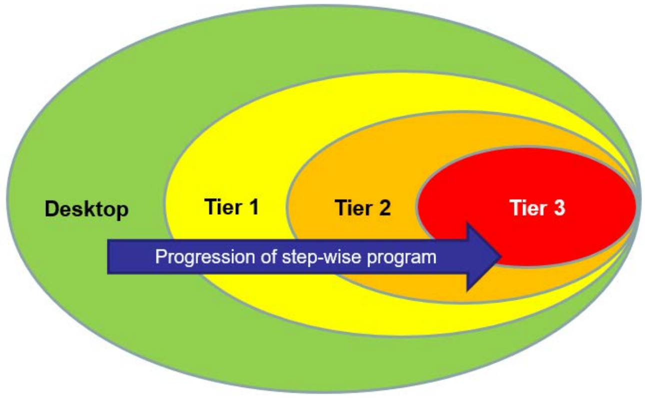

FIGURE 3. EXAMPLE TIERED (STEPWISE) APPROACH FOR PRESSURE PIPE INFRASTRUCTURE ASSET MANAGEMENT

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

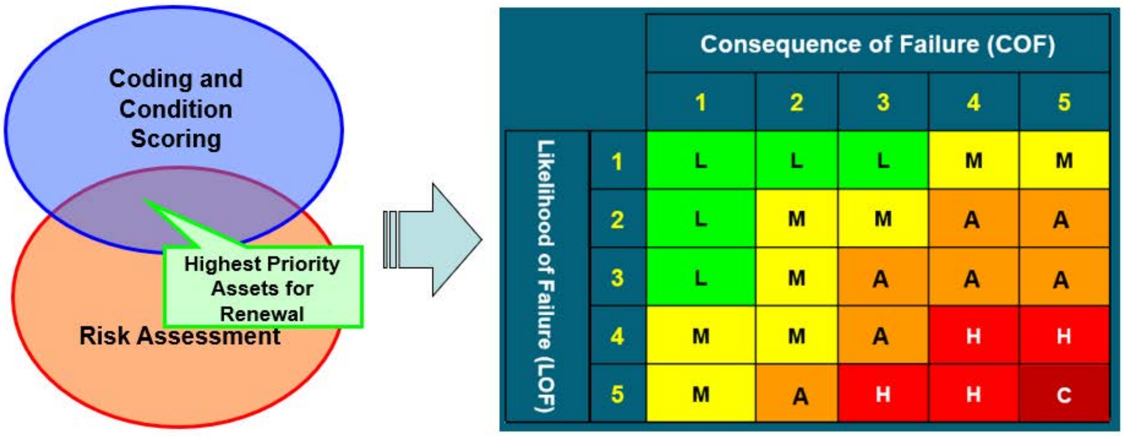

FIGURE 5. EXAMPLE DATA FLOW FROM INSPECTION TO ASSET RISK SCORING

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.

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

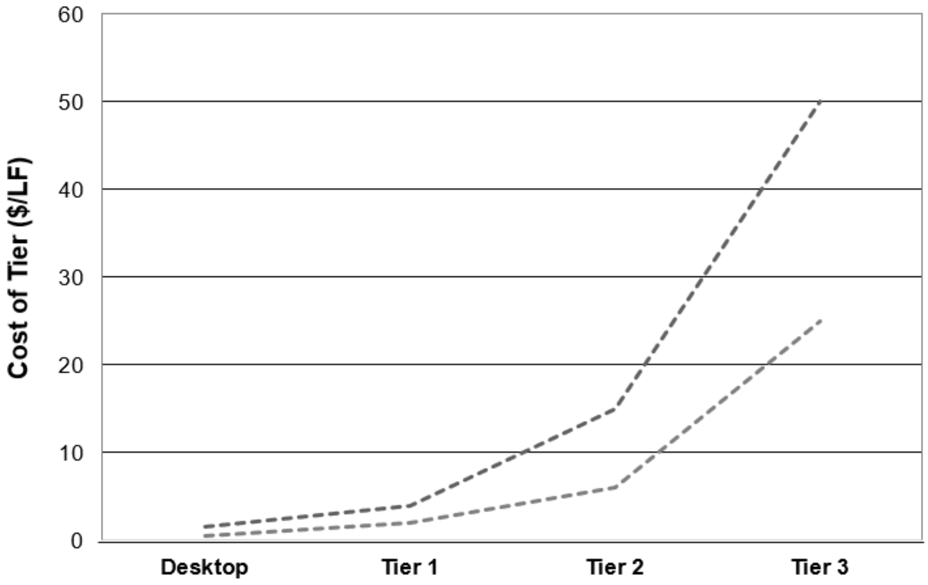

FIGURE 6. PLANNING LEVEL COSTS VS. INSPECTION TIER

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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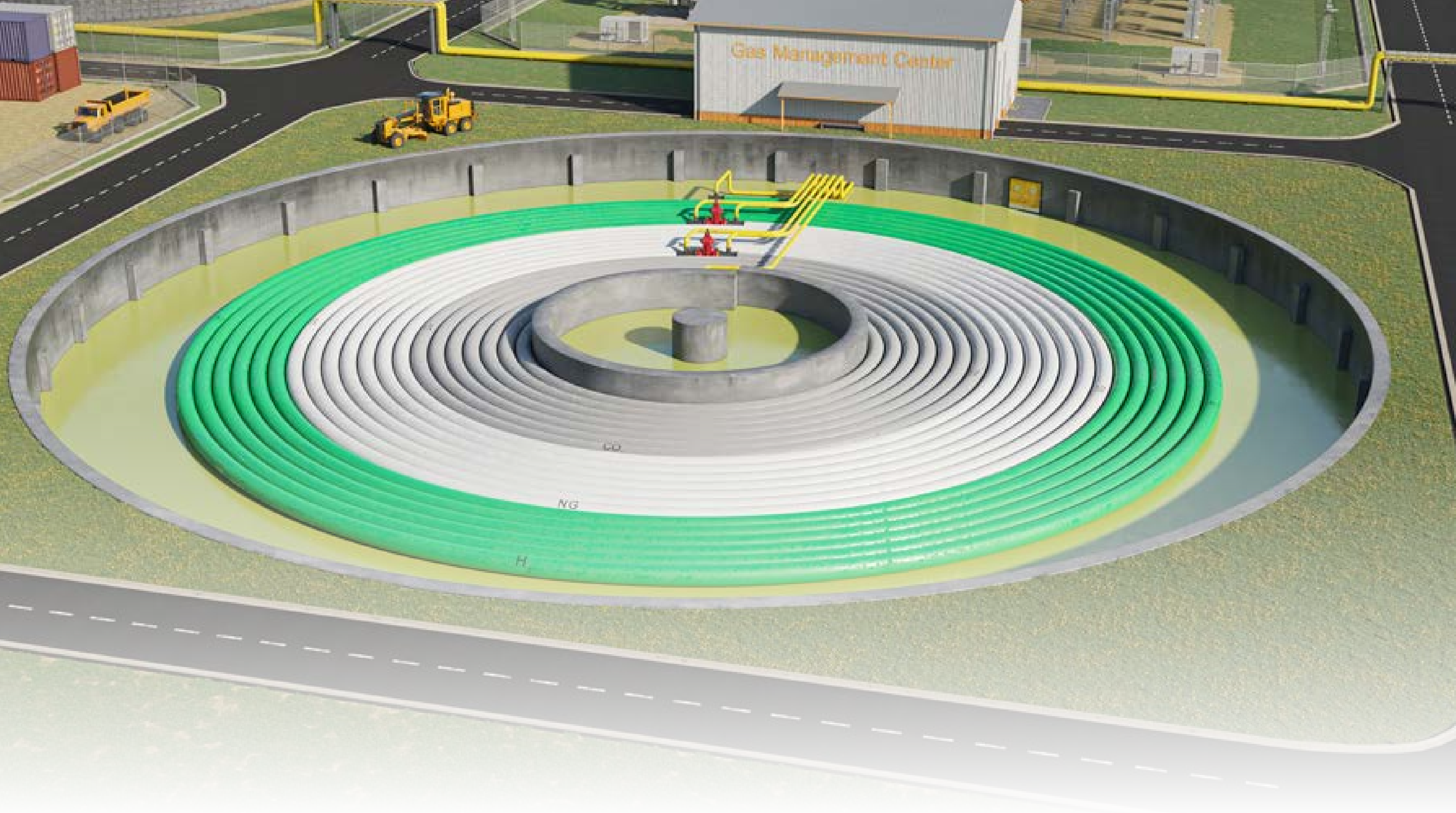


HYDROGEN – MANAGING THE TRANSITION OF PIPELINE ASSETS

Interest in the use of hydrogen as an energy vector has increased significantly in the past few years. Hydrogen is planned to play a significant role in the deep decarbonization of the energy sector — transportation, industrial processes, ammonia production, natural gas supplementation, seasonal energy storage, and other difficult areas to decarbonize lead the end-use applications for hydrogen. The U.S. Department of Energy (DOE) H2@SCALE initiative predicts a serviceable consumption potential of over 100 million metric tons of hydrogen per year in the U.S. if it were to replace existing fossil fuels. There are aggressive initiatives coming out of the U.S. DOE that include $8B U.S. dedicated to hydrogen hubs across the United States and additional tax and carbon credits via the Inflation Reduction Act passed in 2022.

Most of the hydrogen produced and consumed today is in the industrial market with industrial gas companies leading the initiatives. Most of the hydrogen is produced through steam methane reforming of natural gas (SMR) which has some carbon emissions associated with it. The true promise of hydrogen comes in the form of low carbon intensity (CI) processes like green hydrogen production (renewable electricity powering electrolysis), SMR with carbon capture, or other emerging production methods with low carbon intensity (autothermal reforming with CC, biomass, etc.). With the low CI potential, there has been a paradigm shift in the past few years where utilities, transportation companies, and even technology companies are making one hundred billion dollar plus investments in producing and consuming hydrogen for their energy needs.

The momentum in the hydrogen market leads to the need to develop comprehensive production, distribution, and end-use equipment manufacturing and supply chains. Many of the on-going product designs in the hydrogen market simply take a product that was created for the natural gas market and slightly tweak it to fit hydrogen applications — upgrading materials of construction, volumes, etc.

this approach is the customer is often left with a system that isn't optimized for hydrogen use and often has issues with reliability. Early commercialization efforts have resulted in many lessons learned in creating hydrogen specific products from the ground-up, with hydrogen use at the forefront of the design.

Distribution of Hydrogen

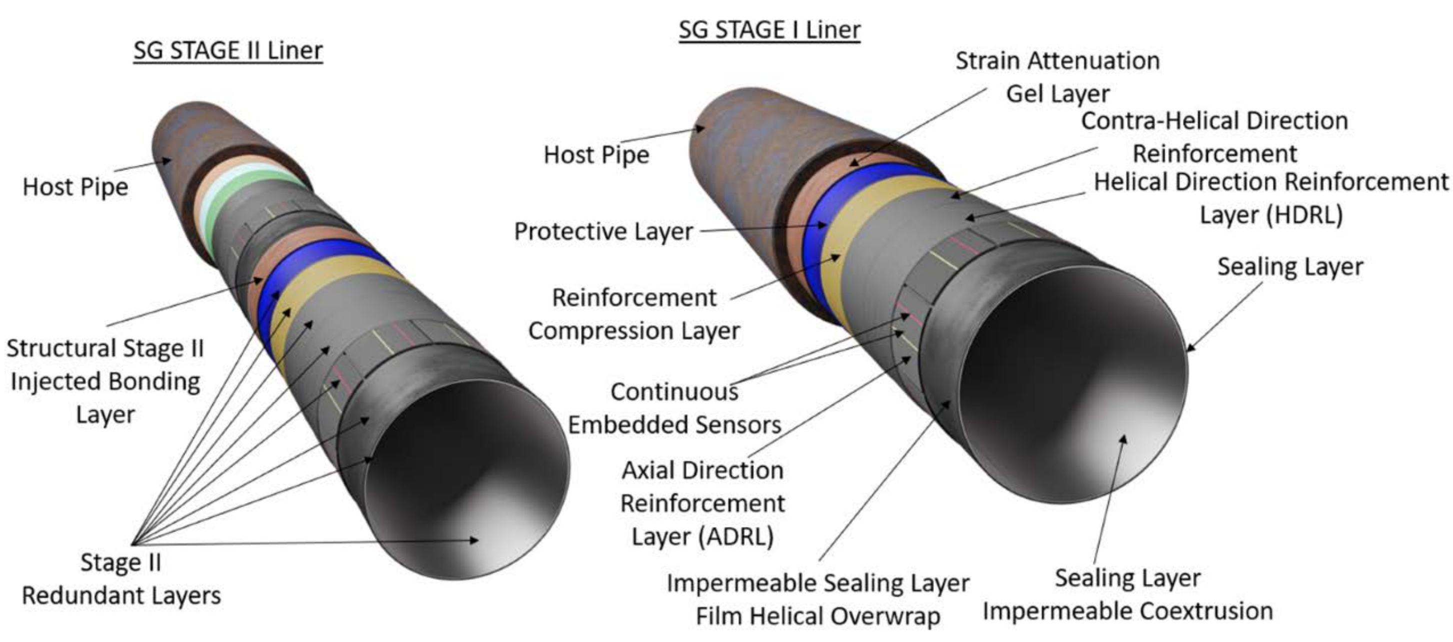
One of the key areas of interest for the hydrogen market is the distribution of hydrogen throughout the U.S. The distribution topic is often met with complacency or brushed off as "easy" when performing project planning for hydrogen initiatives. This complacency is twofold: 1) people can take for granted existing energy infrastructure in the U.S. and how long that took to build out (e.g., vast natural gas pipeline network across the U.S.) and 2) people underestimate the logistics of transporting hydrogen with regards to the value proposition to the distribution company.

Currently, most of the hydrogen is moved over the road by gaseous tube trailers or liquid tankers. Gaseous tube trailers are cost competitive over relatively short distances — typically less than 20 miles. Liquid tankers are used when needing to move the hydrogen across multiple states, however, they come with their own complications as liquid hydrogen needs to be maintained at -253oC. With ambitious growth targets for hydrogen over the next decade, considerations for transitioning the existing energy pipeline infrastructure to safe and resilient hydrogen transmission across the U.S. need to be adapted. There is only about 1,600 miles of hydrogen pipelines in the U.S. today, almost exclusively in the gulf coast region. Most of these pipelines are considered low-pressure, < 1,000 psig, and are used for industrial processes throughout the gulf. The value proposition of installing hydrogen pipeline transitioning technologies across the U.S. will depend on supply and demand and how quickly the hydrogen economy scales; however, there are technical issues that need to be addressed today to ensure the safe deployment of hydrogen ready pipelines soon.

Considerations for Hydrogen Pipeline Asset Management

One of the biggest areas of R&D interest in hydrogen pipelines is in material compatibility. There are many initiatives across the world that explore hydrogen compatibility of materials — in the U.S. the DOE's H-Mat consortium is a great resource to further understand hydrogen material compatibility. In addition, the U.S. DOE has funded hydrogen blending initiatives that look at existing natural gas infrastructure and the use of hydrogen or hydrogen/natural gas blends with existing materials. Some of the main issues with hydrogen compared to natural gas pipelines include hydrogen embrittlement, hydrogen permeation, hydrogen reducing the strength of the pipeline, and even the molecule size of hydrogen which may make it more prone to leaking.

Equally, the capability for owners and operators to secure the required right of way, local and federal permitting and regulatory approval for new steel or composite open trench pipeline installations is limited at best. This regulatory barrier is to a great extent based on public perceptions of catastrophic



environmental and or human tragedy events from pipeline failures in the past. These perceptions are exacerbated by the fact that hydrogen is a new and to a great extent a misunderstood energy source, resulting in both warranted and unwarranted fears about the environment and public safety in the event of a pipeline leak. The regulatory and social incompatibility with installing new hydrogen pipelines only bolsters the need for new, resilient, and safe liner technologies to transition existing energy pipeline infrastructure for hydrogen transmission and distribution.

Hydrogen has a low volumetric energy density when compared to something like methane (main component of natural gas) — depending on pressure and temperature conditions methane would be 8x — 10x the volumetric density of hydrogen. This leads to a need for higher pressures when exploring hydrogen applications and the current steel pipeline infrastructure is not rated for this increased compression. In addition to the higher pressures, pipeline systems may need to flow at higher flow rates to accommodate the differential in energy content that needs to be delivered to end-use equipment. Innovative, ultra-high pressure transitioning liners that are purposely built for hydrogen applications are a necessity to the future success of the hydrogen market.

A major goal in the asset management of hydrogen capable pipelines will be leak detection and localization. Leak detection for all types of pipelines has come under scrutiny in recent years. There has been a significant push from regulatory bodies to

eliminate hazardous leaks and minimize releases from pipelines and pipeline facilities — the latest major requirements coming from the PIPES Act of 2020. Hydrogen won't be exempt from these requirements and, complicating things further, hydrogen is much more difficult to detect than something like natural gas. There is a need for unique ways to monitor the health of existing and future pipelines, especially for hydrogen applications, in any asset management plan. Companies are exploring leak detection monitoring and drone technologies that could fly pipelines as part of their operations plans. One of the more promising technologies is an innervated tubular composite liner system with integrated fiber optics that are coupled with AI/ML fusion interrogators to actively monitor the integrity of the composite liner, detect and localize leaks within a few inches, and provide significant remote monitoring and reassurances to pipeline operators.

Although there are some lower pressure hydrogen pipelines already in operation, the need for higher pressure and higher flow, liner modified pipelines in the future will lead to special regulatory considerations when commercializing products. Fortunately, the Pipeline and Hazardous Materials Safety Administration (PHMSA) has an entire office dedicated to new technologies and special waivers. The process for both a new technology and special waivers are relatively the same, a company needs to lay out what exemptions they need from applicable regulations and test procedures, typically 49 CFR Part 192 for hydrogen pipelines, and submit those to PHMSA for review and approval. New technology considerations will have a higher level of scrutiny but will lead to special waivers for future installations. With hydrogen still being in the "emerging" phase, companies should budget plenty of time to interface with PHMSA on these efforts as they can be considerable.

Final Thoughts

The hydrogen economy has a significant amount of hype behind it and in a lot of regards, appears to be moving full steam ahead based on the current enormous global investment in hydrogen technologies. Today's distribution methods through tube trailers or liquid tankers won't hold up with the volumes needed to make hydrogen a reality — pipeline transition technologies need to be developed. Key areas to consider when taking on a hydrogen pipeline asset development include material compatibility, pressure rating, and flow rate capability. Designing pipeline systems for leak detection is a major (regulatory) advantage on projects and a monumental advantage to proper asset management. Engaging PHMSA early and often will be a necessity for any hydrogen pipeline transitioning project.

ABOUT THE AUTHORS

Michael Peters has been working in hydrogen systems R&D and commercialization for over a decade, specializing in renewable electrolysis and hydrogen infrastructure. He has worked on projects from production to end-use and everything in-between. He joined EnServ in January of 2022, previously he was at the National Renewable Energy Laboratory based out of Golden, Colorado. During his time at NREL, he led many multi-million-dollar R&D projects, including the $15M hydrogen blending CRADA project from DOE's HyBlend initiative. Mike joined EnServ as the Lead Hydrogen Consultant and Business Development Manager — looking to grow EnServ's portfolio in conventional and renewable fuels.

Kent Weisenberg is the Managing Partner and Chief Technology Officer for BrainDrip, LLC, directing BrainDrip's IQ4H2 Lab in Jacksonville, FL and their NEW4H2 Hub at the Energy Innovations Center in Pittsburg, PA. He has been working in the pipeline renewal systems development and commercialization for over three decades, most recently focusing on the development and implementation of novel technologies for renewable energy infrastructure. He is the sole named inventor on over 50 pipeline renewal materials and methodology patents, with multiple recent publications for systems utilizing novel innervated tubular composites for high pressure hydrogen, NG/H_2, RNG and Ammonia transmission, line packing, localized storage, as well as the autonomous embedment of continuous interrogation receptors in legacy pipelines. Kent is also an industry advisor and panelist for the U.S. Department of Energy (DOE) and the National Renewable Energy Laboratory (NREL) AMC - 'Idea Lab' contributing his skills at identifying, developing, and implementing visionary ideas and process improvements to drive efficiency, safety, resiliency, and productivity for renewable energy infrastructure projects. He is an active member of Engineers Without Borders and remains a steadfast champion for the trenchless technology industry as a multi-talented subject matter expert lending decades of experience as successful and visionary designer, engineer, and developer of innovative and scalable pipeline and ancillary technologies.

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WHY SUBSURFACE UTILITY ENGINEERING (SUE) AND NOT JUST 811?

We've all heard this sentence before: "We don't need to spend money on SUE when we can just use 811 marks!"

Well...that depends on what you are trying to accomplish.

I have over 23 years of combined experience spanning both the 811 Industry and the SUE Industry - and I have a huge amount of respect for both - but the two industries *could not* be more different. One is used for designing and planning projects, while the other is used for immediate excavation damage prevention.

They are both extremely important...just different.

Which one is needed in each situation depends on several factors, such as:

- State law requirements
- When excavation is taking place
- Whether the data will be used in the design/planning process or as a direct precursor to excavation
- *Many more...*

811

The 811 industry's purpose is to *increase excavation safety* and *reduce dangerous and expensive damage* to vital underground utilities. It protects excavators, homeowners, the public, and others from project delays, injuries, and even death.

A technician working directly for a utility company (or working for a company *hired* by a utility company) will receive a ticket that is "called in" to 811 by the individual performing the excavation. The technician has, at most, 48 hours to mark the utilities they are responsible for within the requested work area - regardless of the magnitude of the ticket. They will still have to mark all applicable utilities within 48 hours, whether they are *at one single address* or span an *area 10 miles long*!

The technician will use electromagnetic Pipe and Cable Locators (PCLs) to identify the location of the utility they are responsible for within a certain tolerance zone (typically 18" to 36" horizontally, depending on state law). The path of the utility is marked on the ground with paint and flags using standard American Public Works Association (APWA) colors.

Tools Used:

- PCLs (usually only one type instead of a full suite).
- Records from utility owners.

Pros:

- Completed within 48 hours.
- Used to give excavator paint and flags on the ground to avoid utilities.
- Increases the chances of safe excavation in nearly all cases.

Cons:

- Primarily a production-based industry technique because this method is based on "per ticket pricing." This results in the field technician often being rushed, which can cause the quality and accuracy of the work to diminish.
- Only utility owners who have signed up for the 811 service will be notified; any utility owners who have not signed up for this service will have unmarked utilities in the field that are in danger of a strike.
- A field technician's training is often limited to *2 to 4 weeks*, at most.

Subsurface Utility Engineering (SUE)

As discussed in *ASCE/UESI/CI 38-22 "Standard Guideline for Investigating and Documenting Existing Utilities,"* the Subsurface Utility Engineering (SUE) industry's purpose is to acquire, process, characterize, assess quality, and present utility information for project development, led by a professional engineer in responsible charge who is subject to relevant liabilities and statutes regulating professional engineering.

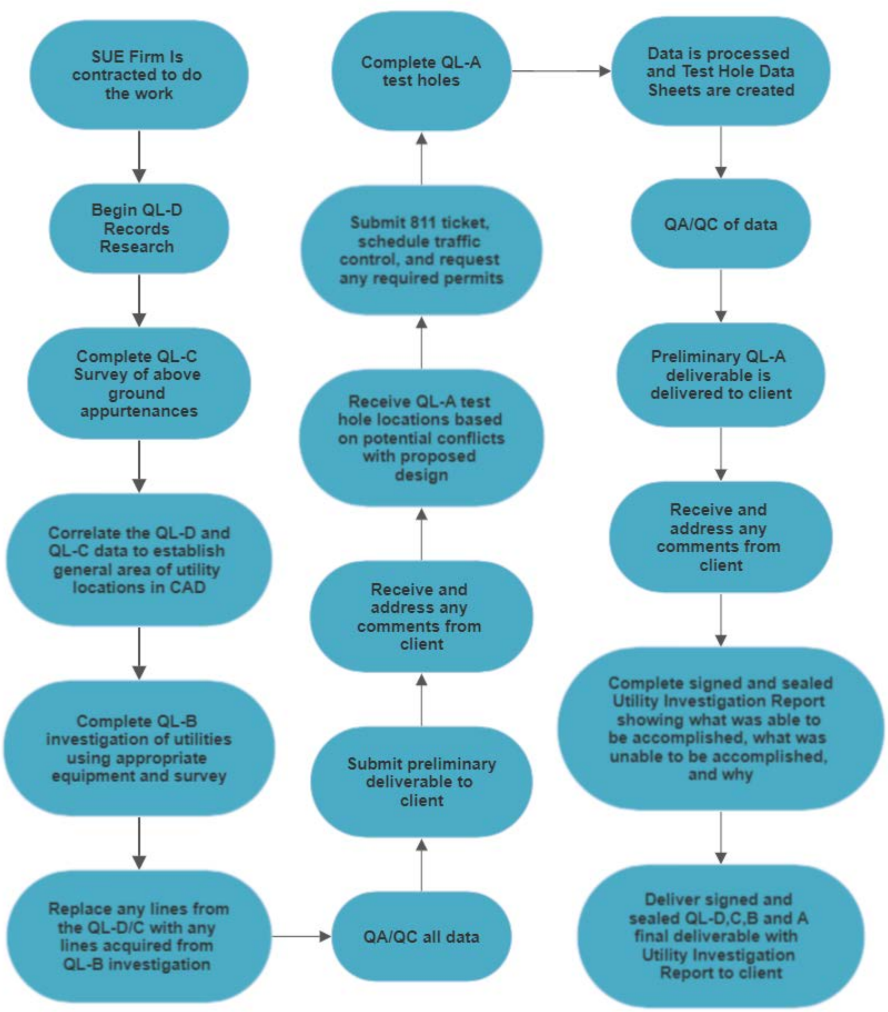
SUE uses civil engineering practices to collect data about existing utilities. This includes the use of traditional and emerging

White	Proposed Excavation
Pink	Temporary Survey Markings
Red	Electric Power Lines, Cables, Conduit, and Lighting Cables
Yellow	Gas, Oil, Steam, Petroleum, or Gaseous Materials
Orange	Communication, Alarm or Signal Lines, Cables, or Conduit
Blue	Potable Water
Purple	Reclaimed Water, Irrigation, and Slurry Lines
Green	Sewers and Drain Lines

collection and documentation with advances in geophysical investigation and data management technologies, design and construction knowledge of past and current utility systems, and scientific concepts for assessing and defining the quality and relative uncertainty of utility information. The practice of SUE leads to deliverables that are signed and sealed by responsible professionals who directly oversee the Utility Investigation and develop the resulting documentation of existing subsurface utilities at their achieved Utility Quality Levels.

SUE Quality Levels

- **Quality Level D (QL-D)** — This Level is the most uncertain as to a utility's location or existence. The SUE data is derived from records research, as-builts, oral recollection, Texas811, etc.
- **Quality Level C (QL-C)** — Collecting QL-C SUE data involves using QL-D data and surveyed surface visible utilities features (valves, handholes, pedestals, manholes, etc.) to obtain a better understanding of the potential horizontal alignment of the subsurface utility. QL-C SUE data is *less* uncertain than QL-D SUE, as it is tied to visible surface indications. However, whether the utility passes directly through or is offset from the surface indications is part of the uncertainty. To reduce this uncertainty all access points should be opened - except those that present concerns for safety or security.
- **Quality Level B (QL-B)** — Collecting QL-B SUE data involves the use of surface geophysical methods, coupled with QL-D and QL-C SUE data, to "designate" the approximate horizontal alignment of utilities. QL-B SUE data is less uncertain than QL-C or QL-D SUE data. The uncertainty of the applied geophysical method, such as using a PCL, is affected by depth and soil types (moisture content, metallic salts, etc.) and can be distorted by other electromagnetic fields or other conductive utilities in the area. The PCL geophysical method has two parts — first, a "transmitter" creates a signal that is fed into a conductive element of the utility (found at valves, handholes, manholes, etc.) and then a "receiver" can then follow along on the ground for the strongest emanations of that signal. These points are then flagged, surveyed, and mapped.



- **Quality Level A (QL-A)** — This is the *least* uncertain Quality Level for a specific location. Collecting QL-A SUE data involves utilizing non-destructive methods to directly expose and measure the utility both horizontally and vertically. One uncertainty for Test Holes that needs to be addressed is to make sure you are measuring the intended utility. QL-A SUE data is typically collected using high pressure air or water and vacuum excavation. It can also be performed by hand-digging on shallow utilities. In either case, it must be non-destructive to the utility.

Tools Used:

- Multiple PCLs (RadioDetection, Vivax-Metrotech, Subsite, etc.)
- Survey GPS Units with Data Collector
- Survey Total Stations
- Ground Penetrating Radar (GPR)
- Acoustic Locators
- Sonde
- Schonstedt Magnetic Locator
- Witching Sticks
- Tonable Rodder
- Grade Rods (for inverts and test hole depths)
- Vacuum Excavation Trucks
- Coring Machine
- Rock Bar
- Traffic Control (signage, attenuator truck, etc., based on roadway regulation requirements)
- CAD Software (Autocad, Microstation, etc.)
- 3D Scanner for vault mapping

Pros:

- Field technicians are given the necessary time to properly investigate utilities in and around the project limits.
- Field technicians typically utilize a full suite of necessary tools to properly investigate.
- Field technicians document access points, equipment used, frequencies, etc. to ensure all data is repeatable.
- The methods utilized typically result in more precise utility locations.
- Utility locations are surveyed in for future use by designers.
- QL-A test holes provide most accurate location of utility.
- A documented QA/QC process ensures deliverables are as accurate and complete as possible.
- The entire SUE investigation process is under the responsible charge of a Professional Engineer.

Cons:

- Can be costly*.
- Requires more time to complete due to the thoroughness of the investigation performed.

*Although SUE requires upfront costs that are not always accounted for in project budgeting, multiple studies between 1999 and 2012 by USDOT, ASCE, the Ontario Sewer and Watermain Contractors Association, PennDOT, and the Region of Lombardy show that in many cases, the total project savings incurred by using SUE *greatly* outweigh the cost. For example, a 2012 study by PennDOT of 22 SUE and 8 non-SUE projects showed an *11.39:1* Return on Investment (ROI) for the projects that used SUE. In other words, the study showed that $11.39 can be saved in project costs for every $1 spent on SUE on road projects[1].

ABOUT THE AUTHOR

Marc Hendricks has over 23 years of experience in the Utilities industry. He started his career as a field technician and has served as a SUE professional for the last 7 years. He serves as the Director of Utilities overseeing Texas and Colorado for ARS Engineers Inc.

AI-BASED COMPUTER VISION PROVIDES INNOVATION TO OPTIMIZE SEWER REHAB AND ASSET MANAGEMENT DECISION MAKING

The Sewer Network

A Sanitary Sewer Collection System is a series of pipes, manholes, and lift stations that convey wastewater from homes and businesses to a treatment plant. In the US, there are over 875,000 miles of public sewers and 500,000 miles of private laterals. Over one third of US wastewater utilities are unable to engage in proactive asset management and instead find themselves reacting to sewer overflows, sinkholes, pipe collapses, and storm events of increasing severity.

This deterioration of critical wastewater infrastructure contributes to over 800 billion gallons (or 120,000 Olympic-size swimming pools) of overflowing sewage annually in the US, polluting our oceans, rivers, and lakes. Solutions have proven expensive, with the American Society of Civil Engineers (ASCE) estimating an $80 billion annual funding gap for US water utilities between capital needs and actual capital spending.

Sewer operators have a critical role in managing the public health and the affordability of wastewater services for the community. One area of innovation making a difference in overcoming this challenge is in the recent application of emerging capabilities in Automated Defect Recognition (ADR) (commonly referred to as Artificial Intelligence, or AI) and Cloud Computing to NASSCO's Pipeline Assessment Certification Program (PACP™) data, driving optimization in the design and implementation of trenchless rehabilitation projects.

Operator assisted sewer AI allows the sewer operator to focus on prioritizing maintenance activities like the type and frequency of cleanings, the timing and location of point repairs, determining the need of additional condition assessment or remaining useful life (RUL) and replacement cost efforts, the evaluation of lining or other rehab trenchless technologies, and the development of the replacement capital plan.

The maintenance goals and objectives for municipal sewer utilities include:

Goal: Maintain sanitary sewer system and related infrastructure to ensure uninterrupted service.

Objective 1: Annual closed-circuit CCTV" inspection of existing sanitary sewer lines and all new collection systems.

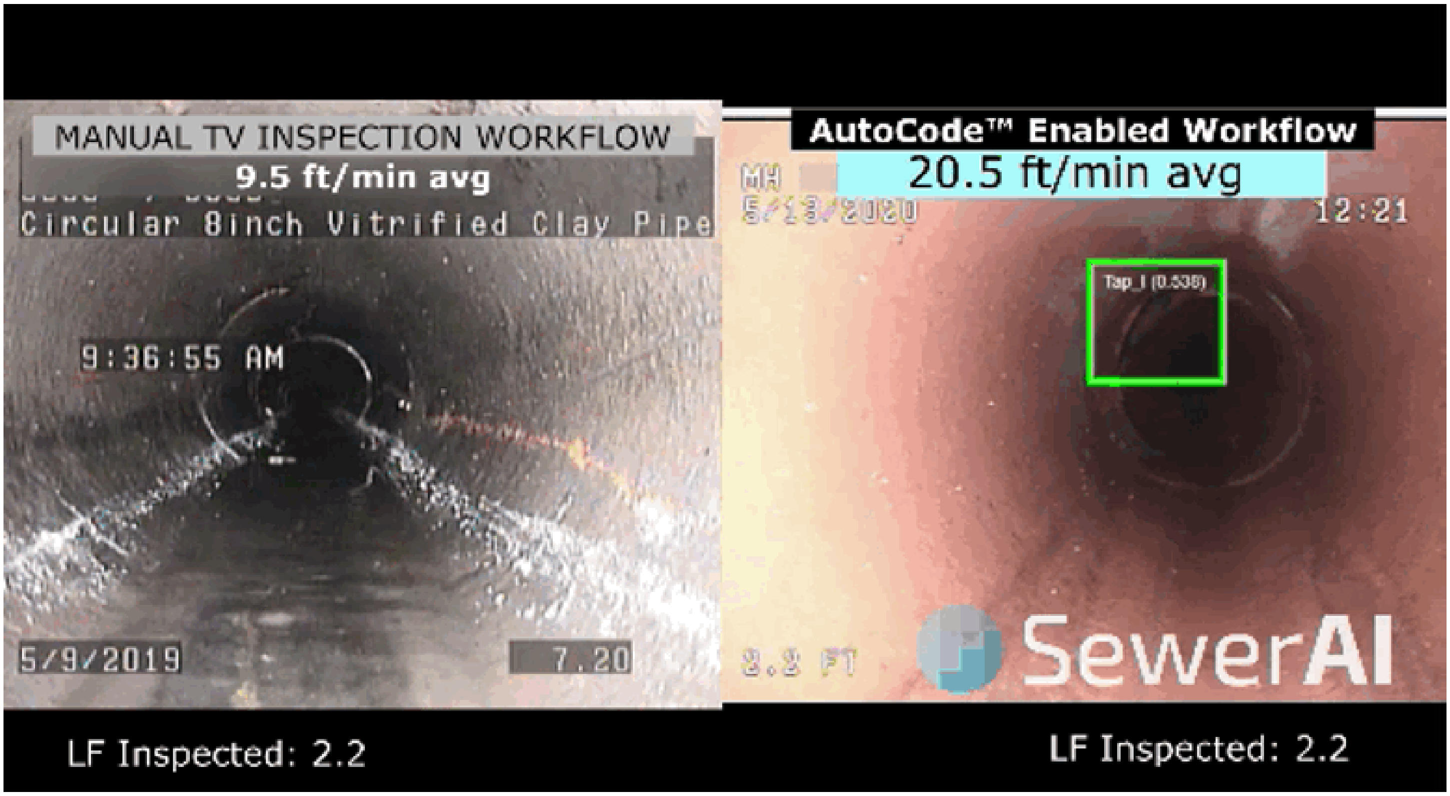
Objective 2: Annually clean the sanitary sewer system.

Objective 3: Conduct monthly sand/grease interceptor inspections.

Objective 4: Conduct root cutting for service connections.

Computer Vision

Human assisted task automation is called computer vision, which is when an AI gains



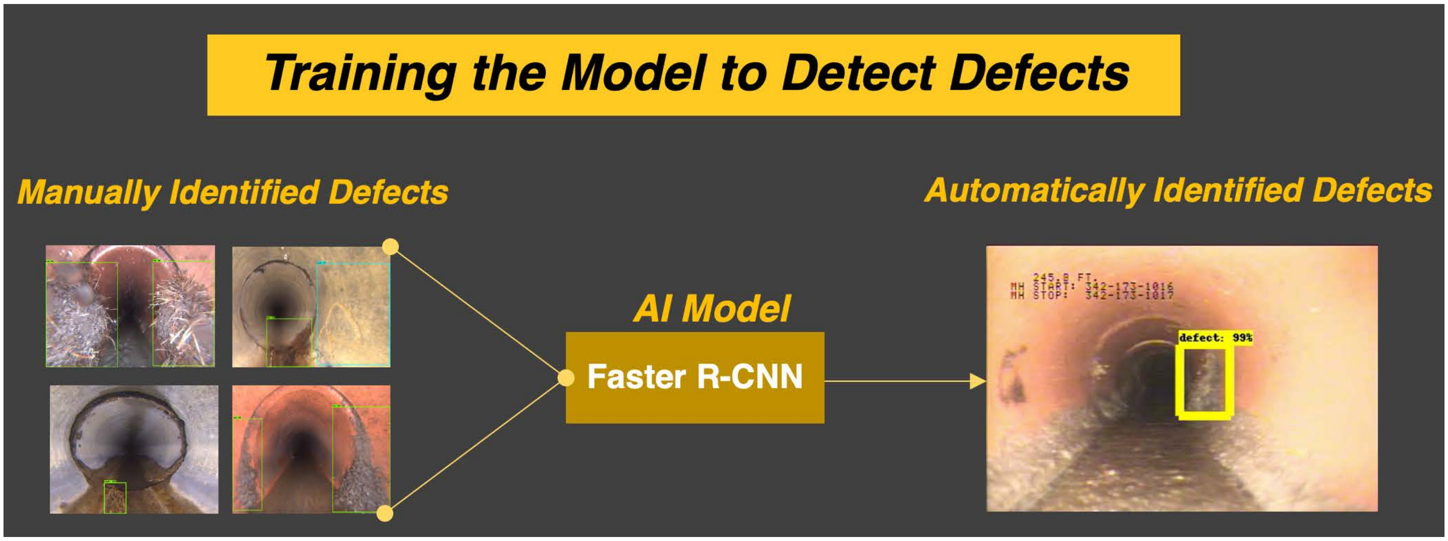
a high-level understanding of objects and/or conditions from digital images or videos, such as CCTV data collected from sewer and storm pipeline inspections. Software engineers use machine learning as a way of training an algorithm so that it learns for itself how to fulfill a specific objective, and this happens by exposing the algorithm to various (and numerous) examples that enable it to adjust itself to make improvements over time.

Pipe Condition Assessment Standardization

Developed by NASSCO in partnership with the Water Research Center (WRc), PACP, with 226 distinct condition codes, is the North American licensed adaptation of the United Kingdom's TV inspection coding system developed by the WRc. This coding system is the recognized standard in the United Kingdom and much of Europe and Asia.

Since 2001, PACP guidelines, created by NASSCO, have been widely used in condition assessment of buried drainage infrastructure. Its catalogue of observations enables one to describe a feature quantitatively and with a 1 to 5 severity grade. After two decades of use, our industry now possesses an abundance of PACP data, in the form of electronic databases and media files from countless inspections, stored on local servers, in external hard drives, and now, increasingly, stored and streamed on the Web, for use in Cloud-based applications. This increased access to large amounts of PACP data, combined with emerging capabilities in Machine Learning (ML) has enabled advanced analytics for support of predictive and prescriptive decision-making. This includes Computer Vision models for ADR, enabling descriptive condition assessments with more consistency, rigor, and efficiency, provides ample opportunity to improve outdated data management and asset planning practices.

NASSCO's PACP-Based Asset Management Objectives of Asset Management is to maintain function or level of service as cost effectively as possible while maintaining individual components (assets) at lowest life cycle cost possible. Each sewer asset has a life cycle from design, construction/installation, operations, maintenance, repair/rehab to replacement or disposal. Asset management seeks to continuously identify cost savings and efficiencies in each of the life cycle phases to improve the financial areas of current revenues and expenses for operations and maintenance and capital expenditures typically funded with long term debt. Good asset management is always integrated with long-term financial planning and rate funding setting scenarios.



Standardization provides accuracy, consistency and cost savings when it comes to data management and analytics. While defect coding standardization does not yet exist for water pipes, standardization does exist for sewer pipe condition assessments. The National Association of Sewer Service Companies (NASSCO) trains and certifies technicians and engineers. PACP (Pipeline Assessment Certification Program) is the North American Standard for pipeline defect identification and assessment, providing standardization and consistency to the methods in which pipeline conditions are identified, evaluated and managed. The goal of PACP is to have pipeline system owners create a comprehensive database to properly identify, plan, prioritize, manage, and renovate their pipelines based on sound condition evaluations.

- PACP asset management seeks answers for the following questions:
- What pipes, manholes, and laterals do we own?
- Where are these assets located?
- What are their materials, dimensions, depth, and ground cover?
- What is the condition of each asset?
- What other community assets would be affected by failure of a particular asset?
- Which assets are critical to sustained performance?

- What are my best O&M and CIP investment strategies?
- What will be the rehabilitation cost?
- What effect will this have upon the utility budget?
- How should all of this be communicated to stake holders?

PACP can assist in developing an asset management plan by collecting asset information including:

- Pipe segment length
- Relative location details
- Pipe size
- Pipe shape
- Pipe material
- Upstream manhole data
- Pipe segment lateral data
- Consequence of failure
- Defect codes (Structural and O&M)
- Condition grades

AI Supports Workforce Retention and Training

Wastewater Collections Operators perform skilled construction, repair, and maintenance of wastewater system facilities. They operate a variety of power equipment and ensure public health by preventing sewage overflows and blockages. They inspect, clean, maintain, construct, and repair wastewater collection systems including sanitary sewers, storm drains, pump stations, pipes, manholes, and catch basins (access points). https://www.workforwater.org/

AI does not replace the operator or take away the need for certification. AI can accelerate the training for new recruits and leverage the trained operator applying their skills to more value added and meaningful duties. Computer vision software automatically recognizes defects and features in pipes assists in generating condition assessment reports, at a significantly faster rate (~4X) than if performed manually, and with a higher degree of accuracy (95-100%) and consistency. This allows the sewer utility, engineers, and contractors to save time and money, and complete more pipe inspections.

CCTV Direct Assessments

Human assisted computer vision using AI/machine learning applied to CCTV data of sewer pipes sits at the top of the sewer network condition assessment and asset management pyramid. These direct condition assessments coded with defect catalogs can quickly, accurately, and effectively provide the basis for all other asset management program decision making. Based on this low-cost AI approach of coding the condition of each sewer pipe, the decision can be made as to where and when additional resources and funding should be allocated for asset work order maintenance and asset management activities moving a utility from a reactive (high cost) mode to a planned and predictive (lower cost) strategic operation. This is especially true for compliance mitigation strategies for consent decrees, the management of sanitary overflows (SSO) and the reduction of the Inflow and Infiltration (I&I) responsible for increased flows to the treatment plant (as high as 45%) resulting in higher water treatment costs passed onto rate payers, causing community equity and affordability issues.

Conclusion

Sewer condition assessment and asset management also integrates with the sustainability elements of a triple bottom line (TBL) approach evaluating the social, environmental, and both tangible and intangible economic costs. All these efforts build resiliency into the sewer network from risk mitigation to recovery, from climate events or man-made malevolent acts. AI and machine learning will continue to enhance our understanding and operational experiences when it comes to our drinking water, clean water, and reuse infrastructure networks and treatment operations. Public and private utilities, operators, engineers, and contractors each can benefit through the inevitable adoption and acceptance of new technologies like computer vision which better protects our quality of life from the potential threat of service failures, contamination, and higher costs.

ABOUT THE AUTHOR

Director of Business Development at SewerAI, NASSCO P/L/MACP® Trainer, Trenchless Advocate

Email: esullivan@sewerai.com

Eric is an underground construction professional who specializes in solutions for infrastructure condition assessment and trenchless technologies. Working with water and sewer utilities, consulting engineers, and contractors, Eric has fulfilled a variety of accountabilities in his 15 years in the industry as an operations manager, business development manager, professional certification trainer, CCTV operator, inspection system and vacuum truck technical sales rep, and sewer services project manager. Eric has been a NASSCO Trainer since early 2012, and has led NASSCO programs throughout the US and Canada to TV operators, asset managers, and consulting engineers.

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Outreach: Ashutosh Suhas Mangle	**Outreach:** Rishitha Reddy Kasarla

Purdue University — College of Engineering Construction Engineering and Management (CEM) Division Coordinated by the CEM UIT (Underground Infrastructure Team)

During the past few years, Purdue CEM has made a dedicated effort to get engineering students more aware, excited and committed to careers related to underground construction. This is done at the undergraduate and graduate level. This is accomplished through our internship program for undergraduate students which require 3 — 12-week internships before they can graduate.

Purdue is blessed by having both a NASTT and a UCA Student Chapter which work jointly to provide undergraduate and graduate students with maximum opportunity to developed leadership skills and to get them actively involved is all aspects of developing underground space from utilities to large tunnels. Professor Dulcy Abraham is the faculty advisor for our NASTT chapter, and professor Tom Iseley is the faculty advisor for our UCA chapter.

Our major accomplishment during the Fall semester was to take 22 students to Fort Wayne, IN to visit the 3RPORT CSO tunnel. Please contact us for our project report if you are interested. We are very thankful for the financial support provided by UCA of SME.

Our programs at Purdue cannot adequately prepare UC leaders without industry partners. We can do the academic component but that is not enough. Our students are encouraged during their university experience to accomplish the following 3 things:

- Do the best job they can academically to get the best grades,
- Developed leadership skills by being involved in student chapters, and
- Get maximum exposure to the UC industry.

The last bullet is where we need your help.

We plan to accomplish 2 major opportunities to expose students to the UC industry:

- Getting 30 students to the Underground Construction Technology (UCT) conference on Feb 7-9, 2023 in Orlando, Florida (https://uctonline.com/tag/underground-construction-technology/). Last year our delegation was 25. Please contact us for our trip report if you are interested.
- Getting 30 students to visit the CSI precast concrete manufacturing facility in Macedonia, Ohio and also visit one of the Northeast Ohio Regional Sewer District (NEORSD) tunnel projects in Cleveland on March 3, 2023.

Beavers & UCA Provide Support to Purdue Construction Engineering and Management (CEM)

The Beavers is a heavy engineering construction association. It is a social, honorary organization formed in 1955. It was organized and continues to be managed by construction companies and individuals who are or have engaged in heavy engineering construction. The Beavers encourages students to be involved with the heavy engineering construction industry. On October 3 and 4, Dave Woods (Executive Director Beavers, Inc. & Beavers Charitable Trust) and John Bollier (President of the Board of Directors for the Beavers & Stacy & Witbeck, Inc.) visited the division of Construction Engineering and Management (CEM) at Purdue University and met with CEM students and faculty members. The CEM at Purdue University started in 1979. Dr. Tom Iseley joined the CEM in 2020 and his position at Purdue (Beavers Heavy Construction Distinguished Fellow) is funded in part by the Beavers.

Left to right: John Bollier. Tom Iseley, and Dave Woods — Purdue University

On October 22, twenty UCA of SME, NASTT, and ASCE G-I Student Chapter members at Purdue University along with 3 CEM faculty members visited the Three Rivers Protection & Overflow Reduction Tunnel (3RPORT) project in Fort Wayne, Indiana. Special thanks to Lance Waddell (Lane Construction) and Sara Doran (Schnabel Engineering) for hosting Purdue University group and providing the tunnel tour. The tunnel depth is about 220 feet below the ground surface. The 3RPORT project is a segmentally lined tunnel with 19-foot bore diameter and 16-foot finished diameter. There are seven connections to the tunnel (drop shafts). The project will reduce the number of CSOs into the rivers by 90% (it can convey about 800 million gallons per day. Also, thanks to Everett Litton (WSP) for making the trip arrangement. Purdue CEM would like to express sincere appreciation to UCA and all the affiliated "Down For That" societies (UCA of SME, ASCE, DFI, Beavers, Moles, and NASTT) for providing the financial support for this trip.

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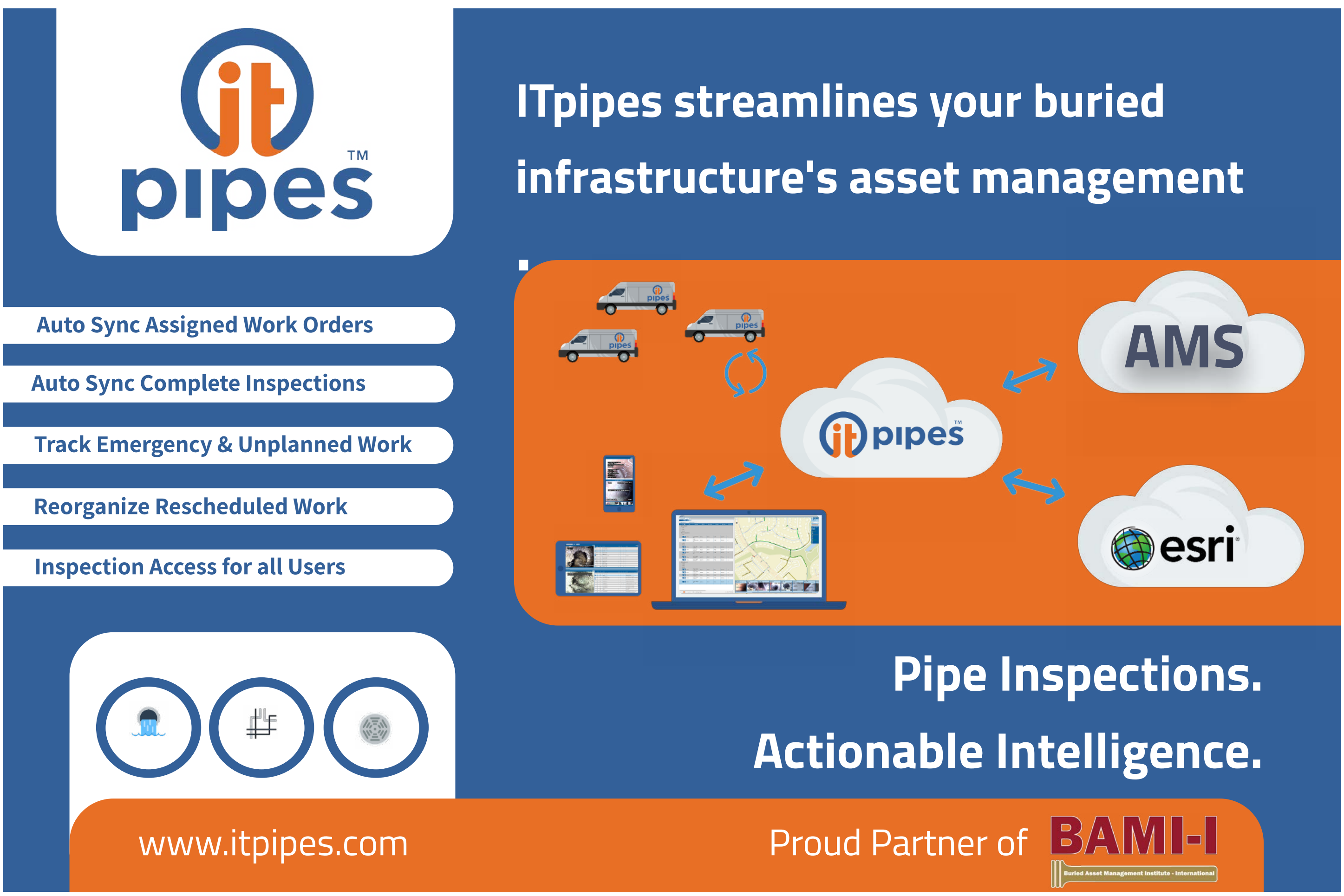

GOOD DECISIONS START

WITH GOOD INFORMATION

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