NIST Special Publication 1300

Measuring Up to Sustainable Water

NIST-Virginia Tech Workshop on Aging Water Infrastructure September 9-10 2010

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NIST National Institute of Standards and Technology • U.S. Department of Commerce

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EXECUTIVE SUMMARY

The NIST-VT workshop identified funding priorities for federal institutions and other funding sources for sustainable water infrastructure systems in order to align fundamental and applied research with long-term needs. The workshop started with several keynote presentations to frame the topics. The keynotes were followed by breakout sessions to develop and rank potential research and educational activities. The workshop concluded with all the attendees developing a consensus on a prioritized list of research goals. The workshop was organized into 5 breakout discussion areas: Pipeline Failure Modes and Mechanisms, Pipe Condition Assessment Technologies, Pipeline Renewal Engineering Technologies, Pipe Locating Technologies, and Education, Outreach, and Training.

Federal agencies are attentively focused on critical water infrastructure needs. NIST recognizes opportunities to contribute to water research in such areas as 'Water infrastructure', 'Filtration Membranes', and 'Water Analysis.' Achieving pipeline safety and integrity will require improvements in data collection and in measurement technologies. Smart infrastructure capable of self-inspection and self-reporting holds great promise towards achieving improved pipeline asset management. The EPA's Sustainable Water Infrastructure Initiative helps to focus the Agency's priorities towards helping utilities to provide reliable service to their customers and to meet the Clean Water Act and Safe Drinking Water Act requirements. The EPA's Office of R&D recognizes opportunities to evaluate and demonstrate innovative technologies to improve the cost effectiveness of the operation, maintenance, and replacement of aging and failing drinking water and wastewater infrastructure. Water conservation and reuse is also recognized as important.

The utilities are focused upon sustainable service to their customers, and upon regulatory compliance. Thus, WERF's membership is focused upon the asset management challenges currently facing wastewater utilities. Areas of research need include public communication, benchmarking, development of case studies, decision/analysis implementation guidance, and assessment of remaining asset life. WRF identified research needs pertaining to achieving and optimizing infrastructure reliability to ensure a continuous, safe, and uninterrupted supply to customers. Asset management areas of particular interest include leakage management and water use, materials longevity and deterioration, main breaks, condition assessment, repair and rehabilitation, corrosion and corrosion control, distribution system water quality, pressure management, and distribution system optimization. WSSC provided a presentation specifically regarding PCCP and LCP water main failures. This case study touched upon aspects pertaining to all of the breakout topics and appropriately showcased the complexity and importance of real world asset management challenges faced by water & wastewater utilities, which challenges require significant investment in cross-disciplinary research to resolve.

The workshop participants represented a diverse cross section of researchers from academia, utility, consultant, industry, and federal institutions and were all invited specifically for their expertise pertaining to water infrastructure needs. Experts within each subject area led the 5 breakout discussions; the moderated discussions permitted capturing the diverse opinions regarding “What are we concerned about, what do we want to measure, and how?” Polling of attendees then assisted with ranking the priority of the suggested research needs from each of the 5 discussion areas into the overall Top 10 identified needs. The common theme was the need for a resilient and sustainable water infrastructure system, and the research that would be required to accomplish that goal. In order to be achieved, many of the research priorities will first require the development of measurement standards and tools, so that standard data can be collected and analyzed. This foundational research, particularly suited to the resources of NIST, is therefore of the absolute highest priority for the water and wastewater industry.

The overall top ten (10) research needs are (not in ranking order):

- Need for a national standard on how to collect, store, retrieve, and analyze pipe infrastructure data.
- Need for design and operation of standardized test beds and in-situ test beds.
- Need to classify the most critical structural components to be investigated and the type of material structure.
- Need to develop a test bed for controlled environment testing of renewal technologies to be used to evaluate and improve technologies.
- Need to develop Metrics for Infrastructure Sustainability and Resiliency, Define the engineering meaning and how to measure “sustainable” and “resilient” for water infrastructure systems.
- Need to develop Standard Reference Materials for use with geophysical methods for locating buried utilities.
- Need to develop standardized methods and measurements for the collection of condition assessment data on existing assets to improve: data analysis methods; maintenance and renewal prioritization; and design, operation, and maintenance of renewal technologies. Data collection and reporting standards are needed for every type of condition assessment data available for every individual inventoried maintenance item in existence.
- Need to develop standardized methods and measurements for the collection of QA/QC data and long-term condition and performance data of renewed assets to guide O&M needs over the life-cycle of renewal technologies.
- Need to link failure modes, mechanisms, and indicators with condition assessment, and prioritize tools and techniques to identify potential failure.
- Need to standardize Infrastructure Asset management practice and define best appropriate practices and leave it to the individual entity to decide what works the best for their organization. Need to help promote stakeholder collaboration.

More details on these and other suggested topics can be found in the following report. This information will be used by NIST and other funding agencies for internal program planning and will form the basis for development of new collaborations across organizations to address tasks of mutual interest.

ACKNOWLEDGEMENTS

This workshop was supported by the NIST (Dr. Michael Fasolka, Senior Scientific Advisor, NIST-Gaithersburg). The workshop was also held in partnership with Institute for Critical Technology and Applied Science (ICTAS) at Virginia Tech.

The workshop organizers gratefully acknowledge the significant contributions of Mr. Grant Whittle, a doctoral candidate, Dr. Jai Jung post-doctoral fellow, and several graduate students at Virginia Tech. We also appreciate the detailed review by several members of the water infrastructure community, including Dan Murray, Michael Royer, Walter Graf, Frank Blaha, and Duncan Rose.

We would like to thank the organizations and individuals that contributed to planning and hosting, invited speakers, session leaders, moderators, and attendees.

The findings, statements and opinions presented in this report are those of the authors and workshop participants, and do not necessarily represent those of the NIST and Virginia Tech.

ACRONYMS

NIST	National Institute of Standards and Technology
VT	Virginia Tech
USEPA	US Environmental Protection Agency
USBR	US Bureau of Reclamation
WERF	Water Environmental Research Foundation
WaterRF	Water Research Foundation
AWWA	American Water Works Association
ASCE	American Society of Civil Engineers
AIC	American Institute of Constructors
CGA	Common Ground Alliance
NASTT	North American Society of Trenchless Technology
WSSC	Washington Suburban Sanitary Commission
PCCP	Pre-stressed Concrete Cylinder Pipe
ECP	Embedded Cylinder Pipe
LCP	Lined Cylinder Pipe
NDE	Non Destructive Evaluation
RFID	Radio Frequency Identification
CIPP	Cured-in Place Pipe
SUE	Subsurface Utility Engineering
CCTV	Closed Circuit Television
BIM	Building Information Model
CA	Condition Assessment
RE	Renewal Engineering

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1. INTRODUCTION

This workshop was designed to sharpen the focus of programs of the National Institutes of Standards and Technology (NIST) by matching the measurement technology capabilities of NIST with existing technology gaps in the realm of assessing water infrastructure performance to prioritize their repair, rehabilitation, and replacement. The one and half day workshop, jointly sponsored by NIST and Virginia Tech (VT), was held at the VT Falls Church Campus. With invited researchers from academia, utilities, industry, and federal institutions, the workshop identified opportunities and knowledge gaps relative to critical areas of sustainable water infrastructure. The goal of the workshop was to develop a prioritization that can guide fundamental and applied research at federal institutions and entities funding research in sustainable water infrastructure systems. Key questions intended to be answered by the workshop include “What are we concerned about, what do we want to measure, and how?” NIST is interested in developing new metrics and methods that push the limits of measurement science, and this interest is complementary to research in both academia and industry, where the focus may be more on fundamental research, and/or process design. The agenda for this NIST-VT Water Measurement workshop and the participant list are presented in **Appendix A** and **B**, respectively.

2. PURPOSE OF WORKSHOP

Water distribution and wastewater collection systems are pillars of civilization, supporting agriculture, industry, environment, transportation, culture, and health. The U.S. has thrived on advances and investments in water and wastewater systems made by prior generations [NAE, 2003, A Century of Innovation: Twenty Engineering Achievements that Transformed Our Lives], yet these neglected assets are now failing at unacceptable rates even as demands on the systems increase. As we contemplate “The Dawn of the Replacement Era,” where an unprecedented investment in pipeline assets will be required [American Water Works Association (AWWA), 2001, Dawn of the Replacement Era: Reinvesting in Drinking Water Infrastructure], it is critical that we develop the knowledge necessary to make sound decisions, and build legacy assets that will sustain future generations. There has been a steady decline in the state of our water and wastewater infrastructure over the past two decades and there is a growing concern that these facilities may be inadequate both for current requirements and for projected future growth (USEPA, 2005).

Pipeline infrastructure in North America has become inadequate to sustain a growing economy (ASCE, 2005). Huge expenditures are needed to repair, rehabilitate, and replace public facilities (ASCE, 2000). If the deterioration of pipeline infrastructure is allowed to continue, local governments will suffer severe economic consequences. It is estimated that the cost of replacing all water mains in the United States would run to $348 billion (ASCE, 2000). The estimated cost to upgrade the water transmission and distribution systems is $77 billion (ASCE, 2000). Although the federal government has spent more than $71 billion on wastewater treatment programs since 1973, the nation’s 16,000 wastewater systems still face enormous infrastructure funding needs in the next

20 years to replace pipes and other constructed facilities that have exceeded their design life (ASCE, 2000). With billions being spent yearly for water and wastewater infrastructure, the systems face a shortfall of at least $21 billion annually to replace aging facilities and to comply with existing and future federal water regulations (ASCE 2000). Funding for renewal of these systems is limited, and a deferred maintenance, "out-of-sight, out-of-mind" philosophy still prevails in many regions. Monetary investment alone will not resolve this dilemma; it must be met with a new and robust approach to sustainable water infrastructure.

The workshop started with several keynote presentations to frame the topics. The keynotes were followed by breakout sessions to develop and rank potential research and educational activities. The workshop concluded with all the attendees developing a consensus on a prioritized list of research goals. The workshop identified five topic areas for discussion: Pipeline Failure Modes and Mechanisms, Pipe Condition Assessment Technologies, Pipeline Renewal Engineering Technologies, Pipe Locating Technologies, and Education, Outreach, and Training.

3. SUMMARY OF KEYNOTE PRESENTATIONS

During the course of one and half days, the workshop provided academic and practical context and ideas for the workshop goals within keynote presentations, as described in **Appendix C**. Video recording of workshop presentations are presented in **Appendix D**. A brief summary of each keynote presentation is presented below.

a) ***"National Institute of Standards and Technology (NIST): Promoting U.S. Innovation and Industrial Competitiveness"*** **Dr. Michael Fasolka, Senior Scientific Advisor, NIST-Gaithersburg.** Dr. Fasolka presented an overview of NIST's mission, current activities, and programs. He began by describing the importance of regulations and standards which influence approximately 80% of global merchandise trade. The mission of NIST is to promote U.S. innovation and industrial competitiveness by advancing "Measurement Science," "Standards," and "Technology" in ways that enhance economic security and improve people's quality of life. NIST realizes that the industrial and scientific communities need to develop and commercialize new technologies to accomplish this mission. Currently, NIST has many programs and thousands of human resources to achieve their goals and is "paving the way to innovation. NIST laboratory programs are focusing on buildings and physical infrastructure, energy, environment, healthcare, information technology, manufacturing, and quantum science. In the presentation, NIST material measurement resources were explained in detail as well as NIST extramural programs. NIST expects to contribute to water research in such areas as "Water infrastructure," "Filtration Membranes," and "Water Analysis."

b) ***"Condition Assessment of Physical Infrastructure: Data & Standard Needs***" **Dr. Stephanie Hooker, Materials Reliability Division Chief, NIST-Boulder.** Dr. Hooker discussed NIST's efforts to develop standards, to advance measurement science, to validate technologies, and to solve the most critical measurement problems. She addressed pipeline safety and integrity challenges where codes and standards need to be developed in order to ensure safe distribution of fuels. In the U.S., the water and wastewater infrastructure volume is enormous and it is rapidly aging. Since the size of our systems is so large, quantitative data for decision-making is necessary. In addition, the infrastructure inspection today is mostly visual; there is only limited use of non-destructive evaluation (NDE) and continuous condition monitoring technologies. In the future, infrastructure inspection technologies are expected to be developed with the ability to perform "self-inspection" and "self-reports" (smart infrastructure). To develop such "smart infrastructure," some measurement solutions such as improved inspection accuracy, real-time structural health monitoring, measurement of full-field strains during deformation, and dynamic strain sensing with MEMS resonators are needed. Recently, NIST-Boulder upgraded mechanical test facilities and NIST-Gaithersburg installed new mechanical test facilities to accelerate the development of condition assessment technologies. Dr. Hooker also introduced other technology development efforts during the presentation.

c) ***"Aging Water Infrastructure (AWI) Research Program: Innovation & Research for the 21st Century"*** **Mr. Dan Murray, Manager, Office of Research and Development, EPA.** Mr. Murray introduced the goals and approach of AWI's research program to evaluate and demonstrate innovative technologies in order to improve the cost effectiveness of the operation, maintenance, and replacement of aging and failing drinking water and wastewater infrastructure. Condition assessment and rehabilitation of water distribution and wastewater collection systems were briefly discussed. Advanced concepts regarding new innovative infrastructure designs, including technologies for wastewater and reuse of water, were also discussed. Mr. Murray showed environmentally friendly infrastructure such as permeable pavement systems and addresses several unique features and green components. The AWI research program is putting EPA in the forefront of addressing the nationwide high priority need for drinking water and wastewater infrastructure research. EPA is playing a national and international leadership role by cooperating and collaborating with its federal, national, and international research partners, in order to assist utilities towards more effective implementation of comprehensive asset management. These efforts will help utilities to provide reliable service to their customers, and to meet the Clean Water Act and Safe Drinking Water Act requirements. AWI is thereby helping to better safeguard human health by diminishing the risk of waterborne illnesses, and is supporting EPA's Sustainable Water Infrastructure Initiative.

d) ***"Overview of Environmental Protection Agency (EPA) Research on Buried Water Infrastructure"*** **Mr. Michael Royer, Program Manager, Aging Infrastructure Research, EPA.** Mr. Royer presented an overview of EPA's key research topics, including condition assessment, rehabilitation, repair, and replacement of buried pipe. The details of each topic were carefully explained in the presentation. Research approach and current research activities were summarized for each topic area. Various innovative, emerging technologies were introduced. Technology forums, research outputs, and expected impacts of rehabilitation were also summarized.

e) ***"Asset Management Research – Measuring Up to Sustainable Water*" Mr. Walter Graf, Program Director of infrastructure management at Water Environment Research Foundation (WERF).** Mr. Graf introduced the major research areas of WERF and their approach. WERF is focused on asset management and the challenges pertaining to public communication, benchmarking, case studies, decision/analysis implementation guidance, remaining asset life, and supporting technologies. Mr. Graf also addressed innovation and research required to improve wastewater infrastructure for the 21st century.

f) ***"Water Infrastructure Research"* Mr. Frank Blaha, Program Manager at Water Research Foundation (WaterRF).** The mission of infrastructure research work and application is to advance the science of water to improve the quality of life. A specific need is to help water utilities achieve and optimize infrastructure reliability in order to ensure a safe and uninterrupted supply to customers. Key research areas of interest were discussed in detail including asset management, leakage management and water use, materials longevity and deterioration, main breaks, condition assessment, repair and rehabilitation, corrosion and corrosion control (including lead and copper rule work), distribution system water quality, pressure management, and distribution system optimization. Finally, Mr. Blaha answered the key question of the NIST-VT workshop for WRF – "what are we concerned about, what do we want to measure, and how?"

g) ***"Failure of PCCP Water Mains*.**" **Mr. Michael Woodcock, Principal Engineer of Infrastructure Systems Group at Washington Suburban Sanitary Commission (WSSC).** Mr. Woodcock provided a case study of Pre-stressed Concrete Cylinder Pipe (PCCP) and Lined-Cylinder Pipe (LCP) asset management challenges. He focused on the failure of PCCP and LCP water mains and the effects of these failures. The possible causes of failure were also introduced. The failure types and indicators of failure are mentioned during the presentation and the importance of condition assessment of the pipe is addressed. Condition assessment tools such as finite element analyses, acoustic/sonic monitoring, and fiber optics were discussed.

h) "Water Infrastructure Management, Sustainability, and Resiliency" Dr. Sunil Sinha, Associate Professor, Civil & Environmental Engineering, Virginia Tech. Dr. Sinha introduced the concepts of water infrastructure asset management, the parameters to be measured for water infrastructure system sustainability, and the emerging areas of research related to infrastructure resiliency (rapidity, robustness, and resourcefulness). He covered pipe failure modes and mechanisms, the role of sensor technologies, and why improvements in data structure and data management are required to support pipe prediction modeling. He also presented on-going research, and educational and outreach efforts at Virginia Tech related to water and wastewater pipeline infrastructure systems.

4. TECHNICAL PROGRAM SUMMARY

The workshop was conducted in several break-out sessions focused on five themes, each with its own goals and objectives, as briefly described hereafter.

a) **Pipeline Failure Modes and Mechanisms:** Pipe failures result when applied forces exceed the strength of the pipe material. Forces applied to buried pipe can be categorized into five groups–those produced by (1) internal pressure, (2) bending forces, (3) compressive forces, (4) soil movement induced tensile forces, and (5) temperature induced expansive forces. The strength of the pipe material can also degrade due to corrosion, aging, and material fatigue. The physical/structural, operational, environmental and other critical factors (see Figure 1) by themselves or interactively *(e.g.,* excessive loadings in concrete pipe with poor pipe bedding) can cause a pipe to crack and fracture, resulting in infiltration and exfiltration to/from the surrounding environment.

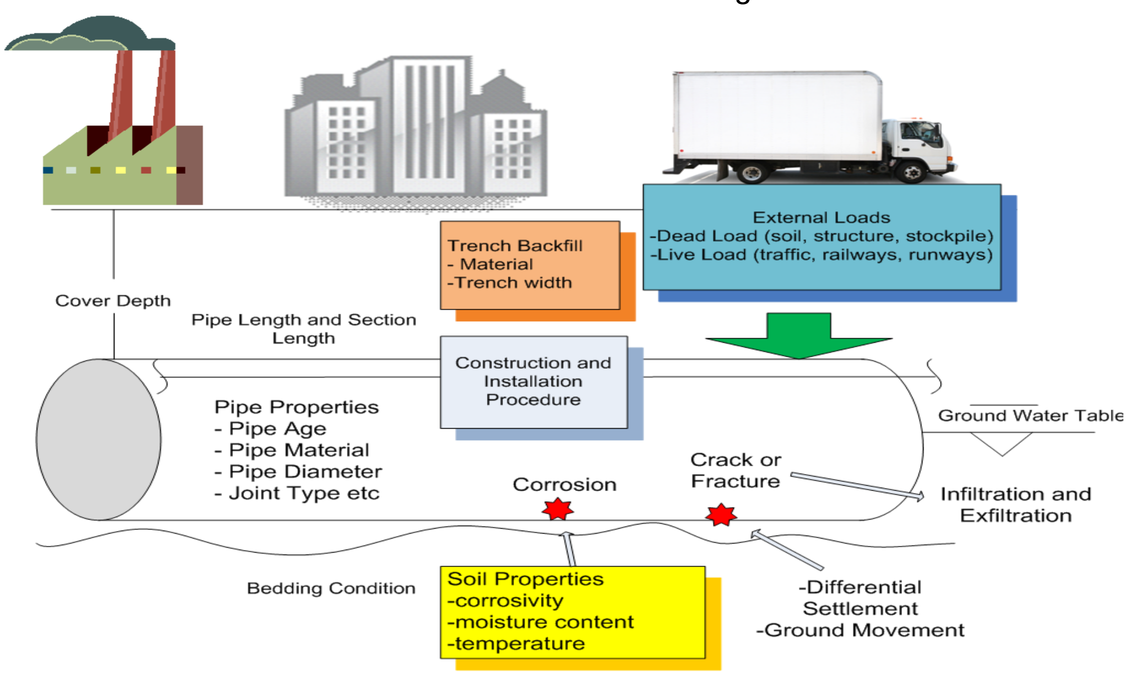

Figure 1. Representative Factors Affecting Condition and Performance of Buried Pipes

In addition to the factors outlined above, degradation in the structural capacity of a pipe to a minimum acceptable level of service is strongly affected by the maintenance strategy, which can profoundly extend the life of pipeline. Finally, we note that while failure modes based on pipe material are well known, the mechanisms of pipe failures are not fully understood. Due to a lack of time-dependent data and analysis of pipe failure, it is very difficult to develop a reliable model to predict deterioration. Thus, there is an urgent need for performance data from accelerated aging tests and a thorough understanding of influences of various parameters on pipe behavior.

b) **Pipeline Condition Assessment Technologies:** Utilities must use their limited funding in an optimal way to repair, rehabilitate, and replace pipes. When data associated with the condition of pipe is insufficient or unavailable, then utility managers cannot make sound asset management decisions, leading to an increased risk of failure, increased operations and maintenance costs, and higher life cycle costs for the pipe infrastructure. Obtaining such data is more challenging than for other infrastructure assets because pipes are mostly buried and generally inaccessible. Variations in pipe properties and external conditions in a collection (wastewater) or distribution (drinking water) system further complicate the development of a comprehensive asset management system.

Existing condition assessment technologies can be broadly categorized as Internal and External Technologies, depending on whether a particular technology is invasive or non-invasive, and Emerging Technologies (Table 1).

Table 1. Various Condition Assessment Technologies

Existing Technologies		**Emerging Technologies**
Internal	**External**	
CCTV Inspection	Half-Cell Measurement	Fiber Optic Sensing
Sounding, Dye Testing	Magnetic Detection	Embedded Sensors
Leak Noise Correlator	Electromagnetic Acoustic	Smart Sensors
Acoustic Leak Detection	Inductive Profiling	X-ray External Surface
Acoustic Emission	Wave Impedance Probe	Thermography Imaging

The energy sector has conducted regular inspection of its metallic pipelines for well over 60 years and has realized significant cost savings from vigilant inspection. One common strategy for inspecting pipelines located above grade includes visual inspection by a trained professional. However, for pipelines located in difficult to reach locations or buried below the surface, the installation of sensors or the use of remote sensing technologies is necessary for non-destructive evaluation (NDE) of pipeline conditions. A major sensor technology that has found widespread use in the energy sector for monitoring pipeline health is ‘smart pigs’.

c) **Pipeline Renewal Engineering Technologies:** EPA states that “*System Renewal includes a wide range of Repair, Rehabilitation, and Replacement techniques that bring the pipeline system at acceptable levels of performance within budgets* [U.S. EPA, 2007, Innovation and Research for Water Infrastructure for the 21st Century – Research Plan].” Renewal of pipeline systems is an engineering challenge when compared to infrastructure assets like bridges, dams, and buildings, because they are "out-of-sight" and "out-of-mind." There are many technologies available and under development for the repair, rehabilitation, or replacement of existing pipelines. Common renewal issues include corrosion, root intrusion, joint dislocation, tuberculation, and ground settlement. Numerous materials, installation methods, diameters, and construction practices are also in use, creating a challenge for the utility and the designer. Comprehensive system renewal is further complicated by variations in physical, chemical, geographical, technical, and condition of existing and renewed pipe. Ultimately, research in pipeline renewal engineering is required because long-term performance data are unavailable, real-world applications are risk-inherent, and large sections of the infrastructure have reached (or are nearing) their lifetimes. The determination of the range of use/limitations of various renewal technologies is complex, and detailed research is needed. Table 2 presents current repair/rehabilitation/replacement technologies.

Table 2. Repair/Rehabilitation/Replacement Technologies for Pipeline

REPAIR	**REHABILITATION**	**REPLACEMENT**
Spot Repair Methods: (Binders, Wraps, Non-shrink grouts, etc.) or Minimal invasion repair projects (Joints, Bends, non-contact repairs, etc.)	Insertion Pit Required: Sectional Slip-lining (Rigid & Flexible), Continuous Slip-lining (HDPE & PVC), Diametrically reduced HDPE liners (thermally & mechanically)	Open-trench Replacement
Localized Repair Methods: Sleeves (CIPP, Fiber-reinforced CIPP, Metal) bedding, etc.	Limited Access Capable: Cured-In-Place Pipe (CIPP), Fiber-reinforced CIPP, Fold & Form PVC, Grout-In-Place, Structural Panel, Structural Coating	Trenchless Replacement Methods: Pipe Bursting, Pipe Splitting, Pipe Eating, Pipe Reaming
Non-structural Coatings (leak sealing and corrosion protection): Cement Mortar Lining, Calcite Lining, Epoxy Resin System, Spray-On linings, etc.	Pressure Applications Only (limited external load resistance): Hose Liners, Fiber-reinforced Hose Liners, Mechanically Deformed/Reformed HDPE Liners, etc.	Abandon & Trenchless Replacement: Jacking, Micro-Tunneling, Horizontal Directional Drilling, etc.

d) **Pipeline Locating Technologies:** Sub-surface Utility Engineering (SUE) identifies, locates, maps, and analyzes a range of information to accurately ascertain the location of buried pipes. Since most pipes are buried and generally inaccessible, planning for renewal activities is extremely difficult. Any differences in “as-planned” and “as-built” location of pipes can cause accidental damage to pipes by third parties. Damage to underground utilities has been identified as one of the most dangerous problems for the construction industry, and the American Institute of Constructors (AIC) identified damage to underground utilities as the third most important problem for contractors. Accurately locating pipes will ensure more confident planning and management. A more recent and comprehensive definition by the American Society of Civil Engineers in a pending document “Standard Guidelines for the Collection and Depiction of Existing Subsurface Utility Data” is as follows: *A branch of engineering practice that involves* *managing certain risks associated with: utility mapping at appropriate quality levels, utility coordination, utility relocation design and coordination, utility condition assessment, communication of utility data to concerned parties, utility relocation cost estimates, implementation of utility accommodation policies, and utility design*. Four quality levels are recognized [ASCE, 2009] and summarized in Table 3.

Table 3. Four Quality Levels Recognized by ASCE (ASCE, 2009)

Quality Level D	Information derived from existing records or oral recollections
Quality Level C	Information obtained by surveying and plotting visible aboveground utility features and by using professional judgment in correlating this information to Quality Level D information.
Quality Level B	Information obtained through the application of appropriate surface geophysical methods to determine the existence and approximate horizontal position of subsurface utilities. Quality Level B data should be reproducible by surface geophysics at any point of their depiction. This information is surveyed to applicable tolerances defined by the project and reduced onto plan documents.
Quality Level A	Precise horizontal and vertical location of utilities obtained by the actual exposure (or verification of previously exposed and surveyed utilities) and subsequent measurement of subsurface utilities, usually at a specific point. Minimally intrusive excavation equipment is typically used to minimize the potential for utility damage. A precise horizontal and vertical location as well as other utility attributes is shown on plan documents. Accuracy is typically set at 15 mm vertical, and to applicable horizontal survey and mapping accuracy as defined or expected by the project owner.

The majority of buried pipe location technologies work on the principle of scattering of electromagnetic waves by buried objects. Among the most widely used technologies for locating buried pipes are Ground Penetrating Radar (GPR), Electrical Resistivity, and Seismic Reflection. Several emerging technologies being researched for locating utilities are RFID (radio frequency identification) tags, marker balls, and other embedded sensors. However, no one technology can precisely locate all buried pipes.

e) **Education, Outreach, and Training Program:**

Asset management is maintaining a desired level of service for what you want your assets to provide at the lowest life cycle cost. Lowest life cycle cost refers to the best appropriate cost for rehabilitating, repairing or replacing an asset. There is a need to give future professional a working knowledge of pipeline infrastructure asset management and provide them with an understanding of infrastructure techniques and their potential applications. The goal of collaboration should be to create a broad-based university-industry-public works partnership to further the development of pipeline technologies on an ongoing basis. Industry participants should help develop and use technologies, and public work agencies should play an important role in providing test sites for fundamental study of the system, promising new technologies, and methods.

5. DISCUSSION SESSION GOALS AND GUIDING QUESTIONS

The Discussion Sessions were a major part of the NIST-VT workshop and were divided into five breakout sessions as previously described in Section 4.

Breakout Session 1: *Pipeline Failure Modes and Mechanisms*

- Leader: Mike Woodcock, Washington Suburban Sanitary Commission (WSSC)
- Moderator: Tom Iseley, IUPUI
- Reporter: Alison St. Clair, Graduate Student, VT

Session Goals

- Define research need related to various pipe failure mode
- Define research need for understanding pipe failure mechanism

Guiding Questions

- Is there need for design and operation of standardized test beds to advance understanding of water pipeline failure modes and mechanisms?
- Should we evaluate the impact of mechanical, thermal, chemical, and biological factors, external interferences, and maintenance on performance and residual life of pipes and do we have the measurement tools required?
- What material and structural parameters are critical for characterization and modeling of pipeline condition and do we have the measurement tools required?
- What level of numerical modeling is required to establish a threshold of alarm?
- What measurements and data are necessary to capture the performance of connections (joints, valves, hydrants, etc.), and can these be made through reduced-scale testing?
- What are the most critical structural connections that should be investigated, and in what type of structures (for example PCCP has a very complex structure)?

Breakout Session 2: *Pipeline Condition Assessment Technologies*

- Leader: Richard Thomasson, Malcolm Pirnie, Inc. / Graduate Student, VT
- Moderator: Richard Nelson, CH2M HILL, Inc.
- Reporter: Mohammed Aijaz, Graduate Student, VT

Session Goals

- Define research needs related to existing and emerging condition assessment technologies
- Define research needs for innovative condition assessment technologies

Guiding Questions

- Should we systematically evaluate and improve existing/emerging condition assessment technologies in controlled environments?
- Should we systematically evaluate and improve existing/emerging buried pipe locating technologies in controlled environments?
- Is there a potential need for controlled-condition research for testing and verification of condition assessment technologies, sensor deployment /capabilities/limitations?
- What measurement support could we provide to agencies to extend routine inspections to the maximum time frame their condition warrants? Or, are agencies interested in minimizing inspection time in order to focus effort and resources in other areas?
- Is there a need for reference artifacts for baseline evaluation of NDE signals, including signal/noise levels, error due to specific internal defects, and error due to improper understanding of material behavior and influences of material on NDE system signals?
- Do we need "gold standard" NDE methods for cross-correlation and qualification of new NDE systems? Should there be new Standard Reference Materials (SRMs) with intentionally induced flaws for field calibration of NDE tools?
- Should consensus standards for inspection procedures be revised to improve uniformity and further reduce error? Should we do real-time monitoring?

Breakout Session 3: *Pipeline Renewal Engineering Technologies*

- Leader: Richard Thomasson, Malcolm Pirnie, Inc. / Graduate Student, VT
- Moderator: Grant Whittle, Ultraliner, Inc. / Graduate Student, VT
- Reporter: Kristi Steiner, Graduate Student, VT

Session Goals

- Define research need related to repair, rehabilitation, and replacement of existing pipelines
- Define research need for renewal engineering recognizing that renewal engineering is complex and time-consuming

Guiding Questions

- Should we systematically evaluate and improve existing/emerging renewal engineering technologies in controlled environments?
- Is there potential need for controlled-condition research for testing and verification of repair, rehabilitation, and replacement technologies and methods?
- What measurements or data are necessary to understand the effects of the condition of the host pipe, pressure, water chemistry, strain rate such as blast or impact, etc.?
- What fatigue data or measurements are necessary to validate the implementation of renewal material, technology, and methods proposed for use to renew old pipelines?
- Do renewal technologies require any special measurement tools?

- Can the data from condition assessment be used in a standardized way to help prioritize the renewal decisions within the utilities?
- Once the renewal technology has been installed, what measurements are needed to ensure that it is working properly?

Breakout Session 4: *Pipeline Locating Technologies*

- Leader: Mark Wallbom, Underground Imaging Technologies (UIT), Inc.
- Moderator: David Jeong, Oklahoma State University
- Reporter: Lewis Hutchins, Naval Facilities Engineering Command, DC

Session Goals

- Define research need related to Sub-surface Utility Engineering (SUE)
- Define research need for accurately locating pipes

Guiding Questions

- Should we systematically evaluate and improve existing/emerging buried pipe locating technologies in controlled environments?
- Is there potential need for controlled-condition research for testing and verification of locating technologies, sensor deployment/capabilities/limitations?
- Is there a need for reference artifacts for baseline evaluation of NDE signals, including signal/noise levels, and error due to improper understanding of material behavior and influences of material on NDE system signals?
- Do we need "gold standard" NDE methods for cross-correlation and qualification of new NDE systems? Should there be new Standard Reference Materials (SRMs) with intentionally induced flaws for field calibration of NDE tools?
- Should consensus standards for locating procedures be revised to improve uniformity and reduce error? Should we use embedded locating technologies?

Breakout Session 5: *Education, Outreach, and Training Program*

- Leader: Matthew Stolte, Town of Blacksburg, Virginia
- Moderator: Wayne Francisco, GHD, Inc.
- Reporter: Leon F. Gay, Graduate Student, VT

Session Goals

- Define research need related to education, outreach, and training programs

Guiding Questions

- Is the public aware of the current condition of civil infrastructure systems and the importance of asset management?
- Are education programs focused on both short-term and long-term goals?
- Is there any relationship between good asset management practice and funding/incentives?
- Is there any system for engineers to go beyond compliance with minimum standards to achieve long term performance goals?
- Do any organizations currently propose a framework to achieve standardization and certification of the practice?

- Understanding the importance of asset management is crucial for all levels of employees. Is there any program available to educate the employees?
- How can we enhance the transfer of the valuable experience of retirees to the next generation?

6. DISCUSSION SESSION RESULTS AND RESEARCH NEEDS

Breakout Session 1: *Pipeline Failure Modes and Mechanisms*

Discussion Summary

During the first day's discussion, a number of topics and themes emerged. One topic which was stressed was the potential of linking the failure modes and mechanisms with condition assessment. This would require prioritizing instruments and techniques to identify potential failure. Identification of pipe repairs in relation to a particular failure mode was also discussed. Another suggestion brought forth was the development of a common language which would include specific coding for imperfections, and failure definitions. Development of data standards was also a topic of interest. Understanding the materials and correlating them with the buried infrastructure will aid in development of these standards. The second day's discussion resulted in adding to the past day's comments and the addition of several more potential areas of research. The pipe failure modes associated with the pipe manufacturing needs to be cataloged. Defining failure modes and correlating them to critical locations within the pipe will also be of great benefit. Identifying and prioritizing the high risk pipe failure scenarios was also discussed.

Research Needs

- Need for design and operation of standardized test beds and in-situ test beds.
- Need to evaluate the impact of mechanical, thermal, chemical, and biological factors, external interferences, installation methods, QA/QC and maintenance on performance and residual life of pipes; need to develop tools to measure them.
- Need to establish a threshold of alarm through numerical modeling.
- Need to establish the measurements and data necessary to capture the performance of connections (joints, valve, hydrant, etc.) through testing and/or reduced-scale testing.
- Need to classify the most critical structural connections to be investigated and the type of material structure.
- Need to link failure modes with condition assessment and prioritize instruments and techniques to identify potential failures.
- Need to develop a standard language and codes for reporting imperfections and need standard failure definitions.
- Need to define various failure modes and how to identify where they are located.
- Need to identify failures that can be predicted and that can be controlled.

- Need to identify repair options in relation to particular failure modes. Need to evaluate the pipe material type with the failure modes.
- Need to correlate the failure modes with imperfections that can be identified on the inside or on the outside of pipes.
- Need to understand the materials and correlate with the buried infrastructure system in order to develop best practices for condition assessment and performance prediction.
- Need to identify and prioritize high risk pipe failure scenarios.
- Need for cataloging pipe failure modes from pipe manufacture. Need to identify service type.
- Need to identify parameters that are critical for characterization and modeling of pipeline condition. Need to identify tools to measure the parameters.

Breakout Session 2: *Pipeline Condition Assessment Technologies*

Discussion Summary

During the first and second day's workshop discussion on Condition Assessment technologies, several recurring themes were brought-up. Utilities have difficulty choosing and matching the correct condition assessment technology to the specific condition assessment inspection/monitoring need (i.e., particular type of pipe, etc.). There are issues regarding the perceived cost of the technologies and the actual real world cost. There is a lack of understanding regarding what data is actually being obtained from the various condition assessment technologies. Challenges are being faced regarding uniformity/compatibility between data obtained from different inspectors, companies, and utilities. There is a lack of understanding on how to effectively utilize and convert results obtained from Condition Assessment technologies into actionable responses. Condition Assessment data should integrate into an asset management plan (rehab, replace, etc.) in order to guide operation and maintenance decisions required to achieve target minimum levels of service (pertaining to safety, leakage, performance, etc.). Also utilities want more guidance on how specifications and standards can be used to better ensure the quality of their condition assessment data, and how to translate that data into better asset management. The specific needs are further elaborated below.

Research Needs

- Need to document CA technology capabilities (i.e., maximum distance of sensor placement, minimum threshold of sensitivity, etc.) so that CA technologies can be built into new/replacement construction to facilitate health monitoring.
- Need for guidance on defining failure (based on performance, safety, etc.). Need for agencies to develop standards for classifying Condition Levels/Failures Levels for pipes (i.e., Level 1-10, Green to Red, etc.) to help define what is an acceptable level of service.
- Need for standard definitions, codes, and classifications of pipeline condition data to aid in decision support tool development.
- Need exists for creating additional CA inspection standards; only standards currently in existence are for visual codes when using CCTV.

- Need for guidelines on pipe design for new mains (i.e., recommended # of access ports, defined size of ports, etc.) to minimize future CA inspection costs; this is a particular need with pressure pipes.
- Need for standardized specs to be used for condition assessment to streamline the process and put more effort into actual inspections.
- Need for national baseline data collection standard similar to European standards currently in place (i.e.,, German DIBT standard). These standards involve testing the technologies under ideal conditions to establish minimum performance specifications. The specification requirements are compared with the test results obtained during field construction / operation to establish a performance baseline. The baseline data can then be compared to future performance data to measure change over time, to assist in determining the end of service life.
- Need for measurable reliability standards (e.g., metric of number of false-positives and false negatives) so that utilities can be better informed when spending funds.
- Need for guidance on how to measure the infiltration and inflow, or exfiltration from laterals and water service lines.
- Need for a smart pipe research facility where older pipe samples removed from service can be used to test condition assessment technologies under controlled conditions.
- Need for guidance regarding when to use the various CA technologies (which technologies are applicable for specific types of pipe, etc.). Similarly, need for CA technologies to be broken down into survey level (system level), or pin-point level (i.e., pipe specific).
- Need for estimations of the value and cost/benefit of CA technologies.
- Need for data standards to be developed in a controlled environment that define the accuracy and precision of various condition assessment technologies in regards to what is being measured.
- Need for standard nomenclature, definitions, and measurements pertaining to all components, features, performance criteria, and imperfections within water, wastewater and storm water pipelines and appurtenances.
- Need for utilities to know level of detail, what to measure, etc. when reporting metrics from CA inspections.
- Need for a national standard on how to collect, store, retrieve, and analyze pipe infrastructure data.

Breakout Session 3: *Pipeline Renewal Engineering Technologies*

Discussion Summary

Several speakers addressed the many challenges presented by our aging water infrastructure. Some of the general points brought up by keynote speakers regarding pipeline renewal were the need for standard terminology, guidance on how to analyze condition assessment/other data to understand when localized repair versus pipeline replacement is appropriate, guidance on how to more quickly validate the capabilities and limitations of new technologies so that they can be integrated into the field with confidence, and guidance on how to evaluate long-term performance and costs. There was a strong focus on the following: Lack of data to enable long term performance analysis; the true risks involved in the actual implementation of technologies; determining the correct prioritization parameters for renewal projects given the large number of pipe sections nearing or past their useful life; and improving the current design controls in regards to both structural equations and constructability. In general, there were many discussions on how to fill the gaps in knowledge regarding the renewed pipe performance, asset management strategies, design equations, installation/construction processes, QA/QC procedures, post construction O&M requirements, and life-cycle costing.

Research Needs

- Need to develop a test bed for controlled environment testing of renewal technologies. The test bed should then be used to evaluate and improve renewal technologies.
- Need for controlled-condition research to determine the minimum data required to define the true limitations and capabilities of renewal methods and to provide guidance to avoid incorrect application of technologies.
- Need to identify existing tools that can improve measurements and data collection.
- Need to develop tools to enable key measurements and data collection not possible with available technologies. (provide better understanding of the effects of condition of host pipe, pressure, water chemistry, strain rate such as blast, seismic, or impact loads, strain concentration at local imperfections, etc.)
- Need to identify fatigue data or measurements necessary to validate the implementation of renewal material, technology, and methods proposed for use to renew old pipeline. Where tools exist, necessary measurements and data should be determined, and where tools do not exist, the project should also involve the development of tools.
- Need to identify or develop special measurement tools to improve the design, application, and performance assessment of renewal technologies.
- Need to develop standardized methods and measurements for the collection of condition assessment data on existing assets to improve data analysis methods, renewal prioritization, and design of renewal technologies. Need standards for data collection on every individual inventoried maintenance item.
- Need to develop standardized methods and measurements for the collection of QA/QC data and long-term condition and performance data of renewed assets to guide O&M needs over the life-cycles of renewal technologies. Need standards for data collection on every individual inventoried maintenance item.
- Need standardization of QA/QC and data collection necessary at the end of installation to promote more careful manufacturing, transportation, and installation procedures. Standardized baseline data is essential to effectively measure change in performance over time.
- Need to develop standards specific to renewal technologies for pressure rating, earthquake resistance, and other such design certifications.

- Need to develop and publish detailed testing protocol guidelines for each renewal technology. Standard testing protocols will be used for round robin testing of renewal technology materials to determine confidence limits and expected variance related to material claims.
- Need to identify advances that have been made to enhance equations for renewal engineering design where significant gaps currently exist. (i.e., Pipe soil system analysis components, side wall support analysis, host pipe geometry, gap between host pipe & liner, local imperfections, fats/oils influence on flow rates, etc.)
- Need to characterize and classify local imperfections in pipe liners and incorporate their influence during the design phase. Research has shown that large scale local imperfections can frequently control liner performance life, even eclipsing the influence of global imperfections such as ovality, but the industry design standards do not currently control their influence. Local imperfections can potentially be mathematically considered directly in the design equations or else accommodated for with constructability design controls.
- Need to identify factors that cause catastrophic failures, especially with pressure pipes, as opposed to those that merely cause reduced physical characteristics and gradual performance failures. These factors need to be incorporated into design and failure prediction methods.

Breakout Session 4: *Pipeline Locating Technologies*

Discussion Summary

Locating buried utility assets is a significant challenge for the utility industry. Buried infrastructure is one of the largest assets of a city, and the complexity of the underground infrastructure leads to many challenges when excavating in an urban environment. State "one-call" systems have been mandated in response to the growing instances of utility hits. These programs place a mark on the surface, however, the marks are only accurate to approximately +/- 18-24 inches from the line and provide a two-dimensional location of the buried asset according to the frequently inaccurate "as-built" records. Current pipeline locating technologies have limited three-dimensional capability but when paired with a complimentary technology can often produce an accurate location of a utility. Mounting a GPS receiver onto an array of ground penetrating radar systems is one way in which the combined use of technologies is improving utility mapping.

Damage to underground utilities has been identified as one of the most dangerous problems for the construction industry. The DIRT Report, released by the Common Ground Alliance, shows the number of utility hits is increasing and is supplemented by data from the FHWA Office of Pipeline Safety's report which documents 300+ deaths and upwards of $360 million in damages for the reporting period. As a result, many industry associations including the Common Ground Alliance (CGA), the American Society of Civil Engineers (ASCE), Federal Highway Administration (FHWA) and North American Society for Trenchless Technology (NASTT) all currently have research initiatives underway to help address the problem. The need to focus research on several specific areas was verified though the discussion during the NIST-VT workshop.

Research Needs

- Need to have standardized methods and measurements for determining the capabilities and limitations for technologies? (i.e., range, precision, accuracy, applicability, etc.)
- Should we use new technologies? For example, Laser Clouding. We recognize value of BIM for vertical construction, same should be for horizontal
- Can damage to existing utilities be detected after laying new utility, such as with directional drilling?
- Is there a need to test and validate geophysical methods in controlled environments?
- Need to develop accurate standards/goals for locating technologies
- Need to develop Standard Reference Materials for the use of geophysical methods to locate buried utilities
- Need for validation protocols for locating technologies
- Need to develop standardized field procedures for the application of geophysical methods that take into account the many different settings available and the surrounding environment
- Need to develop guidance for documenting abandoned buried utilities

Breakout Session 5: *Education, Outreach, and Training Program*

Discussion Summary

Educational institutions need to take a more active role in infrastructure asset management standardization, outreach to the public, and utility employee training at all levels. A large number of workers are retiring or about to retire, posing significant challenges to the water management sector. The experience of trained workers in the field is valuable and it is necessary to transfer their knowledge to the next generation. Academic institutions should find ways to engage retirees for contributing in the training of the upcoming generation of workers.

Research Needs

- Need to develop standards for data collection and reporting, and guidance on applicable methods for Infrastructure Asset management
- Need to develop Metrics for Infrastructure Sustainability and Resiliency. Need to define the engineering meaning and how to measure “sustainable” and “resilient” in the context of water infrastructure.
- Need to develop certification program for Infrastructure Asset Management practitioners
- Need to provide the stakeholders with an improved understanding of long lived assets, and the associated unique asset management challenges
- Need to train the upcoming generation of workers (web-based training program)

- Need to train all workers (including operators, field engineers, etc.) with basic understanding of asset management practice. Understanding asset management importance and processes should not be exclusively an engineering issue. Perhaps one way to do this is to incorporate asset management topics into operators' certification programs.
- With the increasing volume and criticality of our legacy infrastructure, we need to change the civil infrastructure educational focus to go beyond mere design and construction of new assets, and have an increased emphasis on operation and maintenance of legacy assets.
- Need to educate engineers to understand that their professional duty must go beyond designing infrastructure to ensure compliance with mere minimum design standards, but rather designing to achieve long term performance minimums. This is the core paradigm shift in the education of engineers that is essential for asset management principles to ever succeed.
- Need to provide controversial topics such as Sustainability and Resiliency with specific, measurable meanings in regards to water infrastructure.
- Need to find mechanisms to transfer knowledge from a rapidly retiring workforce to a new generation. Today's retirees should be integrated into training programs for the upcoming generation. The generation change is also an opportunity to change how things are done.
- Need to outreach to general public in order to raise awareness of the current condition of civil infrastructure systems and therefore the value of infrastructure asset management.
- Need for a multidisciplinary understanding of infrastructure asset management issues. Problems in the field are increasingly the result of city level decisions instead of business unit decisions. Public policy managers need a more thorough understanding of the issues involved with infrastructure asset management.
- Need to provide education programs about asset management pertaining to both short-term and long-term assets. Civil infrastructure systems are usually long lived assets that require a different approach from short lived assets. Business strategies encouraged according to the management needs of short-lived assets are not always adequate for infrastructure.
- Need to estimate the return on investment for education, outreach and training activities on infrastructure asset management, as well as the return on investment for implementing an asset management plan.
- Need to relate good asset management practices with funding and incentives for organizations and utilities. To encourage asset management adoption, asset management plans must be integrated into the financial process for approving bond issues, loans, and grants. With long-lived infrastructure, asset management planning is a critical component of financial risk management.
- Need to integrate multi-sector needs and approaches (buildings, transportation, utilities, others) into city-wide and nationwide infrastructure asset management standards. Compatible, integrated reporting standards are required to improve asset allocation in order to ensure the continued viability of our communities.

7. CONCLUSIONS and RECOMMENDATIONS

The NIST-VT Water Measurement workshop was held to develop a prioritization for fundamental and applied research at federal institutions and entities funding research in sustainable water. The participants represented a diverse cross section of researchers from academia, utility, consultant, industry, and federal institutions. They identified resilient and sustainable water infrastructure systems as the overarching goal to pursue.

The details of the voting process and results are presented in **Appendix E**. Through the voting process the participants identified the top ten (10) priorities for water infrastructure research needs as summarized below (in no particular order):

- Need for a national standard on how to collect, store, retrieve, and analyze pipe infrastructure data.
- Need for design and operation of standardized test beds and in-situ test beds.
- Need to classify the most critical structural components to be investigated and the type of material structure.
- Need to develop a test bed for controlled environment testing of renewal technologies to be used to evaluate and improve technologies.
- Need to develop Metrics for Infrastructure Sustainability and Resiliency, Define the engineering meaning and how to measure “sustainable” and “resilient” for water infrastructure systems.
- Need to develop Standard Reference Materials for use with geophysical methods for locating buried utilities.
- Need to develop standardized methods and measurements for the collection of condition assessment data on existing assets to improve: data analysis methods; maintenance and renewal prioritization; and design, operation, and maintenance of renewal technologies. Data collection and reporting standards are needed for every type of condition assessment data available for every individual inventoried maintenance item in existence.
- Need to develop standardized methods and measurements for the collection of QA/QC data and long-term condition and performance data of renewed assets to guide O&M needs over the life-cycle of renewal technologies.
- Need to link failure modes, mechanisms, and indicators with condition assessment, and prioritize tools and techniques to identify potential failure.
- Need to standardize Infrastructure Asset management practice and define best appropriate practices and leave it to the individual entity to decide what works the best for their organization. Need to help promote stakeholder collaboration.

Achieving the resiliency and sustainability vision will require a revolutionary change in the water infrastructure asset management processes typically followed to generate fundamental knowledge and develop enabling technologies. The various stakeholders within water infrastructure community must work together to accelerate progress toward these highly interdisciplinary and multidisciplinary research needs.

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APPENDIX A

WATER INFRASTRUCTURE WORKSHOP AGENDA

Dates: Thursday September 9thand Friday September 10th, 2010
Location: Northern Virginia Campus, Falls Church, VA
Thursday, September 9th - 8:00am to 5:30pm

8:00am
Arrive at the Northern Virginia Center (NVC), 7054 Haycock Road, Falls Church, VA 22043

8:30am
Welcome
Senior Scientific Advisor, NIST-Gaithersburg, Michael Fasolka

8:40am
Overview of MSEL Plan (Aging Infrastructure, Safety, and Reliability)
Materials Reliability Division Chief, NIST-Boulder, Stephanie Hooker

9:00am
Current Research & Education in Sustainable Water Infrastructure Management
Co-Director SWIM and Associate Professor, Virginia Tech, Sunil Sinha

9:30am
Keynote General: US EPA (Aging Water Infrastructure Research and Education Programs)
Manager, Office of Research and Development, EPA, Dan Murray

10:00am
Break (light refreshment provided)

10:30am
Keynote Failure Mode & Mechanism: Sunil Sinha (Overview and Fundamental Understanding)
Co-Director SWIM and Associate Professor, Virginia Tech, Sunil Sinha

11:00am
Keynote EPA (Environmental Protection Agency) Pipeline Infrastructure Projects
Program Manager, Aging Infrastructure Research, EPA, Michael Royer

11:15am
Keynote WaterRF (Water Research Foundation) Water Infrastructure Projects
Program Manager, Infrastructure Asset Management, WaterRF, Frank Blaha

11:30am
Keynote WERF (Water Environment Research Foundation) Water Infrastructure Projects
Program Manager, Infrastructure Asset Management, WERF, Walter Graf

11:45am
Keynote USBR (Bureau of Reclamation) Water Infrastructure Projects
Program Manager, Infrastructure Asset Management, USBR, Daryl Little

12:00noon
Lunch (box lunch provided)
1:00pm

Role of Breakout Sessions: Dr. Sunil Sinha

a. ***Breakout Three Themes***
   I. Pipe Failure Mode & Mechanism
   II. Pipe Condition Assessment & Locating Technologies
   III. Pipe Repair, Rehabilitation, and Replacement Technologies
b. ***Breakout Discussion Areas:***
   I. Fundamental Understanding, Material Behavior, and Sensors
   II. Standards and Measurements Gap
   III. Long-term Performance, Reliability, and Need for Acceleration Testing
   IV. Database, Data Mining, Simulation, and Predictive Modeling
   V. Education, Outreach Activities, and Professional Training Needs
c. ***Purpose of Breakout:***
   I. Identify and document key issues
   II. Identify and document major gaps
   III. Identify short-term and long-term needs
   IV. Prioritize research agenda
   V. Prioritize education, outreach, and training agenda

Breakout Sessions

1:30pm

Pipe Failure Mode and Mechanism

a. Leader: Mike Woodcock, Washington Suburban Sanitary Commission
b. Moderator: Tom Iseley, IUPUI
c. Reporter: Alison St. Clair, Graduate Students, VT

2:15pm

Pipeline Condition Assessment

a. Leader: Richard Thomasson, VT
b. Moderator: Richard Nelson, CH2M HILL
c. Reporter: Mohammed Aijaz , Graduate Student, VT

3:00pm

Break (light refreshment provided)

3:30pm

Pipeline Renewal Engineering

a. Leader: Ed Kampbell, Rehabilitation Resource Solutions
b. Moderator: Grant Whittle, VT
c. Reporter: Kristi Steiner, Graduate Student, VT

4:15pm

Pipeline Locating Technologies

a. Leader: Mark Wallbom, Underground Imaging Technologies
b. Moderator: David Jeong, Oklahoma State University
c. Reporter: Lewis Hutchins, Graduate Student, VT

4:45pm

Education, Outreach, and Training

a. Leader: Matthew Stolte, Town of Blacksburg
b. Moderator: Wayne Francisco, GHD
c. Reporter: Leon F. Gay, Graduate Student, VT

5:30pm
Meeting Adjourns

Dates: Thursday September 9th and Friday September 10th, 2010
Location: Northern Virginia Campus, Falls Church, VA

Friday, September 10th – 8:00am to 12:00noon

8:00am
Arrive at the Northern Virginia Center (NVC), 7054 Haycock Road, Falls Church, VA 22043

8:30am
Role of Breakout Sessions

a. ***Breakout Three Themes***
   I. Pipe Failure Mode & Mechanism
   II. Pipe Condition Assessment & Locating Technologies
   III. Pipe Repair, Rehabilitation, and Replacement Technologies
b. ***Breakout Discussion Areas:***
   I. Fundamental Understanding, Material Behavior, and Sensors
   II. Standards and Measurements Gap
   III. Long-term Performance, Reliability, and Need for Acceleration Testing
   IV. Database, Data Mining, Simulation, and Predictive Modeling
   V. Education, Outreach Activities, and Professional Training Needs
c. ***Purpose of Breakout:***
   I. Identify and document key issues
   II. Identify and document major gaps
   III. Identify short-term and long-term needs
   IV. Prioritize research agenda
   V. Prioritize education, outreach, and training agenda

9:00am
Review and Comment on Document (key issues and major gaps) from Thursday Discussion

10:00am
Break (light refreshment will be provided)

10:30am
Review and Prioritize Research Agenda (short and long term)

11:00am
Review and Prioritize Education, Outreach, and Training Agenda (short and long term)

11:30pm
Concluding Remark

12:00noon
Workshop Adjourns

APPENDIX B

Water Infrastructure Workshop List of Participants

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APPENDIX C

Workshop presentations are only on the CD version of the report

APPENDIX D

Workshop video recordings are only on the CD version of the report

APPENDIX E

Water Infrastructure Research Needs Voting Results

The NIST-VT Water Measurement workshop prioritizes the fundamental and applied research for water. In the prioritization process, a diverse cross section of researchers including academia, agency, utility, consultant, and technology providers were involved. The workshop identified research needs for each breakout session as described in Section 6 and the lists of research needs are sent to various researchers to prioritize the needs. The lists of research needs and vote results are summarized in Tables 4 to 8.

Table 4. Research Needs for Breakout Session 1

Research Need	Academic	Agency (NIST, EPA, WERF, etc)	Utility	Consultant	Technology Provider
Breakout Session 1: *Pipeline Failure Modes and Mechanisms*					
Need for design and operation of standardized test beds and in-situ test beds	**1**	**1**	**2**	**1**	**2**
Need to evaluate the impact of mechanical, thermal, chemical, and biological factors, external interferences, installation methods, QA/QC and maintenance on performance and residual life of pipes and tools to measure them	**1**	**1**			
Need to establish a threshold of alarm through numerical modeling		**1**			
Need to establish the measurements and data necessary to capture the performance of connections (joints, valve, hydrant, etc.) through testing and/or reduced-scale testing				**1**	
Need to classify the most critical structural connections to be investigated and the type of material structure	**1**	**1**	**1**	**1**	**1**
Need to link failure modes with condition assessment and prioritize instruments and techniques to identify potential failure	**1**	**1**	**2**	**1**	**1**
Need to develop a common language, specific coding, imperfections and failure definitions					**3**
Need to define various failure modes and where it is located				**1**	
Need to identify failure one can predict and one can control					**1**
Need to consider repairs in relation to particular failure mode. Need to evaluate the pipe material type with failure mode			**1**		
Need to correlate the inside with the outside pipe failure modes				**1**	
Need to develop standards. Need for understanding the materials and correlate with the buried infrastructure system				**1**	
Need to identify and prioritize high value pipe failure scenarios	**1**		**1**		
Need for cataloging pipe failure modes from pipe manufacture. Need to identify service type	**1**				
Need to identify parameters that are critical for characterization and modeling of pipeline condition. Need to identify tools to measure the parameters		**1**			**2**

Table 5. Research Needs for Breakout Session 2

Research Need	Academic	Agency (NIST, EPA, WERF, etc)	Utility	Consultant	Technology Provider
Breakout Session 2: *Pipeline Condition Assessment Technologies*					
Need for standards for CA technologies so that CA technologies can be built into new/replacement construction to facilitate health monitoring	**1**	**1**		**1**	
Need for guidance on defining failure and need for agencies to develop standards of Condition Levels/Failures Levels for pipes to help define what is an acceptable level of service	**1**	**1**		**1**	
Need for standard definitions and classifications of pipelines to aid in decision support				**1**	
Need exists for creating CA inspection standards; only current standards are for visual codes when using CCTV		**1**			**1**
Need for guidelines on pipe design for new mains to minimize CA inspection costs in future				**1**	**1**
Need for standardized specs to be used for condition assessment to streamline the process and put more effort into actual inspections					**1**
Need for national baseline standard similar to European standards currently in place. These standards involve testing the CA technologies under ideal conditions prior to placement to establish a baseline. These are compared with the results obtained at the end of service life	**1**			**1**	**1**
Need for measureable standards so that utilities can be better informed when spending funds			**1**		**1**
Need for guidance on how to measure the infiltration and inflow from laterals and water service lines			**1**		**1**
Need for a better definition and direction for smart pipe facility development to identify the deteriorated condition causative parameters by using older pipe installed in the past but removed from service for testing under varying conditions	**1**				**1**
Need for guidance for when to use the various CA technologies (which technologies are applicable for specific types of pipe, etc.). Similarly, need for CA technologies to be broken down into survey level (system level), or pin-point level			**1**		**1**
Need for estimations of the value and cost/benefit of CA technologies			**1**		**1**
Need for laboratory standards to be developed in a controlled environment that defines the level and detail of what is being measured regarding various condition assessment technologies		**1**			
Need for standard nomenclature for definitions of water, wastewater and storm water pipelines and appurtenances	**1**				**1**
Need for utilities to know level of detail, what to measure, etc. when recording metrics from C.A. inspections			**1**		
Need for a national standard on how to collect, store, retrieve, and analyze pipe infrastructure data	**2**	**2**	**2**	**1**	**1**

Table 6. Research Needs for Breakout Session 3

Research Need	Academic	Agency (NIST, EPA, WERF, etc)	Utility	Consultant	Technology Provider
Breakout Session 3: *Pipeline Renewal Engineering Technologies*					
Need to develop a test bed for controlled environment testing of renewal technologies. The test bed should then be used to evaluate and improve renewal technologies	**2**	**1**	**1**	**2**	**2**
Need for controlled-condition research to determine the minimum data required to define the true limitations and capabilities of renewal methods and to provide guidance to avoid incorrect product uses					**2**
Need to identify existing tools that can improve measurements and data collection				**1**	
Need to develop tools to enable key measurements and data collection not possible with available technologies.		**1**			**1**
Need to identify fatigue data or measurements necessary to validate the implementation of renewal material, technology, and methods proposed for use to renew old pipeline.				**1**	
Need to identify or develop special measurement tools to improve the design, application, and performance assessment of renewal technologies					
Need to develop standardized methods and measurements for the collection of condition assessment data on existing assets to improve data analysis methods, renewal prioritization, and design of renewal technologies.	**1**	**2**	**2**	**1**	**1**
Need to develop standardized methods and measurements for the collection of QA/QC data and long-term condition and performance data of renewed assets to guide O&M needs over the life-cycles of renewal technologies and need standards for data collection on every individual maintenance item	**2**	**2**	**2**	**1**	**2**
Need standardization of QA/QC and data collection necessary at the end of installation to promote more careful manufacturing, transportation, and installation procedures			**1**		**1**
Need to develop standards specific to renewal technologies for pressure rating, earthquake resistance, and other such design certifications					
Need to develop and publish detailed testing protocol guidelines for each renewal technology. Standard testing protocols will be used for round robin testing of renewal technology materials to determine confidence limits and expected variance related to material claims	**1**		**1**		**1**
Need to identify advances that have been made to enhance equations for renewal engineering design where significant gaps currently exist					
Need to characterize and classify local imperfections in pipe liners and incorporation of their influence during the design phase.	**1**				
Need to identify factors that cause catastrophic failures, especially with pressure pipes, as opposed to reduced physical characteristics. These factors need to be incorporated into design and failure prediction methods					

Table 7. Research Needs for Breakout Session 4

Research Need	Academic	Agency (NIST, EPA, WERF, etc)	Utility	Consultant	Technology Provider
Breakout Session 4: *Pipeline Locating Technologies*					
Need to have standardized ranges for technologies? (i.e., accuracy and applicability)	**1**		**1**	**1**	**1**
Should we use new technologies? For example, Laser Clouding. We recognize value of BIM for vertical construction, same should be for horizontal		**1**	**1**	**1**	**1**
Can you detect damage to existing utilities after laying new utility, such as with directional drilling?		**1**			**1**
Is there a need to test and validate geophysical methods in controlled environments?	**1**	**1**		**1**	**2**
Need to develop accurate standards/goals for locating technologies		**1**	**1**		**1**
Need to develop Standard Reference Materials for the use of geophysical methods to locate buried utilities	**2**	**2**	**2**	**1**	**2**
Need to validation protocols for locating technologies	**1**		**2**		**1**
Need to develop standardized field procedures for the application of geophysical methods that take into account the many different settings available and the surrounding environment	**1**			**1**	**1**
Need to develop guidance for documenting abandoned buried utilities	**1**			**1**	**1**

Table 8. Research Needs for Breakout Session 5

Research Need	Academic	Agency (NIST, EPA, WERF, etc)	Utility	Consultant	Technology Provider
Breakout Session 5: *Education, Outreach, and Training Program*					
Need to develop standardization for Infrastructure Asset management	**2**	**1**	**2**	**2**	**2**
Need to develop measurement of Metrics for Infrastructure Sustainability and Resiliency, Define the engineering meaning and how to measure “sustainable” and “resilient”	**2**	**2**	**2**	**1**	**1**
Need to develop certification program for Infrastructure Asset Management practitioners		**1**	**1**		**1**
Need to provide the stakeholders with an understanding of long lived assets					**1**
Need to train the upcoming generation of workers (web-based training program)					**1**
Need to train all workers with basic understanding of asset management practice					**1**
Need to change the focus of programs related with civil infrastructure in educative organizations from design and construction of new assets, to maintaining and operating the existing ones.		**1**		**1**	
Need to encourage engineers to go beyond compliance with minimum standards to achieve long term performance minimums for the infrastructure	**1**			**1**	
Need to provide controversial topics on infrastructure such as Sustainability and Resiliency with specific, measurable meanings					**1**
Need to standardize Infrastructure Asset management practice and certification of practitioners.					**1**
Need to provide adequate training on asset management to all levels of employees in businesses within the field.					
Need to find mechanisms to substitute a quickly retiring generation on infrastructure asset management workforce.			**1**		**1**
Need to outreach to general public in order to raise awareness of the current condition of civil infrastructure systems and therefore the value of infrastructure asset management		**1**		**1**	
Need of a multidisciplinary understanding for infrastructure asset management issues. Problems in the field are increasingly at the city level instead of business unit. Public policy need to understand the issues involved	**1**		**1**		
Need to provide education programs about asset management of both short-term and long-term assets.					
Need to estimate the return on investment for education, outreach and training activities on infrastructure management, as well as the return on investment for implementing management plan					
Need to relate good asset management practices with funding and incentives for organizations and utilities					
Need to integrate multi-sector (buildings, transportation, utilities, others) in to infrastructure asset management approaches	**1**				**1**