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Innovative Internal Camera Inspection and Data Management for Effective Condition Assessment of Collection Systems

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National Risk Management Research Laboratory - Water Supply and Water Resources Division

Innovative Internal Camera Inspection and Data Management for Effective Condition Assessment of Collection Systems

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Disclaimer

Foreword

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Acronyms

AMWA	Association of Metropolitan Water Agencies
CAMS	Comprehensive Asset Management System
CCTV	Closed-circuit television
CIP	Capital Improvement Program
CIS	Customer Information System
CMMS	Computerized Maintenance Management System
CMOM	Capacity, Management, Operation and Maintenance
CSAP	Continuous Sewer Assessment Program
CUPSS	Checkup Program for Small Systems
DMS	Data Management System
DVD	Digital Video Disk
FEMA	Federal Emergency Management Agency
FIS	Financial Information System
FWWD	Fort Worth Water Department
GIS	Geographic Information System
GPS	Global Positioning System
HDPE	High-density polyethylene
HID	High-intensity discharge
I/I	Infiltration and inflow
LCD	liquid crystal display
LED	Light-emitting diode
LSCCR	Large Sewer Condition Coding and Rating
MACP	Manhole Assessment Certification Program
MGNDC	Metropolitan Government of Nashville and Davidson County
MWS	Metro Water Services
NAAPI	North American Association of Pipe Inspectors
NACWA	National Association of Clean Water Agencies
NASSCO	National Association of Sewer Service Companies
NRC-IRC	National Research Council of Canada Institute for Research in Construction
O&M	Operations and maintenance
PACP	Pipeline Assessment and Certification Program
PTZ	Pan-tilt-zoom
PVC	Polyvinyl chloride
QA/QC	Quality assurance/quality control
SCRAPS	Sewer Cataloging, Retrieval and Prioritization System
SCREAM™	System Condition & Risk Enhanced Assessment Model
SPU	Seattle Public Utilities
SQL	Structured Query Language
SSET	Sewer Scanning Evaluation Technology

SSO	Sanitary Sewer Overflows
USEPA	U.S. Environmental Protection Agency
VCP	Vitrified clay pipe
WEF	Water Environment Federation
WERF	Water Environment Research Foundation
WRc	Water Research Centre
WRS	Water Resources Services
WWTP	Wastewater treatment plant

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Executive Summary

The primary objective of this guidance document is to identify and evaluate innovative closed-circuit television (CCTV) and related technologies currently used by more advanced wastewater utilities to conduct condition assessment programs. The document is intended to facilitate the transfer of these innovative technologies to utilities at large. The steps in developing and implementing a condition assessment program are presented along with related practical guidelines. Technology applications and lessons learned from seven utility case studies are summarized and used to illustrate specific concepts. Detailed case study reports are presented in Appendix A.

Chapter 1 provides an introduction to condition assessment, which is a major component of an asset management program. Condition assessment provides the critical information needed to assess the physical condition, remaining useful service life, and long-term performance of each asset. The recommended approach for developing and implementing a condition assessment program is presented. It consists of six steps:

- Step 1. Identify program objectives.
- Step 2. Evaluate costs and benefits of condition assessment.
- Step 3. Develop asset inventory database.
- Step 4. Inspect assets.
- Step 5. Analyze data.
- Step 6. Make decisions based on condition assessment data.

Steps 1 through 3 are discussed in Chapter 1, using examples from the utility case studies to illustrate key points. Step 4 is discussed in Chapter 2, and Steps 5 and 6 in Chapter 3.

For Step 1, it is important to outline the utility-specific objectives as the initial step in program development. Example objectives from the utility case studies include determining pipe condition, planning maintenance strategies, addressing aging infrastructure, and addressing public scrutiny of rate increases.

In Step 2, utilities may need to justify the costs and benefits of the condition assessment program to obtain the approval of their governing board. Typical costs include direct costs of pipe inspection; labor costs associated with program planning, data analysis and reporting; and cost of service disruptions due to inspection work. Typical benefits of condition assessment include avoided costs for emergency repairs, environmental damage, and premature replacement of pipe and improved customer service and service reliability.

In Step 3, the utility develops an asset inventory database and compiles historical system data such as pipe diameter, length, and installation dates; system map; and inspection and maintenance records for the collection system. The utility should understand the content and form of existing data and should identify data gaps and data quality issues. Some utilities have linked their asset inventory database with a geographic information system. The City of Huntsville, Ala., has learned that it is important not only to link CCTV data to a map, but also to integrate it with other inspection and repair data. When viewed together, the various data help “tell the story” of an asset and its condition over time. The asset inventory database is useful for other applications. For example, the Seattle Public Utilities uses the asset data as input for a sewer pipe risk model.

Step 4 (inspect assets) is typically accomplished using conventional CCTV inspection. CCTV is a cost-effective technology providing the broadest base level of data used in condition assessment. Since the late 1990s, many utilities have replaced analog video cameras with digital video cameras and have identified a number of benefits. The emergence of other camera-based technologies such as zoom cameras and digital scanning offers new options for inspection.

Zoom camera technology captures still images or recorded videos similar to traditional CCTV, but uses a stationary camera mount. The camera is lowered into a manhole and the camera "zooms" down each pipe entering or exiting the manhole. Utilities that have adopted zoom camera technology have realized benefits in the speed and cost of inspections compared to inspection programs that use only conventional CCTV. Disadvantages of zoom camera technology include the lack of pan and tilt viewing and the inability to accurately measure and locate defects. Also, zoom cameras cannot see around horizontal bends in pipes. Some utilities use zoom camera technology for system-wide screening to identify critical pipes that need immediate maintenance or more detailed CCTV inspection.

Digital scanning provides a more consistent and complete assessment of pipe condition than CCTV, and data can be assessed independent of the real-time sewer inspection. Digital scanning uses self-propelled crawlers to transport digital cameras through sewer lines. Unlike conventional CCTV, digital scanning uses high-resolution digital cameras equipped with wide-angle (fisheye) lenses, which allow the generation of unfolded views of the sides of the pipes. This provides an excellent view of pipe conditions and permits computer-aided measurement of defects and objects. Digital scanning has been used in Europe and Asia for several years, but it has a limited history in North America. The City of Hamilton in Ontario, Canada, is one North American utility that has begun to use digital scanning.

Innovations in CCTV camera deployment include extra-long-range tractors/floats, smaller tractors that can be used for some laterals, tractors that are able to dispatch smaller lateral cameras from the main line and segmented robots that can bend around odd angles in small-diameter pipes.

Some of the issues to consider in selecting a camera include the goals of the inspection program, the pipe diameter and material, anticipated pipe conditions, the importance of the camera's production rate, the level of detail required in the inspection data, and whether the utility plans to purchase equipment or use vendors.

Step 5 (analyze data) involves the coding of pipe defects observed during inspection, the conversion of defect codes to a pipe condition rating and the prioritization of pipes based on condition scores or risk-based scores. Chapter 3 discusses the design and format of defect codes and industry standard code systems such as those produced by the Water Research Centre (WrC), the National Association of Sewer Water Agencies' (NASSCO's) Pipeline Assessment and Certification Program (PACP) and the System Condition & Risk Enhanced Assessment Model (SCREAM™). Some utilities, such as Fort Worth, Texas, have developed their own coding system to better serve their needs. The selection of a data management system such as spreadsheets, condition assessment software and other database software is discussed.

Step 6 (make decisions), the final step in the condition assessment process, uses CCTV data to prioritize assets for various corrective actions including maintenance, further inspection and total pipe replacement. Two primary approaches for decision making are condition-based and risk-based. Because systems typically have more assets that need improvements than available resources, risk-based decision making is generally a good approach. However, whenever the general condition of the asset or asset group is problematic, then a condition-based decision is appropriate. The major difference between the two approaches is the timing for performing corrective action.

Chapter 1. Introduction to Condition Assessment

This report presents practical guidelines on internal camera inspection technology applications and data management practices with a focus on identifying and promoting more innovative technologies and practices. Technology applications and lessons learned from seven utility case studies are used as practical examples in the main body of the report; detailed case study reports are provided in Appendix A.

Chapter 1 provides an introduction to condition assessment and presents a six-step approach for developing and implementing a condition assessment program. This chapter also discusses the first three program steps.

1.1 Background

Condition assessment is an important component of an asset management program, along with the identification and location of assets. For more information on developing an asset management program, see EPA's Checkup Program for Small Systems (CUPSS), which includes a free and easy-to-use tool for developing a tailored asset management plan (http://www.epa.gov/cupss/).

Condition assessment is one of the core components of an asset management program. It provides the critical information needed to assess the condition, remaining useful life and long-term performance of a piping system. The U.S. Environmental Protection Agency (USEPA) defines "condition assessment" as the collection of data and information through direct inspection, observation and investigation, indirect monitoring and reporting, and the analysis of the data and information to make a determination of the structural, operational and performance status of capital infrastructure assets (USEPA, 2007).

After the field inspection, pipe defects are classified using a standard coding system. Pipe condition is assessed using a systematic method based in part on the defects discovered during the inspection in order to produce consistent, useful information. Condition assessment information is used to evaluate/model pipe deterioration and estimate the pipe's remaining useful life. It is also used to make decisions regarding pipe rehabilitation, pipe replacement, or further inspections.

Condition assessment has gained considerable attention in recent years among municipalities and utility districts as a major component of an asset management program. Condition assessment can be used to prioritize infrastructure projects based on the likelihood of pipe failure, thereby easing the financial burden on wastewater utilities and their customers. As Thomson et al. (2004) note, "An estimated $4.5 billion is expended every year on the rehabilitation and replacement of pipes for wastewater collection in the U.S." Local and state governments are required to tabulate the value of their assets (i.e., buildings, roads, utilities, etc.) to support the development of a unified cost accounting system, according to Bulletin 34 of the Governmental Accounting Standards Board. This program requires detailed financial accounting of all assets; however, the level of detail to which it is implemented can vary from city to city. Condition assessment can also assist utilities in implementing USEPA's proposed CMOM (Capacity, Management, Operation and Maintenance) program for sanitary sewer collection systems (USEPA, 2005). The CMOM program requires a municipality that operates a sanitary sewer system to provide adequate conveyance capacity for all parts of the system and to take all feasible steps to halt or mitigate the impacts of sanitary sewer overflows (SSOs).

1.2 Steps to Developing a Condition Assessment Program

Various approaches, ranging from simple to complex, have been developed for performing condition assessment of piping systems. A typical approach follows these steps:

1. Identify program objectives.
2. Evaluate costs and benefits of condition assessment.
3. Develop asset inventory database.
4. Inspect assets.
5. Analyze data.
6. Make decisions based on condition assessment data.

Steps 1, 2 and 3 are discussed in this chapter. Step 4 is discussed in Chapter 2 and Step 5 and Step 6 in Chapter 3.

Figure 1-1 presents an approach for condition assessment that recognizes its iterative nature. In this example, the assets are first identified and an inventory database is established. Next, the impact assessment is conducted to inspect assets and determine their physical conditions. The next step involves setting priorities or rankings, from low to high priority, for different pipes in the system. This step helps the utility determine how often each pipe should be inspected and maintained. As the utility completes additional inspections and maintenance, the priority ranking changes and the utility focuses on the new highest priority pipe. The ever-changing or iterative nature of the condition assessment process justifies investments in asset inventory databases and data management software so that the highest quality information is used to make decisions on asset management.

1.2.1 Step 1 - Identify Program Objectives

The utility may need to justify development of a condition assessment program to its governing board, its customers, or its staff. Therefore, it is important to outline and communicate the drivers or reasons for implementing the program. The program objectives may include the following:

- Comply with federal or state regulations.
- Collect pipe condition information needed for asset management program.
- Collect information on the pipes' service performance.
- Investigate and eliminate sources of infiltration and inflow (I/I) to increase available system capacity.
- Extend asset life by conducting maintenance prior to asset failure.
- Improve performance of sanitary sewer systems.
- Improve operation and maintenance efficiency.
- Identify and improve management of high-risk pipes.
- Reduce service disruptions due to pipe failure.
- Reduce environmental damage due to pipe failure.
- Reduce maintenance costs by reducing inspection frequency of low-risk pipes.
- Improve budget forecasting through expanded knowledge of pipe condition and maintenance needs.

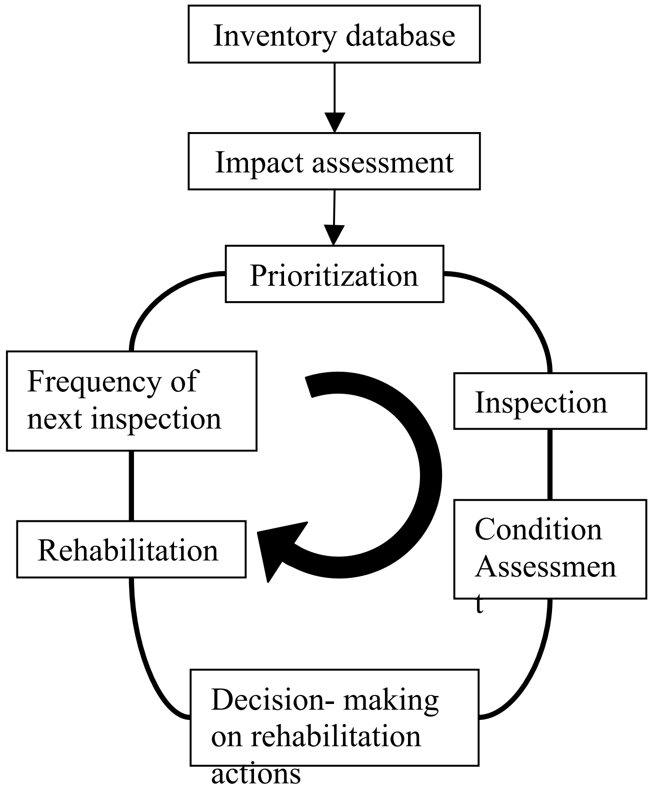

Figure 1-1. Condition assessment steps. Source: McDonald and Zhao (2001).

In a survey of its membership, the Association of Metropolitan Sewerage Agencies (now called the National Association of Clean Water Agencies, NACWA) found that most utilities (70 of 75 survey respondents) conduct regular programs to physically inspect or evaluate their sewer systems using techniques such as visual inspections, CCTV, and Sewer Scanning Evaluation Technology (SSET) (AMSA, 2003). Also, 36 of 75 survey respondents primarily inspect the system to determine its condition.

The City of Fort Worth, Texas has historically used CCTV inspections for a variety of purposes such as evaluating the effectiveness of its cleaning program, documenting pipe condition following pipe rehabilitation and new construction, and finding customer service lateral tap locations (see case study in Appendix A).

The Seattle Public Utilities developed an asset management program in 2001 to address several concerns including aging infrastructure, a lack of information on pipe condition, a trend of stricter environmental regulations, and public scrutiny of recent rate increases. The immediate goal of the asset management program for sewer assets was to minimize risk of infrastructure failure.

1.2.2 Step 2 - Evaluate Costs and Benefits of Condition Assessment

To justify the development and implementation of a condition assessment program, the program's costs must be documented and compared to the anticipated benefits. The costs are typically easier to quantify and should include both the direct costs of inspection and the indirect costs to the utility and other parties of carrying out the inspection and then collecting and analyzing the data. More specifically, the costs of condition assessment include:

- Equipment and labor costs to conduct field inspections including excavation, traffic control, road surface restoration, monitoring and data collection.
- Labor costs before and after fieldwork for planning, data analysis and reporting.
- Cost of service disruptions due to inspection work.

Aside from the costs associated with a specific technology, certain characteristics of a system or specific pipe segments will influence inspection costs. Site location, site setup and the environment all affect deployment costs. For example, difficult site access, high flows, large amounts of debris, and unusually large or small pipes can lead to higher costs. Sewer cleaning alone can double or triple inspection costs. Inspection costs will also vary depending on what specific work is completed as part of the inspection and how the work is accomplished (contractors vs. the utility's equipment and manpower). When comparing inspections costs for two different studies or systems, it is important to understand the work completed and total costs for each case.

The benefits of a condition assessment program are more difficult to quantify and derive. The benefits are mainly associated with the reduction in the risk of failure (likelihood and consequences of failure) and the knowledge that allows maintenance, rehabilitation and replacement to be carried out on the most cost effective schedule. Specific benefits of a condition assessment program may include:

- Reduced sources of I/I.
- Avoided emergency repair costs.
- Avoided costs of extended service disruptions due to a catastrophic failure.
- Avoided restoration costs due to environmental and property damage from a catastrophic failure.
- Avoided public health costs (i.e., injury, death, disease transmission) from catastrophic failure.
- Improved planning and prioritization of rehabilitation and replacement projects due to condition assessment information and improved estimates of service life.
- Avoided costs of premature pipe replacement or rehabilitation.
- Improved customer satisfaction and fewer complaints.
- Improved service reliability.

Comparing the costs to benefits for inspection of gravity sewers and force mains, Thomson (2008) reports that:

- The cost of inspection of gravity sewers is typically low with respect to the value of the asset (e.g., the cost of inspection of a 12-in. diameter sewer at 13-ft depth is less than 1% of the asset value) and the proportion decreases with increasing depth and diameter of the sewer.
- The benefits from inspection of gravity sewers are likely to exceed costs for all but small diameter sewers at shallow depths.
- The cost of inspection of force mains is high, with direct costs (temporary flow bypass, accessing the line, etc.) often exceeding the costs of physical inspection.
- The monetary benefits of inspection may be less than the cost of inspection for smaller lines in less populated areas (fail and fix approach may be chosen), although this ratio may change in

environmentally sensitive areas. The benefits increase greatly for larger diameter force mains and urban areas due to the increased risk of major consequences.

Contrary to Thomson's (2008) findings, some utilities have found that it is not cost-effective to inspect all pipes, and a few have used a formal risk assessment procedure to identify and prioritize pipes that present comparatively greater risks to public health and the environment. For example, Seattle Public Utilities (SPU) determined that there was a critical need for risk assessment when a collection sewer pipe collapsed and caused a sewage backup at a city hospital (refer to the detailed case study report in Appendix A). At the time, all system pipes were scheduled for inspection on a 30-year cycle, and the lack of current pipe condition information created a reactive mode of operation. A sewer pipe risk model, originally developed by Hunter Water Australia (http://www.hwa.com.au/), was adapted and applied to SPU's sewer network to calculate the cost of failure for individual pipe segments and the total annualized cost to the utility over the period between CCTV inspections (Martin, 2004). To estimate the likelihood of pipe failure, the model initially used predictive failure curves generated using a normalized Weibull-type distribution and based on pipe age and material. SPU used the risk assessment and its benefit-cost ratio to help select pipes for inspection and maintenance. Risk modeling conducted in 2004 showed that the cost of conducting CCTV inspections of low-risk pipes exceeded the benefit gained by performing condition assessment (Martin, 2004). Based on these findings, SPU decided to perform CCTV inspection only on high-risk pipes (15% of total pipe length) using a 5-year inspection frequency. In 2007, SPU improved the sewer pipe risk model by applying utility-specific condition information to improve the model's initial estimates of the likelihood of failure (Martin, Johnson and Anschell, 2007). New pipe condition curves were customized for SPU based on actual sewer pipe failure data and CCTV inspection data. An on-going EPA-ORD project, Condition Assessment of Water Transmission and Distribution Systems (Contract No. EP-C-05-057), is currently researching pipe condition curves (http://www.epa.gov/awi/projects/). More information on Weibull distributions can be found at http://www.weibull.com/.

1.2.3 Step 3 - Develop Asset Inventory Database

When performing condition assessment, it is essential to compile an inventory of assets and existing system data. For each pipe segment the following information should be included in the database:

- Unique identification number or code.
- Geographic information (e.g., elevation, latitude, longitude).
- Pipe material.
- Pipe geometry (i.e., diameter (if round), wall thickness).
- Depth.
- Slope.
- Year of installation.
- Soil type, bedding, backfill type.
- Failure history data.
- Maintenance history.
- Inspection records (e.g., smoke testing, dye tracer studies, camera inspections).
- Typical flow conditions.

System maps and geographic information system (GIS) databases (e.g., Figure 1-2) are good information sources for the asset inventory database. Inspection and testing records may include I/I studies: flow data, smoke testing, flow isolation studies, or dye tracer studies. Failure data from the system or research on similar conditions (e.g., soil bedding type, material, age) in utility districts can be used to define the likelihood of failure (Martin, 2004). The linking of the asset inventory database combined with maintenance records to a GIS system is a powerful planning tool. It provides a strong platform to present the data geospatially.

The asset inventory database can be useful for many applications. The City of Fort Worth, TX has developed an asset inventory database and demonstrated its value in reviewing multiple inspection records for a single pipe segment over an extended period of time (refer to case study in Appendix A). SPU uses its asset inventory database as input to a sewer pipe risk model. The model extracts GIS attributes for each pipe (i.e., elevation, installation date, material of construction, and proximity to geologic or structural features) and uses this information to calculate financial, social, and environmental costs of pipe failure. For example, if the sewer pipe is located underneath a building, a multiplier is automatically applied to the cost formula due to the added repair cost.

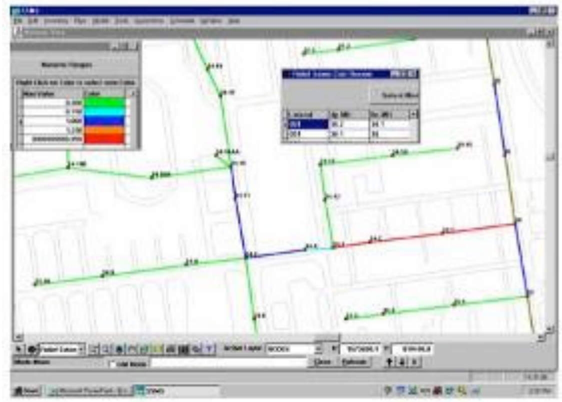

Figure 1-2. Example of a GIS system. Source: Black and Veatch Corp. (2004). Reprinted with permission.

The utility should understand the content and form of existing data in the asset inventory database, and should identify data gaps and data quality issues. When SPU used its GIS data as input to the sewer risk pipe model, some incorrect data were found. For example, pipe elevation data were suspect in about 20% of pipes. With Seattle's hilly terrain, pipe elevation and slope are critical parameters. Data corrections were made in the sewer pipe risk model.

Flow monitoring data should be included in the asset inventory database as the data are useful for prioritizing which part of a system to inspect. Most systems conduct flow monitoring and store historical flow monitoring data, but much of the information is not used. Flow monitoring data are traditionally used to generate hydrographs, which provide information about flow conditions upstream of the meter. Scattergraphs (displays of paired depth and velocity readings that look like a normal pipe curve under normal flow conditions) are constructed to evaluate downstream flow conditions. The use of scattergraphs can give more insight into the decision process and can be used to verify other inspection data and to help calibrate models. Further background information on constructing and applying scattergraphs is provided by ADS (2010).

The City of Huntsville, AL has taken an important step by incorporating CCTV inspection data and digital video files into a GIS-based software application that allows managers and engineers to quickly review CCTV inspections in context with other inspection and repair data (refer to case study in Appendix A). Now, CCTV inspection data and video are easier to access, examine, and compare, allowing managers and engineers to better understand the condition of a system and better plan and manage operation and maintenance (O&M) and rehabilitation programs. The city has learned that it is important not only to link CCTV data to a map, but also to integrate it with other inspection and repair data. When viewed together, the various data help "tell the story" of an asset and its condition over time. Huntsville found and resolved many discrepancies in existing GIS and condition assessment records. The end result was a more accurate and accessible database of historical system conditions. Huntsville recommends that, prior to implementing a similar program, utilities review the type of data needed for the asset management program, including CCTV inspection data, to make sure that the historical asset records are consistent with available GIS data.

Nashville, TN also learned that it is important to integrate GIS data with CCTV, asset, and maintenance management data (refer to case study in Appendix A). The maintenance management system provides a wastewater network browser that stores information and allows it to link together items such as maintenance records, complaints, work orders, and inspection reports. The data integration capability permits users to view all related inspection records for a particular asset. A work order is generated and required resources are selected (labor, equipment, materials). The GIS information is queried and the inspection can proceed.

Chapter 2. Overview of CCTV and Related Inspection Technologies

2.1 Introduction

The term “inspection technology” refers to the various methods used for detecting pipe defects, structural and operational conditions and environmental conditions that could potentially affect pipe condition. These technologies have varying abilities to detect and quantify specific types of pipe defects. A specific inspection technology may have limited application depending on pipe material or pipe diameter. A robust condition assessment method would likely include a variety of inspection technologies, based on the specific characteristics of a utility’s sewer network.

Camera-based inspection technologies (e.g., Figure 2-1) and their use in condition assessment for wastewater collection systems are presented in this chapter. The chapter is organized into the following sections:

- Conventional CCTV inspection.
- Zoom camera inspection.
- Digital scanning.
- Camera deployment.
- Camera selection issues.

Each technology is briefly described, and commercially available and emerging products using the technology are discussed. Table 2-1 provides a summary of typical applications for each technology. Pushrod camera (also known as “push cam”) technology, designed for laterals and small diameter force main applications, is discussed in Section 2.5.1.

Aries Industries.

Table 2-1. Inspection technology overview

Technology		Sewer type			Pipe material	Pipe diameter	Defects detected			
		Gravity	Force main	Lateral			Internal condition	Pipe wall	Leakage	Pipe support
Camera	Conventional CCTV	•			Any	>8 in.	•	•	•	
	Digital scanning	•			Any	6 in.-72 in.	•	•	•	
	Zoom camera	•			Any	>6 in.	•	•	•	

2.2 Conventional CCTV Inspection

CCTV inspection is a very effective method of evaluating and creating a permanent video record of underground pipe conditions. The visual inspection of sanitary sewer lines enables a CCTV operator to locate and identify specific defects that contribute to the infiltration of groundwater into the collection system (Figure 2.2) and exfiltration of sewage into the substrate. This is a well-established and common industry method for pipeline assessment. In a recent survey report (Thomson et al., 2004), 100% of survey respondents from large wastewater utility districts relied on CCTV as their primary method of collection system inspections; hence, it is not surprising that the critical gaps identified in this survey parallel the limitations of CCTV inspection. CCTV provides a means to inspect a pipeline that is either too small or hazardous for direct human entry inspection. The primary disadvantages of the technology are that a CCTV inspection only provides a view of the pipe surface above the waterline and does not provide any structural data on pipe wall integrity or a view of the soil envelope supporting the pipe.

Figure 2-2. Example of infiltration. Image courtesy of RedZone Robotics, Inc.

The technology and level of ancillary equipment used for CCTV inspection of sewer systems vary significantly based on the diameter of the line being inspected. In general, CCTV technology uses a video camera with lighting to provide a visual record of the inside condition of a pipeline. The means to convey the camera through the pipeline vary in complexity from simple pushrod cameras (push cams) to complex remote-controlled robot crawlers. The level of optical control on the camera also varies in complexity. The ability to pan, tilt, and zoom has become the industry standard for selecting sewer inspection technology because it allows the operator to gain a full circumferential view of the pipe.

Figure 2-3. CCTV image of roots in lateral. Image courtesy of RedZone Robotics, Inc.

Data obtained from CCTV inspection include:

- Evidence of sediment, debris, roots, etc.
- Evidence of pipe sags and deflections.
- Offset joints.
- Pipe cracks.
- Leaks.
- Location and condition of service connections.

Figure 2-3 provides an example of a CCTV image that documents root intrusion. As noted above, CCTV technology has limitations because it can only provide a visual representation of the inside surface of a pipe above the waterline. Furthermore, the quality of defect identification and pipe condition assessment using CCTV is highly dependent on many factors including operator interpretation, picture quality, and flow level. In terms of benefits, it is a cost-effective technology providing the broadest base level of data used in condition assessment. Although other technologies can assess the structural condition of the pipe wall (e.g., electro-scanning, acoustic monitoring systems), or the condition of the soil surrounding the pipe (e.g., infrared thermography, ground-penetrating radar), these methods do not provide visual data on leaks, location of service laterals or sediment/debris levels and location. Therefore, CCTV will remain an important inspection tool in condition assessment programs.

Sections 2.3 – 2.5 present innovative technologies related to CCTV and their use in condition assessment for wastewater collection systems. The following technologies will be described, noting manufacturers or providers and typical applications:

- Zoom camera inspection.
- Digital scanning.
- Camera deployment.

2.3 Zoom Camera Inspection

Historically, zoom cameras have been used to perform manhole inspections and to inspect down the pipe in the vicinity of the manhole using a camera mounted on the end of a telescopic pole. Like traditional CCTV inspection, zoom camera inspection involves the generation of still images or recorded video imagery of a pipe of any material. The key difference is that the zoom camera is stationary mounted on a truck, crane, pole (Figure 2-4) or tripod positioned at a manhole and does not pass though the pipe segment being inspected. The equipment is lowered into the manhole to perform the inspection, and the camera "zooms" down any pipe entering or exiting the manhole, capturing images of pipe condition. Newer cameras can pan 360°.

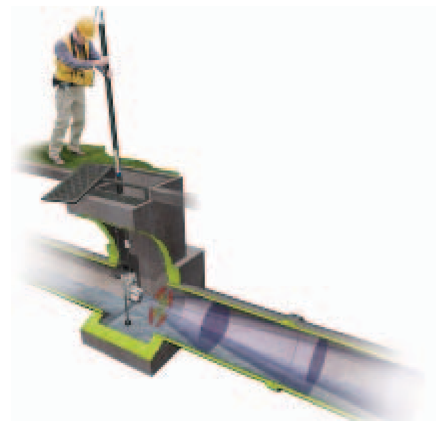

Figure 2-4. Pole-mounted zoom camera. Image courtesy of Envirosight, LLC.

Zoom cameras are not designed to replace conventional CCTV systems, but rather to screen and prioritize pipes that need cleaning or a more detailed inspection with the conventional CCTV camera. Because the sewer pipe does not need to be cleaned before the zoom camera inspection is conducted, the inspection crew can move quickly through a service area and highlight pipe segments that require more detailed inspection. Further, the zoom camera inspection is not subject to delays caused by obstructions in the pipe as often occurs with a crawler-mounted CCTV camera. For these reasons, zoom camera inspection offers an increased production rate compared to CCTV inspection.

Zoom camera performance is often measured in terms of the sight distance (i.e., how far down the pipe the camera can capture an image), and the reader is urged to verify with field data the sight distance claims by camera vendors. In general, sight distance varies with pipe diameter and lighting conditions within the pipe and is limited by pipe conditions such as horizontal bends, deflections, blockages and protruding services (where a building lateral extends into a main sewer line). Limitations on sight distance also mean that defects in the middle of the pipe segment may not be detected; however, a large percentage of defects are often found relatively close to the manholes. Possible reasons for this include vibrations of the manhole due to surface traffic, development of soil voids around a pipeline due to infiltration in and around a manhole, and vertical movement of manholes due to cold weather (Joseph and DiTullio, 2003).

Although zoom camera inspection is a very efficient, cost-effective inspection method, there are some drawbacks. Like all camera technologies, it is only useful for inspecting gravity sewers because force mains and service laterals do not have manholes for access. Zoom camera inspection has the same limitation as traditional CCTV pipe inspection in that the camera cannot see the pipe below the water surface. Also, if the pipe deviates from a straight line due to sagging or deficient installation, the zoom camera will not "see" the hidden defects. The zoom camera does not provide the same detailed visual evaluation as conventional CCTV. Some zoom cameras lack pan and tilt viewing and cannot accurately measure and locate defects. Limitations in image resolution, lighting and optical zoom also pose challenges.

Several commercially available zoom camera models are described in the next section. The reader is advised to contact the camera manufacturers directly for additional product information and new product developments such as improved optical and digital zoom capabilities. Vendor contact information is provided in Appendix C.

Table 2-2. Zoom camera inspection summary

SUMMARY	
Sewer type	Gravity sewers only
Material	Any
Pipe size	> 6-in.
Defects detected	Cracks, leaks, root intrusion, overall surface condition of pipe/manholes
Original application	Manhole inspection
Current application	Typically used to screen and prioritize pipes for more detailed CCTV inspection and/or cleaning.
Status	Commercially available
Advantages	High production rate, effective/efficient at prioritizing segments requiring more detailed inspection/maintenance
Disadvantages	Inability to inspect manhole to manhole for average diameter lines, potential to miss significant defects

2.3.1 Zoom Camera Models

The CUES-IMX truck-mounted zoom camera (Figure 2-5) has a total effective zoom ratio of 300:1 including a 25:1 optical zoom range. The camera is stabilized and remotely controlled by a telescopic boom. It is equipped with high-intensity lights. The camera mounting fork is designed to pan the camera head 360° continuously, tilt mechanically 45° up or 90° down and tilt optically 166°. The camera system can be mounted within an inspection van, all-terrain vehicle or trailer. The camera housing is a damage-resistant, waterproof enclosure 7 in. in diameter and 16 in. in length. The CUES-IMX zoom camera system is equipped with data collection software, GIS software and global positioning system (GPS) equipment. The GIS software and GPS equipment are used to create sewer maps in the field and to create an asset management database for the system. Defects detected during the inspection can be stored in a database along with photos and video clips. All data are geo-referenced to the field-collected GPS coordinates. This is common in the industry and the subject of further discussion in Chapter 3.

Figure 2-5. CUES-IMX truck-mounted zoom camera. Source: CUES, Inc. (2009). Reprinted with permission.

GE Technologies offers a truck-mounted pan-tilt-zoom (PTZ) camera, the Everest Ca-Zoom 6.2 that has three interchangeable camera heads. The PTZ 140 camera head has a 432:1 zoom capability (36:1 optical zoom range) and is equipped with high-powered halogen lighting. It can be deployed through 140-mm (5.5-in.) openings. The PTZ100 and the PTZ270 have 40:1 zoom capability (10:1 optical zoom range) and high-powered LED lighting. The PTZ100 fits through a 100-mm (4-in.) opening; the PTZ270 fits through a 76-mm (3-in.) opening.

Figure 2-6. PortaZoom camera. Source: CTZoom Technologies, Inc. (2006). Reprinted with permission.

CTZoom Technologies manufactures and distributes the PortaZoom camera (Figure 2-6). Key features of the PortaZoom camera include its compact housing (6 in. in diameter), its 312:1 zoom capability (26:1 optical zoom range) and its ability to pan 360°. The camera has full-circumference integrated lighting including peripheral lighting to reduce shadows. The PortaZoom camera can be controlled by a commercially available joystick or by a standard computer keyboard and compatible computer. It can be either truck- or pole-mounted.

Aries Industries offers the HC3000 pole-mounted zoom camera, which has a 432:1 zoom ratio (36:1 optical zoom range). The camera has high-intensity detachable LED lights and can transmit images with wireless technology. A small portable monitor is also available for viewing camera images during the inspection.

AquaData Inc. manufactures the Aqua Zoom system (Figure 2-7). Although not commercially available, it is used by company professionals for consulting services. It is normally mounted on either a truck or tripod, which is claimed to provide better stability compared to pole-mounted devices. It uses a built-in control center and video-recording equipment to perform pipe inspections.

Envirosight, LLC's smaller pole-mounted camera, QuickView, has a total zoom capability of 432:1 (18:1 optical zoom range). The manufacturer reports the camera has a sight distance of 50 to 250 ft in pipe diameters of 6 in. to 60 in. The reader is advised to confirm manufacturer's claims with actual field data.

Figure 2-7. Aqua Zoom camera. Image courtesy of AquaData, Inc. Aqua Zoom is a trademark of AquaData, Inc.

2.3.2 Examples of Utility Experience

The City of Hamilton, Ontario; Hillsborough County (Florida) Water Resources Services (WRS) and the Town of Auburn, Mass., have all implemented zoom camera screening programs to fulfill a variety of objectives. Hillsborough's goal was to conduct an asset inventory and assessment to accomplish the following:

- Locate manholes and cleanouts.
- Inspect manholes and pipelines.
- Establish the condition of manholes and pipelines.
- Identify immediate maintenance and structural needs.

Hamilton uses zoom camera technology to inspect their entire system and prioritize pipes for further inspection using in-line CCTV and other, more advanced methods. Auburn incorporated zoom camera technology (along with CCTV, dye testing, smoke testing, building inspections, and manhole inspections) into their plan to locate and reduce sources of I/I (Rinner and Pryputniewicz., N.D.). Auburn found an added benefit in using the zoom camera inspection data to assign structural codes and O&M service codes.

Utilities that have adopted zoom camera technology as part of their sewer inspection strategy have realized benefits in speed of inspection and cost compared to an inspection program using only conventional CCTV. The speed of inspection for zoom cameras is consistently higher than for traditional CCTV. Also, because the equipment is only in the road for about 15 – 20 minutes, zoom camera inspection is less disruptive to traffic. Inspection rates reported in case studies are approximately 1 mile per day. Hamilton reported 6,152 ft/day. An inspection of storm sewers in Fairfax County, Va., is reported to have averaged 6,250 ft/day (Batman et al., 2008). Auburn reported that a 2-person crew can inspect about 5,000 ft of pipe per day, including 25 manholes, or 10,000 ft without manholes. These rates are roughly one-third to one-quarter of the time needed to inspect pipes using traditional in-line CCTV.

The cost of zoom camera inspection is reported to be one-half to two-thirds less than the cost of cleaning and conventional CCTV inspection, based on case study reports. Auburn's program cost approximately $1.00 per ft (with manhole inspection). Zoom camera inspection in Hamilton costs approximately $1.00 (Canadian) per ft, compared to $5.74 (Canadian) for CCTV. Hillsborough saved $11.4 million by using a combined zoom camera and in-line CCTV program and recommended budgeting $1.00 – $2.00 per ft for a system-wide zoom camera assessment. Fairfax County's costs averaged $3.30 per ft for its combined zoom/CCTV program, and $4.90 per ft when only in-line CCTV was used.

Use of zoom camera technology has enabled utilities to limit and target the amount of pipe requiring more detailed attention. By using a combined zoom and in-line CCTV approach, Fairfax County found that only 66% of its pipe footage needed to be inspected by CCTV (including sections that could not be accessed with a zoom camera). Of the pipe screened with zoom camera, only 36% required subsequent in-line inspection. Auburn's zoom inspection program resulted in plans to clean and perform CCTV inspections on 15,000 ft out of approximately 60,000 ft of pipe. Dallas, Texas, performed a pilot project using AquaZoom and found that 70% of its pipes did not need cleaning, CCTV inspection, or other attention (Renfro et al., 2005). Thus, unnecessary sewer cleaning was avoided, reducing overall program costs.

Zoom camera accuracy compared to CCTV is an important criterion to consider. Utilities need to know how much accuracy will be sacrificed by using zoom camera technology for its expected savings in time and cost. The experience of one utility (Hamilton) provides a useful example. Hamilton compared the results of pipe inspections using both CCTV and zoom camera, as illustrated in Figure 2-8 (Bainbridge and Krinas, 2008). The graph compares how often the pipe condition ratings determined by CCTV and zoom camera inspection are the same (shown as 0 on the x-axis) or different up to four condition ratings (-4 and +4 on the x-axis). These results show that zoom camera and CCTV inspections resulted in the same condition rating approximately 48% of the time. Further, the two technologies differed by one condition rating about 31% of the time.

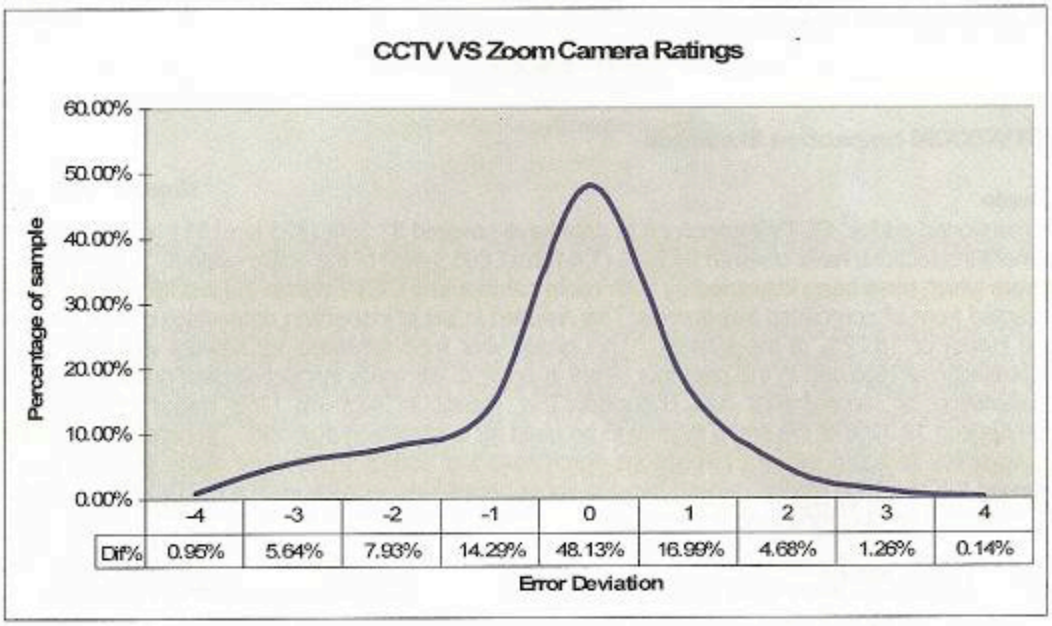

Chart2-Spread of Rating Differences

Figure 2-8. Comparison of CCTV and zoom camera inspections.
Source: Bainbridge and Krinas (2008). Reprinted with permission.

Utility experiences with camera sight distance were reported. It is important to note that sight distance or estimates of pipe length that can be inspected vary depending on the camera model, pipe diameter, and other pipe characteristics. Rinner and Pryputniewicz (undated) noted that zoom cameras can typically inspect 40 ft to 60 ft in each direction in an 8-in. diameter pipe. Bainbridge and Krinas (2008) noted an average zoom camera inspection distance of about 100 ft (30 m) based on inspection of 23,566 manholes and associated piping in Hamilton, Ontario (camera model and pipe diameters unspecified). The variability in these estimates may partially reflect the effects of pipe diameter and lighting on the ability of the camera to see long distances into the pipe. In a larger pipe, for example, the sight distance may be greater and more defects would be detected.

Bainbridge and Krinas (2008) used Hamilton's CCTV data to address questions about whether a zoom camera's sight distance may cause a significant number of defects to be missed. Approximately 59% of the defects identified by CCTV were located within 65 ft (20 m) of manholes, and 76% were within 100 ft (30 m) of manholes. Joseph and DiTullio (2003) estimated that "about 80% of defects . . . are usually located within the first 15 to 20 m [49 to 66 ft] from the manhole." Although the estimates in these two studies differ, both suggest that a large percentage of defects will be detected by zoom camera because a high concentration of defects is located within the commonly referenced zoom camera sight distances. In the case of Hamilton, a zoom camera with an inspection distance of approximately 100 ft might be able to detect 76% of the pipe's defects.

2.4 Digital Scanning

Digital scanning is a state-of-the-art camera inspection technology. Like conventional CCTV, digital cameras are transported through sewer lines using self-propelled crawlers (Figure 2-9). Unlike conventional CCTV systems, digital scanning uses high-resolution digital cameras equipped with wide-angle lenses that allow the generation of two types of images: unfolded views of the sides of the pipes and circular views down the pipe (similar to CCTV) (Figure 2-10). The "unfolded" view of the inner pipe surface provides an excellent view of pipe conditions. This permits computer-aided measurement of defects and objects. Because digital scanning combines a large number of still digital images, it produces a sharper image than video (Knight et al., 2009). Digital scanning provides a more consistent and complete assessment of pipe condition than CCTV.

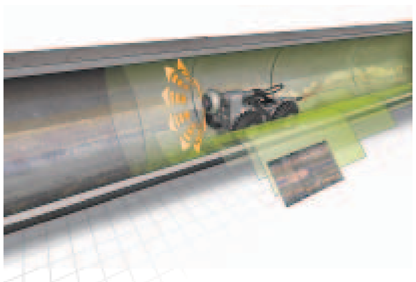

Figure 2-9. DigiSewer digital scanning camera deployed in pipe. Image courtesy of Envirosight, LLC.

During the digital scanning process, data are transmitted to a surface station for real-time viewing and recording for later evaluation. With the defect coding occurring later in the office, digital scanning can progress rapidly in the field. By comparison, conventional CCTV relies on a camera operator in real-time to pan, tilt and zoom the camera into critical areas to collect and store images. If the operator does not see a defect, the camera is not stopped for further investigation.

Digital scanning develops a full digital image of the pipe segment independent of the camera operator. This allows the individual reviewing the recording to control the direction of the PTZ features and to stop the image at any point to capture video clips and images. It provides a second level of quality control in the review process and allows other individual(s) involved in the process (e.g., designers, rehabilitation contractors, and utility owners) to gain insight into the pipe condition. Digital scanning technology is primarily used for gravity lines and can be used with any pipe material. The maximum pipe diameter that can be inspected with digital scanning depends on the specific equipment used, but one manufacturer states that its product can be used in pipes up to 72 in. in diameter. Minimum pipe size is generally about 6 in. Its applicability for inspecting sewer laterals is limited because laterals are typically less than 6 in. in diameter and access is generally through a small diameter cleanout. Digital scanning has limited application in force mains. Like conventional CCTV technology, digital scanning is only able to provide useful images above the waterline; force mains would have to be taken out of service and drained before digital recording. Also, access to force mains typically restricts the use of digital and CCTV technology because force mains are pressurized and do not have access manholes required for the insertion of inspection equipment.

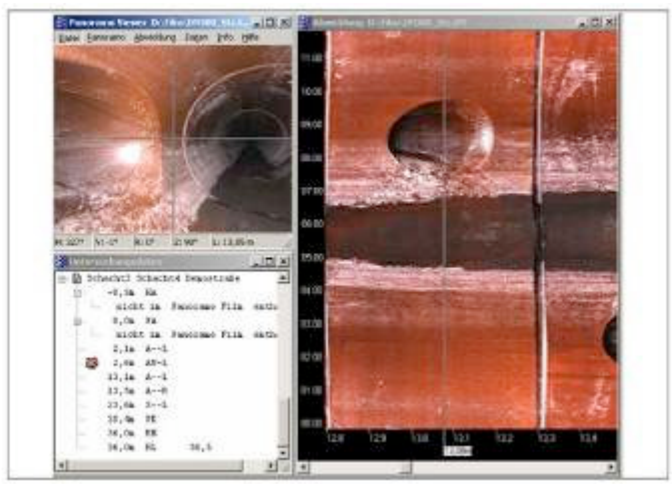

Figure 2-10. Virtual pan & tilt and unfolded pipeline view from RapidView IBAK PANORAMO system. Source: RapidView (2009b). Reprinted with permission.

SSET was developed in Japan in 1994 and introduced through field trials in the United States in 1997. The third-generation SSET was refined by Blackhawk-PAS for commercial marketing. SSET is no longer manufactured or supported, although utilities and contractors that have invested in the equipment continue to use it. SSET uses a fisheye lens that captures a hemispherical front view. The annular part of the image gets digitally scanned and is used to produce the flattened side view of the pipe (Karasaki et al., 2001). White LEDs provide cool, energy-efficient lighting. The unit also contains an inclinometer and gyroscope to provide information on location in the pipe. SSET can be used in pipes ranging from 8 in. to 36 in. in diameter, operating at a rate of approximately 13 ft per minute.

Table 2-3. Digital scanning inspection summary

SUMMARY	
Sewer type	Gravity sewers, limited applicability for force mains and service laterals.
Material	Any.
Pipe size	6 to 72 in. (depending on model and conditions).
Defects detected	Cracks, leaks, root intrusion, overall condition of pipe.
Original application	Inspection of piping.
Status	Commercially available; new applications under development.
Advantages	Increased QA/QC control, additional project personnel able to review/control data imagery; able to make digital measurements of defects; can compare data directly from one inspection to the next.
Disadvantages	More costly and lower production rate than CCTV; only works above water line.

Three digital scanning camera systems marketed in North America are designed for the investigation of water, storm drain, and sewer pipelines. These products are described in the following sections; vendor contact information is provided in Appendix C.

2.4.1 Envirosight - DigiSewer

The DigiSewer system is essentially a new-generation SSET system. It was originally developed by DigiSewer and manufactured by IPEK (provider of crawlers and cameras to Envirosight). DigiSewer was designed to be used for borehole inspection and was first used in Europe in 2003. It was officially released to the North American market in 2007.

DigiSewer uses one high-resolution photo camera with a 180° wide-angle fisheye lens integrated into the front of the rover crawler (Figure 2-11). According to the vendor, DigiSewer can scan 6-in. to 32-in. diameter pipes at a scan speed of 70 ft per minute and can scan pipes approximately 650 ft in length.

2.4.2 RapidView– IBAK, USA – PANORAMO

The RapidView-IBAK, USA PANORAMO system was developed by IBAK Helmut Hunger GmbH & Co. KG of Kiel Germany in partnership with RapidView, LLC. The application was first developed and used in 2002. The first application in the United States was in 2007.

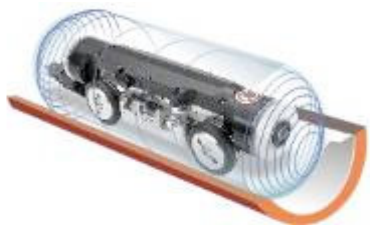

Figure 2-12. RapidView IBAK PANORAMO system. Source: RapidView (2009b). Reprinted with permission.

The PANORAMO system (Figure 2-12) uses two high-resolution digital photo cameras with 186° wide-angle lenses fit into the front and rear sections of the housing. During pipe inspections, parallel mounted xenon flashlights are triggered at the same position in the pipe. The hemispherical pictures scanned are put together to form 360° spherical images. PANORAMO can scan pipes at a speed of up to 70 ft per minute in forward or reverse. According to the manufacturer, this camera system can be used for pipes ranging from 8 in. to 72 in. in diameter.

During the PANORAMO scanning process, the data are transmitted digitally to the inspection vehicle for later retrieval and analysis. The scans can be viewed as live pictures for orientation purposes and for locating any obstructions. In addition, the data are stored in the form of "PANORAMO films" on removable hard disks or DVDs.

2.4.3 CleanFlow/Fly Eye System

The CleanFlow system is a multi-sensor technology developed in New Zealand and distributed in the U.S. by Cues, Inc. It includes laser, sonar and high-definition imaging. The sensors are typically mounted on a float system; however, in low-flow conditions, the laser and high-definition camera are deployed using a skid mount. The system is typically deployed in pipes with diameters of 24 in. to 66 in.

2.4.4 Example of Utility Experience

Digital scanning has been used in Europe and Asia for several years, but it has a limited history in North America. The City of Hamilton is one example of a North American utility that has begun to use digital scanning. In 2006, Hamilton conducted a pilot test using SSET for sewer pipes and was pleased with the superior level of detail provided by this technology, which permits more defects to be coded than with CCTV. Hamilton also benefited from a better understanding of the significance of a defect, as opposed to CCTV results, which only document a defect's existence. The primary drawback with the SSET equipment for Hamilton was the size of the pipe for which it was effective. It was found to work best in smaller pipes (< 36 in. pipe diameter), but the extra expense of highly detailed inspections for the smaller pipes was not justified. Smaller pipes carry lower risk due to the less severe consequences in the event of failure. In larger, more critical pipes, a greater level of detail is needed, but the SSET was not as effective.

Based on recent communication with Hamilton's contractor, pipes up to nearly 5 ft in diameter are now being inspected with digital side scanning. Hamilton also noted that the overall cost for SSET inspection was initially higher than for CCTV despite the greater speed of inspection; coding in the office increased total labor costs. However, Hamilton's contractor has indicated that SSET inspection may now have a cost comparable to CCTV. Hamilton's experience underscores the fluid nature of new technologies, both with respect to technical capabilities and to cost.

As a relatively new technology, digital scanning can be expected to undergo continuing development to increase its capabilities. Similar to most camera technologies, one of the limiting factors for digital scanning performance is camera resolution. In general, resolution for digital scanning decreases with larger pipe size. However, better lighting can help offset this limitation. SSET was originally designed for pipes 8 in. to 12 in. in diameter, but the manufacturer worked to increase this range in response to customer needs. With further development, optical and digital capabilities may continue to improve. Current research is also focused on software enhancements for defect recognition and digital defect measurements. Utilities may wish to keep abreast of developments in this technology as changes in performance and cost may make digital scanning a cost-effective option for pipes where a high level of detail is needed.

2.5 Camera Deployment

Figure 2-13. Mobile robot inspection system. Source: iPEK International GmbH (2009). Reprinted with permission.

In CCTV inspection, cameras are deployed into pipelines in a variety of ways. Mobile robots called crawlers or tractors (e.g., Figure 2-13) are available in a variety of sizes and configurations, enabling their use in various pipes sizes. These robots are typically introduced into the sewer via a manhole. Cameras can also be mounted on float rigs (Figure 2-14) for inspecting large-diameter pipes that are partially filled with water. Pushrod cameras are typically used in smaller diameter pipes (6 in. and less) such as service laterals and are typically introduced into the sewer through a cleanout.

This section describes innovations to vehicles used to carry CCTV cameras as well as technologies that can be added to the conventional camera vehicles to further assist in CCTV inspection.

The combination and integration of two or more inspection technologies onto a robotic platform in order to detect different types of defects and to address the disadvantages of a single inspection technology has been proposed by several researchers. These multi-sensor inspection robots have been commercialized in various forms in Europe, North America, Japan and Australia. The commercial versions include critical sensors (e.g., CCTV, sonar and laser scanners); however, some of the more innovative sensors (e.g., infrared sensors, radioactive sensors and impact-echo hammers) have, for the most part, not been deployed on commercial robots. The robotic platforms using the multi-sensor approach for the assessment of wastewater collection systems include SAM (Sewer Assessment with Multi-Sensors) and PIRAT (Pipeline Inspection Real-time Assessment Technique).

A variety of innovations have been applied to the tractors or crawlers that carry CCTV cameras. These innovations include extra long-range tractors/floats, smaller than typical tractors that can be used for laterals; tractors that are able to dispatch smaller lateral cameras from the main line; and segmented robots that can bend around odd angles in small-diameter pipes.

Figure 2-14. CUES camera float. Source: CUES, Inc. (2009). Reprinted with permission.

Different camera tractor innovations are available from a variety of vendors. Several commercial applications are designed for the investigation of water, storm drain, and sewer pipelines. Push cams are used almost exclusively in smaller diameter sewers such as service laterals. Tractor innovations have been broken down into four groups: small-diameter tractors, long-range tractors, segmented tractors, and lateral launchers (tractors that can launch lateral cameras off of the main inspection vehicle).

2.5.1 Push Cams

Pushrod camera, or push cam, technology involves the inspection of pipelines with a small-diameter camera mounted to a pushrod and reel setup that provides video of the pipeline (e.g., Figure 2-15). This technology is primarily designed for laterals and small-diameter force main applications. Conventional push cams use straight view cameras capable of inspecting pipes 2-in. or more in diameter. Advancements include push cams capable of inspecting pipes smaller than 2-in. as well as steerable and pan/tilt push cams.

Figure 2-15. Crystal Cam – push camera. Image courtesy of Inuktun Services, Ltd.

Push cams are typically used in environments that are too small for crawlers/robotic camera vehicles in small-diameter water and sewer pipes. Conventional push cam systems consist of a camera/probe, cable/reel and computer/recorder/controller. The probe used to advance the camera is usually a semi-rigid rod constructed of fiberglass. The primary limitations are image quality, lighting and the inability to move past obstructions. Table 2-4 summarizes a variety of commercially available push cams.

Table 2-4. Push cam product comparison

Product (Vendor)	Pipe Diameter	Inspection Length	Notes
CrystalCam Push Camera (Inuktun)	>2 in.	Not specified	High-resolution low-light camera. Can be tractor-mounted, can be used as a reverse camera.
Flexiprobe (Pearpoint)	1 to 8 in.	500 ft	Interchangeable camera options with bright white LED lighting.
Hydrus (Rapidview-IBAK, USA)	>2 in.	Not specified	Straight view camera only.
Orion (Rapidview-IBAK, USA)	>4 in.	Not specified	Pan and tilt functions.
Orion L (Rapidview-IBAK, USA)	>4 in.	Not specified	Pan and tilt, includes "steer stick" allowing device to be steered around bends or turns.
Push Camera (Insight Vision)	1 to 12 in.	300 ft	Uses Clearview line of camera heads; large 10.4-in. LCD monitor.

2.5.2 Tractors/Crawlers

Tractors and crawlers are mobile robots used to deploy CCTV through a pipeline (Figure 2-16). Most are wheeled or tracked and tethered by a cable to a controller unit located near the point of entry to the sewer system. Conventional CCTV inspection tractors are larger vehicles that cannot be deployed in smaller pipes or laterals. Many of the tractors cannot be steered and can only inspect pipe runs of 300 to 500 ft. Advancements in technology now include lateral launchers that are able to deploy smaller diameter push cams into laterals, small-diameter tractors that can be deployed in pipes as small as 4 in. in diameter, long-range tractors that can inspect pipes at great distances from the point of entry and segmented robots that can bend around odd bends or angles in small diameter pipes. Tables 2.5, 2.6 and 2.7 summarize a selection of commercially available innovative tractor and crawler technologies.

 **IBAK LISY 150M** Figure 2-16(a). Source: RapidView (2009a). Reprinted with permission.	 **CUES LAMP lateral inspection crawler** Figure 2-16(b). Source: CUES, Inc. (2009). Reprinted with permission.

Figure 2-16 (a) and (b). Examples of pipe inspection crawlers.

Table 2-5. Lateral launcher product comparison

Product (Vendor)	Mainline		Lateral		Notes
	Pipe Diameter	Inspection Length	Pipe Diameter	Inspection Length	
IBAK LISY 150-M (RapidView-IBAK, USA)	>6 in.	Not specified	N/A	N/A	Tungsten carbide wheel for grip.
LAMP (CUES)	6 to 30 in.	1,000 ft	2 to 6 in.	<80 ft	Optional sonde and camera locating receiver.
LAMP II (CUES)	6 to 15 in.	1,000 ft	3 to 8 in.	80 ft	Lateral camera has built-in sonde for locating laterals.
Lateral Evaluation Television System (ARIES Industries)	>8 in.	800 ft	3 to 6 in.	≥150 ft	Lateral camera has built-in sonde for locating laterals.
Lateral Inspection System (RS Technical Services)	8 to 24 in.	1,000 ft	4 to 8 in.	≤100 ft	Picture-in-picture format allows simultaneous viewing of main line and lateral inspections.

Table 2-6. Small-diameter tractor product comparison

Product (Vendor)	Pipe Diameter	Inspection Length	Notes
ELK T100 Mini (Pearpoint)	4 to 10 in.	500 ft	Wheeled tractor
KRA 65 (RapidView – IBAK, USA)	≥4 in.	Not specified	Steerable wheeled camera tractor with electronic stabilizing function
MightyMini Transporter (RS Technical Services)	4 to 12 in.	500 ft	4-wheel drive crawler with adjustable cantilevered camera mount

Product (Vendor)	Pipe Diameter	Inspection Length	Notes
ROVVER 100 (Envirosight-IPEK)	4 to 12 in.	660 ft	Steerable, PVC wheel with titanium spikes for traction
Versatrax 100 (Inuktun)	4 to 24 in.	600 ft	Tracked crawler
Xpress Silver-Bullet Crawler (Insight Vision)	4 to 15 in.	600 ft	4-wheel drive crawler

Table 2-7. Long-range tractor product comparison

Product (Vendor)	Pipe Diameter	Inspection Length	Notes
Versatrax 300 VLR (Inuktun)	>12 in.	6,000 ft	Modular construction for onsite customization, optional reverse camera can be mounted on crawler.
Responder (RedZone)	>36 in.	5,280 ft	Skid steer enabled tractor, Kevlar reinforced buoyant cable, submersible to 500 ft.

2.5.3 Segmented Robots

Electromechanica, Inc. designs custom inspection robotics and other applications. For example, a client may have a specific type of small-diameter pipe system containing tees, wyes, or other angles that a typical tractor or crawler cannot navigate. One such development is the Internal Pipe Inspection Robot. This design uses a unique "inchworm" movement, which optimizes movement within the pipe. The robot itself consists of three arm linkages that expand radially to force the different segments to grip the inside of the pipe and move it along. It uses pneumatic cylinders to provide force to move itself through the pipe. The robot can be outfitted with cameras, sensors or tools to accomplish many different types of tasks in pipe inspection. As noted above, this is not a commercial product, but one that must be custom ordered for a client's specialized needs.

2.5.4 Emerging Technologies

- ***Pushcams*** - The IPEK Agilios pushcam system was developed for small-diameter pipes and has pan/tilt capability. It works in conjunction with the vision control unit and is battery powered.

- ***Autonomous Crawlers*** - An autonomous crawler does not require a real-time remote operator. The crawler's behavior is programmed in advance of deployment. The vehicle is programmed to cue off of particular environmental landmarks. For instance, RedZone Robotics has designed a robot that constantly monitors the diameter of the pipe as the robot moves through the pipe. Infrared sensors atop the vehicle sense when the distance to the roof of the pipe alters radically; this is interpreted as a manhole. The vehicle may be programmed to stop at the first manhole it encounters, or it may stop after encountering some specified number of manholes. Autonomous crawlers are beginning to enter the marketplace.

- ***Autonomous Floaters*** - Automatika, Inc. is developing the prototype of an un-tethered pipe inspection robot called PipeEye (Figure 2-17). The robot is a 12-in. sphere designed to float in pipes greater than 24 in. in diameter. Cameras and lights will operate above the waterline, and ultrasonic transducers will operate below the waterline. The PipeEye system is derived from an oil/gas pipeline inspection module co-developed by Automatika and Shell Oil. The system does not yet have a product status.

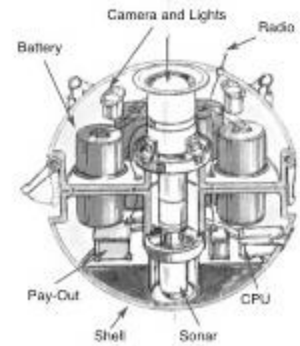

Figure 2-17. PipeEye pipe inspection robot. Source: Schempf (2000). Reprinted with permission.

2.6 Camera Selection Issues

Although conventional CCTV will continue to be an important part of a sewer assessment program, the emergence of other camera-based technologies such as zoom cameras and digital scanning offers new options for inspection strategies. Selection of camera-based technologies will depend on a number of factors, and it may be advantageous to combine one of these newer methods with traditional in-line CCTV.

A utility investigating new camera technologies or implementing changes to its pipe inspection program may benefit from performing a trial run or pilot project to ensure that proper test procedures are in place and that inspection crews are properly trained. Hillsborough County, Fla., for example, benefited from a pilot program, as described in a case study in Appendix A.

Some of the issues to consider in making camera selection decisions are described below.

- **Reason for inspection**. A utility needs to consider whether its goal is to conduct a system-wide inventory and general inspection or to target known problem areas. For a comprehensive inventory of a system, especially one in which it is anticipated that many pipes are in good condition, a zoom camera may be a good choice. For pipe segments where problems are anticipated, proceeding directly to CCTV or an advanced inspection method may be warranted.

- **Time frame**. If information is needed quickly or traffic control is a concern, the speed of inspection may be an important consideration.

- **Level of detail required**. For critical pipes, a high level of detail may be needed, and utilities may decide that a zoom camera will not be appropriate. In this case, a utility may select traditional in-line CCTV or may opt for the greater detail provided by digital scanning, especially if a goal is to track specific defects over time. For pipes of lower criticality (consequence of failure), a zoom camera may be adequate and may be a less-expensive alternative.

- **Anticipated pipe conditions**. The pipe characteristics and condition may make certain technologies more feasible than others. For example, extensive debris may hinder movement of deployment devices such as push cams. A large number of bends in the pipe may limit the use of a zoom camera. The size of manhole required for easy entry into pipes should also be considered. Flow conditions are another important consideration. For example, low-flow conditions are preferred when using technologies that inspect only the dry portions of a pipe.

- **Types and sizes of pipes**. The types of pipes will, to some degree, dictate the choice of camera. For laterals, push cams are generally needed. For larger pipes (> 8 in.), CCTV may be used. For gravity sewers of all sizes, CCTV, zoom cameras, and digital scanning may all be options. Large diameter pipes can pose a challenge for camera-based inspection technologies. The maximum diameter pipe for which a method is effective depends upon the capabilities of the specific model. Lighting is an important consideration, as is the resolution of the camera. Strong lighting is needed to provide enough illumination for larger pipes. Utilities needing to inspect large diameter pipes should consult with manufacturers and contractors to get further information.

- **Purchasing vs. contracting**. When considering a new technology, a utility will need to decide whether to invest in the inspection equipment or to use a contractor. The utility should consider whether the long-term need for the technology is sufficient to justify the expenditure to purchase the equipment and software and to train staff. If several technologies are selected for a comprehensive inspection and prioritization process, subcontracting at least some of the work may be more economical.

Chapter 3. Overview of CCTV Inspection Data Analysis

3.1 Introduction

Sewer condition assessment is performed to evaluate sewer performance status or to prioritize sewer rehabilitation activities. CCTV is an important inspection technique in the condition assessment stage of asset management. It is a traditional technique that relies on the operator's interpretation of visual images to convert the defect image into data for use in corrective action decisions.

This chapter discusses CCTV inspection data for linear assets such as pipes with open channel flow and how these data are analyzed and manipulated in the corrective action process. CCTV can also be used in vertical assets such as manholes. Because all pipes were originally designed to perform at a specified hydraulic performance level under specific conditions, CCTV inspections help reveal whether pipes are performing as designed and, if not, to what extent the design performance is affected and what corrective actions are appropriate.

3.2 Methods for Inspection Prioritization

One of the first decisions in the CCTV inspection process is to identify priority assets for inspection. Ideally, an inspection would occur prior to a performance exception or problem (WEF, 2006).

3.2.1 Selection of Assets for Inspection

A well-developed inspection plan will consider how the data will be used in subsequent asset management steps. The goal is to maximize the value of the inspection while minimizing inspection costs. The plan should focus on program objectives, keeping in mind what data needs are driving the inspections and subsequent decision making. In comparing the costs and benefits of inspection, utilities should consider the value of data as an added benefit. Both the Fort Worth Water Department (FWWD) and Northern Kentucky Sanitation District No. 1 stress the importance of weighing the benefits of the data relative to the overall asset management objectives (see the detailed case studies, Appendix A).

In a survey of its membership, the Association of Metropolitan Sewerage Agencies (now called the National Association of Clean Water Agencies, NACWA) gathered information on inspection frequency, as detailed in Table 3-1 (AMSA, 2003). These survey results show that approximately half of survey respondents inspect less than 10% of their systems each year, resulting in a 10-year or longer inspection period for those systems.

Table 3-1. Survey results of inspection frequency for conveyance systems

Percent of Sewer Pipes Inspected	% (Number) of Survey Respondents
<1% per year	3% (2 of 75)
1% – <3% per year	8% (6 of 75)
3% – <5% per year	15% (11 of 75)
5% – <10% per year	25% (19 of 75)
10% – <20% per year	27% (20 of 75)
20% – <50% per year	4% (3 of 75)

Percent of Sewer Pipes Inspected	% (Number) of Survey Respondents
≥50% per year	1% (1 of 75)
No Answer	17% (13 of 75)

Source: AMSA (2003).

Use of an infrequent inspection rate requires prudence to identify critical assets that need more frequent inspection. For example, the FWWD has a goal of inspecting its entire system within an eight-year period. However, the more critical pipes are inspected at least every four years (see case study in Appendix A). Northern Kentucky Sanitation District No. 1 uses the results of its CCTV scoring and trend analysis to automatically schedule future CCTV inspections (see case study in Appendix A).

The condition assessment process does not rely solely on data from CCTV inspections because gathering the data would take years. Therefore, condition assessment programs generally use a priority risk approach based on probabilistic methods to select assets for inspection. Decisions about which assets to inspect should be related to the utility's program objectives and the assets that pose the most threat in the event of a performance problem. For example, if SSOs pose a significant threat, the utility may want to focus on assets that present the greatest SSO risk.

3.2.2 Prioritization of Assets

Approaches for selecting which assets to inspect can vary from basic methods based on inspection history or performance measures to more sophisticated methods that use predictive modeling and risk assessment. The FWWD, for example, uses the following performance measures to help prioritize sewer inspections:

- SSOs per 100 miles.
- Stoppages/blockages per 100 miles.
- Customer complaints per 100 miles.

Software applications can be retrospective or predictive and rely on the integration of computerized maintenance management systems (CMMS), GIS, customer information systems (CIS) or financial information systems (FIS) (AMWA et al., 2007).

Three approaches described below can be used by almost any size utility to prioritize assets:

- The Canadian National Research Council's approach (McDonald and Zhao, 2001) uses an "impact assessment" to prioritize assets for inspection. Impact assessment is a weighted average of six impact factors: location, soil support, size, depth, sewer function and a seismic factor. This method allows the uniform calculation of the impacts of failure or performance problems.

- The Sewer Cataloging, Retrieval, and Prioritization System (SCRAPS) is based on the general approach of defining risk factors based on consequences and likelihood of failure using Bayesian probability logic (Merrill et al., 2004). It is a tool that can be used when limited condition information is available or retrievable. The term "Consequence of Failure" is defined as the impact of a failure in terms of repair cost, disruption to the public and economy, impairment of system operation, regulatory compliance, public health and safety, and damage to the environment. The same terminology can be applied to the decision-making process used in applying condition assessment to asset management. The impact of a failure must be understood and quantifiable. If the costs can be quantified, this impact can be compared to both the cost of condition assessment and the cost of replacement or rehabilitation.

- NACWA, the Association of Metropolitan Water Agencies (AMWA), and the Water Environment Federation (WEF) produced a publication titled "Implementing Asset Management: A Practical Guide in 2007" (AMWA et al., 2007) that uses a top-down approach to prioritization. The top-down approach uses risk factors similar to SCRAPS. However, this process is based on assigning risk scores to an asset group or set of assets at a system or facility level through spreadsheet matrices. Level of service values and weights are used to produce a numeric consequence of failure score. The likelihood of failure matrix includes physical condition and functional performance criteria that influence the remaining life of the asset. Institutional knowledge and professional judgment are the primary sources of this information. The consequence of failure score is multiplied by the likelihood of failure score, resulting in a risk score used to prioritize the asset groups.

Section 3.5 further discusses risk-based prioritization but with more emphasis on its application to selecting appropriate corrective actions such as pipe repairs, rehabilitation or replacement.

3.2.3 Asset Inspection

The type of inspection performed depends on the objective of the condition assessment program. The climatologic and hydrologic differences across North America will influence the assessment objectives. For example, in coastal areas with high annual rainfall, inspection may focus on pipe capacity. In dry and seasonably warm regions, the assessment may focus on structural condition and service life. Program objectives are discussed in more detail in Chapter 1.

The selected inspection technique needs to be appropriate for the type of asset, and it must provide the data needed to make decisions. CCTV is the most commonly used method of inspecting sewers and locating structural and maintenance defects. It is not a reliable method of locating I/I defects because of difficulties in correlating ground water elevation and movement relative to the asset. The zoom camera is a good, cost-effective method for screening pipes for more comprehensive CCTV inspection, as illustrated in the Hillsborough County case study (see Appendix A).

A detailed work plan that integrates inspection procedures and data management protocols should be established to produce consistent and reproducible inspection results. These documents ideally will outline and address key assessment questions such as the following:

- Which assets are high priorities for inspection?
- How often are lower priority assets inspected?
- How will the CCTV data be used to make assessment decisions?
- What software tools are used for analyzing the CCTV data and planning maintenance work?
- What quality control checks will be performed and by whom?
- How are the CCTV data stored and managed?
- What resources are needed to support the data collection and analysis activities?

3.3 Defect Coding

3.3.1 Code Design and Format

Defect codes classify defects by category, defect type and severity. This helps the utility owner determine the overall physical condition of a pipe and its priority for further inspections and maintenance. Defect codes serve multiple functions in the CCTV inspection and data analysis process:

- Codes serve as unique defect identifiers for operators to link an image from a pipe inspection to a specific pipe defect.
- Standard codes provide a means to reduce operator subjectivity.
- Codes enable different industry coding systems to be "mapped" to each other.

Defect codes can be designed in various ways (e.g., one character or a string of characters). Their design is largely influenced by the code system and CCTV software features. The most traditional design is an acronym consisting of a string of letters or numbers that link to words describing the defect. For example, the acronym BP might represent "broken pipe." The acronym BP3 would provide more descriptive information if "3" represented major severity on a scale of 1 to 3. Similar examples are illustrated in Tables 3-2 and 3-3. Table 3-2 shows some defect codes used by the City of Fort Worth, and Table 3-3 lists some structural defect codes from the NASSCO Pipeline Assessment and Certification Program (PACP) defect coding system. A complete list of defect codes used by Fort Worth is included in its case study in Appendix A; PACP codes are provided in NASSCO (2001).

Table 3-2. Partial listing of defect codes for City of Fort Worth Water Department

Code	Code Description	Severity Ranking				
		1	2	3	4	5
G	Grease	N/A	Less than 10% of pipe diameter	10% to 20% of pipe diameter	20% to 30% of pipe diameter	More than 30% of pipe diameter
R	Roots	Less than 10% of pipe diameter	10% to 20% of pipe diameter	20% to 30% of pipe diameter	30% to 40% of pipe diameter	More than 40% of pipe diameter
OB	Obstruction	Less than 10% of pipe diameter	10% to 20% of pipe diameter	20% to 30% of pipe diameter	30% to 40% of pipe diameter	More than 40% of pipe diameter
DE	Debris	Less than 10% of pipe diameter	10% to 20% of pipe diameter	20% to 30% of pipe diameter	30% to 40% of pipe diameter	More than 40% of pipe diameter
CC	Crack, Circumferential	Hairline	Minor	Moderate	Major	Severe
CL	Crack, Longitudinal	Hairline	Minor	Moderate	Major	Severe
B	Pipe Broken	Hairline	Minor	Moderate	Major	Severe

Table 3-3. Example PACP structural defect codes and descriptions

PACP Code	Description
B	Broken
BSV	Broken soil visible
BVV	Broken void visible
CC	Crack circumferential
CL	Crack longitudinal
CM	Crack multiple
CS	Crack spiral
D	Deformed
FC	Fracture circumferential
FL	Fracture longitudinal
FM	Fracture multiple
FS	Fracture spiral
H	Hole
HSV	Hole soil visible
HVV	Hole void visible
XB	Collapsed brick sewer
XP	Collapsed pipe

Source: NASSCO (2001). Used with permission.

3.3.2 Code Systems

A number of code systems have been developed to classify pipe defects. These systems are described below. In general, the code systems differ in their design and in the degree of detail with which the defect is described. A desirable feature is a defect dictionary that fully describes the defect with a narrative and example photos.

WRc and NASSCO Defect Code Systems

The Water Research Centre (WRc), a water, wastewater and environmental research-based consultancy group in the United Kingdom, developed a set of codes to rank the severity of pipe defects. European authorities adopted the WRc system as their benchmark pipe defect coding standard. The WRc defect coding system is described in the *Manual of Sewer Condition Classification – 4th Edition* (WRc, 2004), which can be purchased from NASSCO (http://www.nassco.org/).

In 2001, NASSCO developed a Pipeline Assessment and Certification Program (PACP) with associated defect codes (http://www.nassco.org/training_edu/te_pacp.html) based on the WRc system (NASSCO, 2001). The PACP defect codes present several advantages and disadvantages, as listed in Table 3-4. NASSCO has also developed the Manhole Assessment Certification Program (MACP), with associated defect codes, and has initiated development of a similar code system for service laterals.

Table 3-4. Advantages and disadvantages of the NASSCO PACP defect code system

Advantages	Disadvantages
• Broad and well-established coding process and training system across North America. • Readily available standardized coding and data recording software. • Good defect code classification system. • Simple and intuitive defect grading scale for operators.	• Standardized codes limit the degree of code customization and adaptations/improvements to coding system as technology evolves. • Three separate rating processes provide different condition interpretations for five coding families (see details in Appendix B). • Simplistic grading hinders definitive analysis cut-off points or sorting ranges when there are a large number of assets. • Scoring process is not integrated with other field inspection techniques. • No built-in or automated process that verifies the correct code was entered. Verification must be accomplished by a subsequent quality control review.

An example utility application of the PACP coding system is provided by Metro Water Services (MWS) in Nashville, Tenn. (see detailed case study in Appendix A). MWS replaced its in-house data management and defect code system, and initially found that using the PACP coding system decreased the department's productivity. As the staff adjusted to the new system, productivity and efficiency increased. Inspection data are now quickly uploaded and available to all MWS employees within 24 hours of inspection. As a result, duplicative inspection efforts are avoided. Inspection results have been much more consistent with the PACP coding system. The utility found that one disadvantage of PACP coding is that it can be too detailed, making it difficult to get complete information when querying for problems. For example, PACP coding has several observation codes for roots in the pipe. When identifying a root problem, different personnel may use different codes. The use of different PACP codes by operators may then cause difficulties when querying for root problems. If the user does not construct the query using the same multiple observation codes that were used to code the defects, the user will not find all instances of root problems.

SCREAM™ Defect Code System

SCREAM™ was developed by CH2M HILL to provide an alternate approach for rating the overall condition of a pipe. It has been integrated into vendor software such as CUES Granite XP software and Wallingford Software's InfoNet program. The SCREAM™ code system is somewhat similar to PACP but includes a more comprehensive list of codes. Manhole and lateral codes were also developed. The SCREAM™ coding process presents several advantages and disadvantages, as summarized in Table 3-5.

Table 3-5. Advantages and disadvantages of the SCREAM™ defect code system

Advantages	Disadvantages
• Flexible code customization to match historical or unique local nomenclature. • Defect codes have a base and maximum score between which the defect is scaled based on extent. • Code scores are specific to most popular pipe materials. • Rating process produces one condition score for each of four coding groups (see Appendix B). • Code system integrates with other inspection techniques.	• Access limited through software vendors and consultants; proprietary software. • Comprehensive code list mandates operator training. • Training and certification materials need more defect photo documentation. • No built-in or automated process to verify that the correct code was entered. Verification must be accomplished by a subsequent quality control review. • System is not widely used.

Appendix B provides more detailed descriptions of the PACP and SCREAM™ code systems, as well as examples to illustrate the coding process.

Alternative Defect Code Systems

The Large Sewer Condition Coding and Rating (LSCCR) system was developed by Canada's National Research Council Institute for Research in Construction (NRC-IRC) based on condition assessment procedures used by WRc and the cities of Edmonton and Phoenix. The LSCCR system is described in *Guidelines for Condition Assessment and Rehabilitation of Large Sewers* (Zhao et al., 2001), which can be downloaded at http://www.nrc-cnrc.gc.ca/obj/irc/doc/pubs/nrcc45130.pdf.

Another option for utilities is to develop their own defect code system. Using a so-called "homegrown" defect code system allows the utility to standardize the condition assessment process at the utility level while being tailored to meet system-specific needs. These defect code systems often mirror some features of commercial software and typically offer a more basic coding method. Their simplicity may be desirable for reducing operator errors and other reasons, but may limit the robustness of the data for use in asset management decision making.

FWWD created its own defect code system (see partial listing in Table 3-2) based on feedback from operators and technicians that the PACP system with 200 codes is too rigid, too complex and too cumbersome. Operators tended to memorize a handful of defect codes and rarely used the others. In some cases, the PACP codes were not specific enough for operator needs/requirements. FWWD's code system is similar to the PACP system, but has fewer codes (75 vs. 200). Some utilities prefer this simpler approach because there is less dependence on the operator's memory to recall an acronym when using software drop-down lists and short-cut keyboard features in CCTV software interface screens.

3.4 Data Handling and Analysis

Data handling, including collection, storage, retrieval, analysis, and reporting, is an important yet often overlooked component of a condition assessment program. Important questions to consider when selecting a data management system include:

- Who needs access to what data?

- What data do I need to review for short-term and long-term decision making?
- What reports will I generate from the data management system?
- How much training is needed to manipulate software or to view data?
- What is my budget for software and training?
- Are there licensing fees and other system maintenance costs?
- Do I want to integrate CCTV data with other historical data?
- Is my staff willing to change to a new, more complex system?
- Is my data transferable to another system if I decide to change vendors?
- Is my software open source or proprietary?

Since the late 1990s, many utilities have replaced analog CCTV cameras with digital models, and have identified a number of benefits. For example, SPU has found that digital information has a long storage life and requires little space. Data retrieval from analog videotapes is difficult, and the tapes degrade after approximately 7 to 10 years (see case studies in Appendix A). Digital storage media (e.g., CDs and DVDs) do have a finite storage life, so data may need to be transferred to other media as the technology evolves. Furthermore, digital inspection data can be easily accessible to a greater number of utility personnel via links from the GIS and computerized maintenance management system.

Utility owners have experienced some initial productivity loss and reluctance from the CCTV operators when implementing the new data formats, and some have found a need for increased resources. The FWWD, for example, found that more information technology support was needed to maintain its software and additional training was required for CCTV operators (see Appendix A). Nashville MWS and Northern Kentucky Sanitation District No. 1 also needed additional operator training and budgeting support with the new CCTV software management system. The FWWD recommends that utilities select CCTV inspection software that is non-proprietary, open architecture based and not developed by the CCTV camera manufacturers.

There are three general approaches to data management software, with varying costs and degrees of complexity:

1. Spreadsheet software.
2. Software specifically designed for condition assessment and asset management.
3. Database software that is not specifically designed for condition assessment.

3.4.1 Spreadsheet Software

Spreadsheet software offers the least costly option for data management and is the most familiar to utility staff. Microsoft Excel and IBM's Lotus 1-2-3 are examples of popular spreadsheets. Most utilities are likely to already have such software. A basic yet effective data management system can be designed; however, as the database expands, the spreadsheets and data links can become overly cumbersome and require a more advanced user to leverage the software. The Seattle Public Utilities used an Excel spreadsheet to apply its pipe risk model (see Appendix A).

3.4.2 Condition Assessment/Asset Management Software

There are numerous commercially available data management programs for CCTV-generated data, ranging in complexity and cost. Examples include Canalis (Aqua Data Inc.); CapPlan Sewer (MWH Soft); Cass Works (RJN Group Inc.); CityWorks (Azteca Systems, Inc.); CTSpec (CTZoom Technologies Inc.); gbaMS (GBA Master Series, Inc.); Granite XP (CUES); Hansen (INfOR); InfoNet (Wallingford Software); Maximo® (IBM); and SEWERview (Cartêgraph, Inc.). USEPA provides free asset management software (Check Up Program for Small Systems, CUPSS) on its Web site (http://www.epa.gov/cupss/). Figure 3-1 is an example of a screen shot of a CUES Granite XP pipe inspection map and camera image. The publication "Implementing Asset Management: A Practical Guide" (AMWA et al., 2007) discusses some of the currently available software applications. Contact information for software vendors is provided in Appendix C.

Figure 3-1. Example CUES Granite XP pipe inspection map with camera image. Source: CUES, Inc. (2009). Reprinted with permission.

Commercially available software designed for condition assessment offers various functions including:

- Document status of pipe being inspected.
- Provide access to text data, video and still photos.
- Code defects in different forms (i.e., acronym, bar codes, touch screen images).
- Customize defect codes to capture local terminology, match historical records and/or support specific local policies/regulations.
- Store defect codes on pipe segments both spatially and temporally.
- Sort and categorize defects by location, type, severity, score, etc.
- Compile defect data into a searchable database.
- Incorporate cost accounting.
- Develop work orders for maintenance calls and ordering spare parts.
- Incorporate GIS functionality into the system.

The utility should identify software that can provide the desired functions. It should also confirm that the software developer can provide training and technical support services as needed to ensure successful implementation.

3.4.3 General Database Management Software

An alternative to commercially available software or a standard spreadsheet is a database designed specifically for a utility's needs. This approach may offer advantages in data processing and analysis time because the database is system-specific. However, it may involve additional up-front costs and require additional technical expertise. Other costs include software licensing fees and staff training.

Database management software systems can be divided into two groups: desktop databases and server databases. Commercially available desktop products include Microsoft Access, FileMaker Pro, Alpha Five, Paradox and Lotus Approach. Desktop products provide the user with significant flexibility to modify and customize analysis and reporting functions. Server databases, such as Microsoft SQL Server, Oracle and IBM DB2, allow the efficient management of large amounts of data. Web-based applications can be developed using either desktop products such as Microsoft Access or server databases.

Northern Kentucky Sanitation District No. 1 (developed its own database system and integrated it with commercially available asset management software (see case study in Appendix A). District personnel found that the process takes time to develop, but provides the flexibility to design engineering analysis and generate reporting queries and work orders at substantial cost savings compared to the prior data management practices. The district also uses condition assessment software discussed in Section 3.4.2 and integrates the software platforms, as illustrated in Figure 3-2.

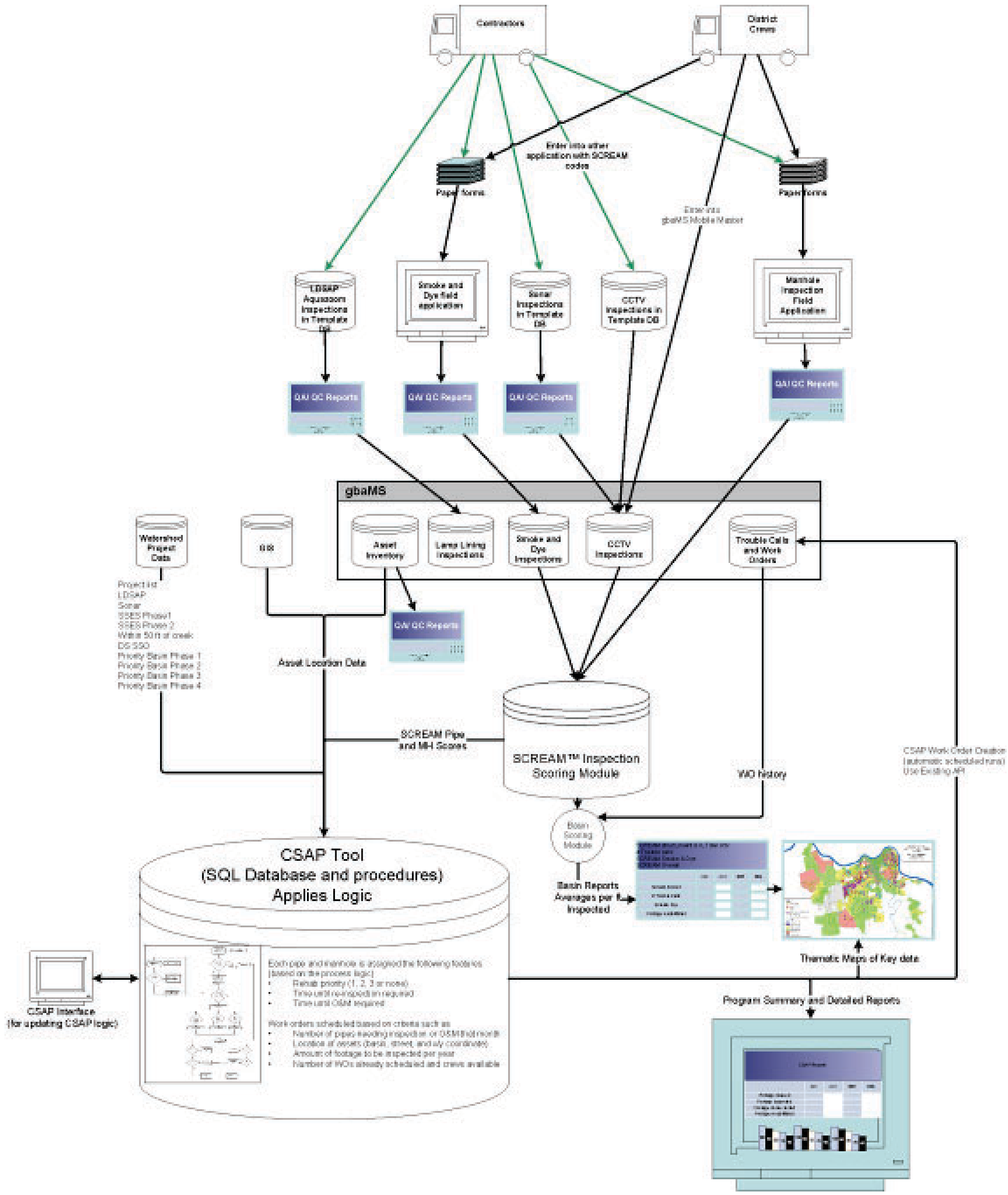

Figure 3-2. The Northern Kentucky Sanitary District No. 1's example integration of general database and condition assessment software. Image courtesy of Northern Kentucky Sanitary District No. 1.

3.4.4 Pipe Rating and Scoring Methods

CCTV data analysis is an important step in condition assessment of pipelines because the results influence the overall pipe condition rating and risk scoring. The approach to CCTV data analysis depends on several factors including:

- The type of asset inspected (e.g., pipe, manhole, service lateral).
- The camera technology used for pipe inspection (e.g., digital CCTV camera, zoom camera, digital scanning).
- The method used to convert pipe defect codes to overall pipe rating and risk ranking.

Figure 3-3 shows the typical steps that occur from the first identification of a pipe defect to establishing the pipe's priority ranking for pipe rehabilitation or replacement.

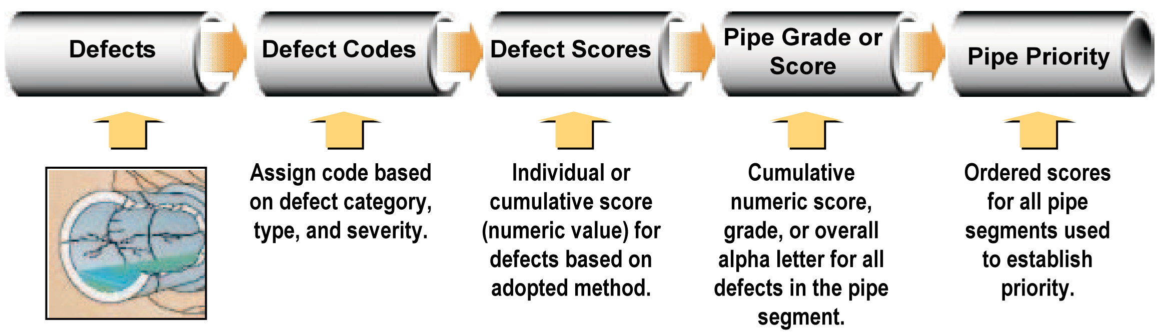

Figure 3-3. Typical steps from defect identification through prioritization of pipe rehabilitation projects. Source: Kathula and Rowe (2004). Reprinted with permission.

Two pipe rating analysis methods are discussed below: PACP and SCREAM™. Details and examples are provided in Appendix B.

PACP Rating Analysis System for Pipes

The PACP uses a numerical grading system to rate the severity of each pipe defect and calculate overall pipe ratings based on grades for individual pipe segments. NASSCO (2001) describes the basis and assumptions used in establishing this grading system:

> "The PACP Condition Grading System only considers internal pipe conditions obtained from TV inspection. While other factors such as pipe material, depth, soils, and surface conditions also affect pipe survivability, those factors have not been included in this version of the PACP Condition Grading System. The PACP Condition Grading System should be used as a tool for screening pipe segments, allowing the User to quickly determine which pipe segments have significant defects. It is expected that as the PACP further develops the PACP Condition Grading System will expand to include other factors."

The defect grading system uses a scale of 1 to 5, with 1 representing a minimal defect and 5 representing the worst defect. Structural and O&M defects are graded separately based on the likelihood of further deterioration or failure. The PACP system uses several terms for expressing pipe condition (NASSCO, 2001):

- Segment Grade Scores: Each pipe segment (manhole-to-manhole pipe run) receives five Segment Grade Scores, one for each of the five grades. The score equals the number of defects multiplied by the grade number. For example, a pipe segment with six Grade 5 defects has a Segment Grade 5 Score of 30 (6 defects multiplied by a grade of 5). If a pipe segment has no defects for a particular grade, the Segment Grade Score for that grade is 0.

- Overall Pipe Rating: The sum of five Segment Grade Scores.

- Structural Pipe Rating: The sum of five Segment Grade Scores considering only structural defects.

- Overall Pipe Rating Index: An expression of the average defect severity found in the pipe segment. The index is calculated by dividing the Overall Pipe Rating by the number of defects.

- Structural Pipe Rating Index: The average severity of structural defects in the pipe segment. The index is calculated by dividing the Structural Pipe Rating by the number of defects.

- O&M Pipe Rating Index: The average severity of O&M defects in the pipe segment. The index is calculated by dividing the O&M Pipe Rating by the number of defects.

SCREAM™ Rating Analysis System for Pipes

The SCREAM™ rating analysis system includes coding individual defects, scoring the overall pipe condition and scoring the structural, maintenance and I/I group defects. The coding of individual defects includes calculation of a base score and a maximum score; the base score represents minor defects (e.g., a point defect or a defect that affects 1 ft or less of pipe length) and the maximum score represents major defects (e.g., a defect that affects the entire pipe segment). For both defect coding and pipe condition scoring, a scoring scale of 1 to 100 is applied with 1 representing a very minor defect and 100 representing the most severe defect (e.g., a collapsed pipe).

The SCREAM™ methodology includes computation of an Overall Pipe Score for the aggregated defects found in the pipe. It also computes a separate score for the structural, maintenance and I/I groups of defects. These scores are calculated using a multiple attribute method that involves advanced root-square-mean mathematical principles. One key principle is to identify and build upon the highest scored defect value found in the inspection (Kathula, 2004).

3.5 Role of CCTV Data in Asset Management Decision Making

The purpose of this section is to highlight and summarize the role of CCTV data in asset prioritization decisions, the final step in the condition assessment process. There are two ways of making decisions, one based on pipe condition information and the second using a risk assessment approach. A risk-based approach is the only way to prioritize for renewal assets that are in the same condition and display the same deterioration rate. A strict condition-based approach is tenable only when resources are available to renew all assets that are worse than a given threshold condition.

3.5.1 CCTV Data Used in Condition-Based Prioritization Decisions

A utility may decide to proceed with work on a particular asset or group of assets because it has a historic record of problematic performance or it meets certain performance measure criteria (see Section 3.2.2). CCTV data are then used to help make a condition-based decision on what action should be used to correct the asset and the priority given to this corrective action. There may be numerous locations and assets that fall into this category and require a relatively short-term fix, for instance within a 1- to-5-year period. However, even within this period, the asset corrective actions need to be prioritized.

The condition-based decision approach has two common decision sequences, which differ primarily on when the cost of the corrective action is considered and what role it has in the prioritization. Figure 3-4 shows the two options.

In Option 1, CCTV inspection analysis leads to an internal condition rating, a prioritization decision, and then a type of corrective action. In this option, the cost of the corrective action can be considered in the selection of the corrective action or after the correction action is selected.

Option 2 is similar to Option 1 except that the corrective action decision is made immediately after the internal condition rating. Generally, the cost of the corrective action is considered when the corrective action decision is made and the cost influences the prioritization decision.

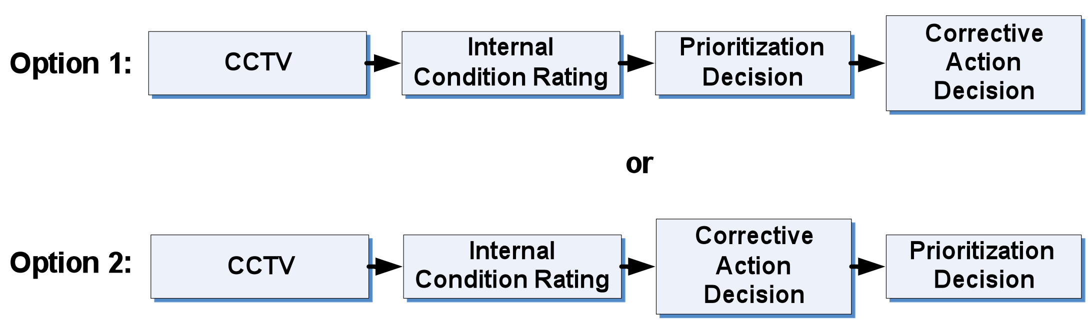

Figure 3-4. Two optional condition-based decision approaches.

Utilities typically use less costly inspection methods for initial evaluations, then progress to more comprehensive and more costly techniques as warranted. For example, utilities may initially inspect manholes and connecting pipes with zoom cameras if the manholes are readily accessible by field crews. Zoom cameras enable utilities to screen the pipes and reduce the number of pipes that require CCTV inspection to only those needing the more detailed investigation.

Utilities that use the PACP rating system need to decide which of the three PACP scoring methods is preferred. A popular method is the Pipe Rating Index method previously discussed. Pipes rated as Grade 4 or 5, for instance, would be evaluated more closely or acted upon first compared to pipes with a of Grade 1 – 3. The grading system screens the assets for further evaluation of replacement or rehabilitation issues and development of a cost estimate for establishing a priority and schedule.

Utilities that use the SCREAM™ rating process prioritize corrective actions based on the single numerical defect score. Usually the utility establishes a range of score values to determine the urgency of a specific corrective action. For instance, Northern Kentucky Sanitation District No. 1 uses a structural score range of 81– 100 to trigger rehabilitation or replacement in its large inceptors, and a range of 61 – 80 triggers future inspections.

3.5.2 CCTV Used in Risk-Based Prioritization Decisions

Because of limited resources, most utilities must prioritize assets for inspection. Therefore, the condition assessment process does not rely solely on CCTV data because it could take many years to complete a system-wide inspection program (Rowe, 2009). The challenge is to understand the possible risks posed by an asset failure and determine at what point to intervene to avoid a failed condition with an unacceptable cost or consequence.

Risk is quantified by the combination of both the likelihood of failure and consequence of failure. CCTV inspection provides data to improve the integrity of the likelihood of failure score. The mathematical expression of risk is (AMWA et al., 2007):

$$\text{Risk} = [(\text{Consequence of failure}) \times (\text{Likelihood of failure})]$$

Various risk-based decision models have been developed for sewer assets. Because CCTV data are not always available for every asset, predictive modeling is often used to determine the likelihood of pipe failure until the asset can be directly inspected. For example, SPU uses a predictive model based on pipe material decay curves to estimate the likelihood of failure (see the detailed case study in Appendix A).

Figure 3-5 presents an example of a risk-based approach to determine the priority assets for more comprehensive inspections or other corrective actions. The “Likelihood of Failure” and “Consequence of Failure” terms in the risk calculation are usually developed by constructing a matrix that lists the important criteria or service level factors and the associated score (AMWA et al. 2007). The “Likelihood of Failure” term considers both current internal condition information and time-based information (e.g., historical work order records). The “Consequence of Failure” term represents time-based information since it considers future events related to pipe failures. Figure 3-5 shows how CCTV data can be incorporated into the prioritization process. If the condition rating of an asset was initially determined by a predictive approach and the asset is then inspected using CCTV, its risk rating should be recalculated and its action reprioritized.

Figure 3-6 is another example of a risk-based prioritization decision framework where the internal condition ratings are all based on CCTV data. Asset prioritization and corrective action Options 1 and 2 are the same as discussed above under Section 3.5.1, Condition-Based Prioritization Decisions.

In conclusions, the primary objective of this guidance document is to identify and evaluate innovative CCTV and related technologies currently used by more advanced wastewater utilities to conduct condition assessment programs. The document is intended to facilitate the transfer of these innovative technologies to utilities at large. The steps in developing and implementing a condition assessment program are presented along with related practical guidelines. Technology applications and lessons learned from seven utility case studies are summarized and used to illustrate specific concepts. Detailed case study reports are presented in Appendix A.

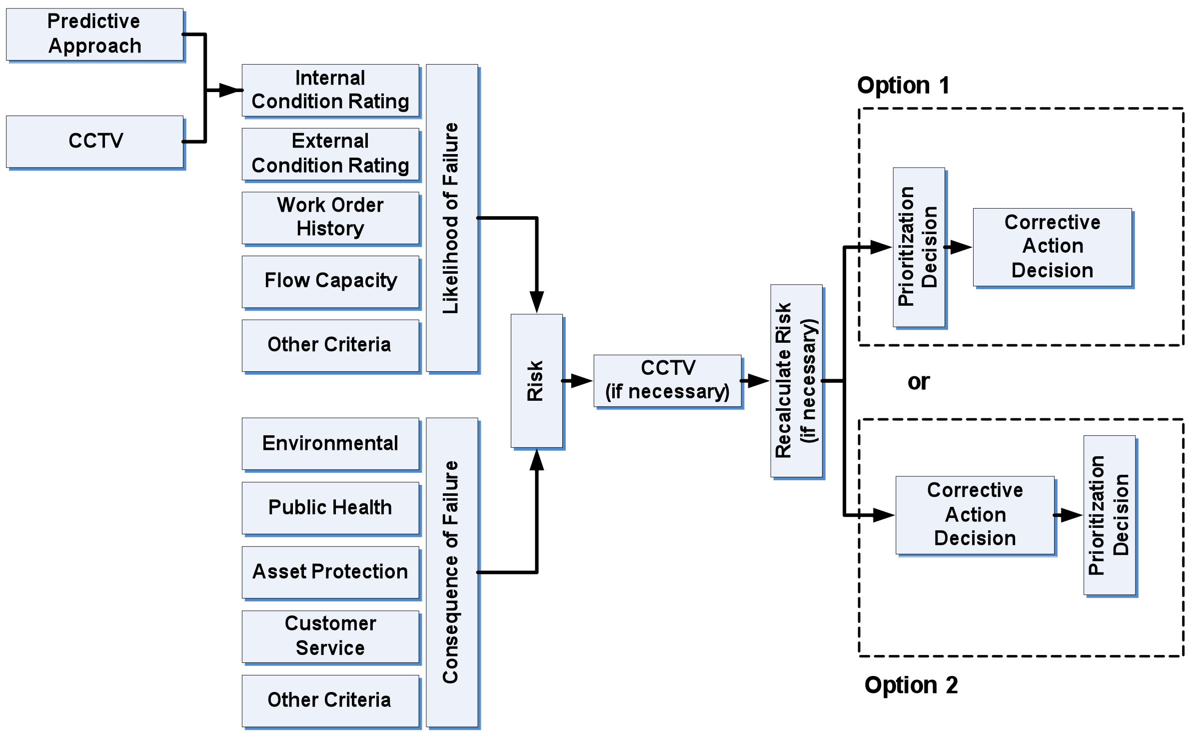

Figure 3-5. Example risk-based prioritization decision framework for multiple internal condition rating input sources.

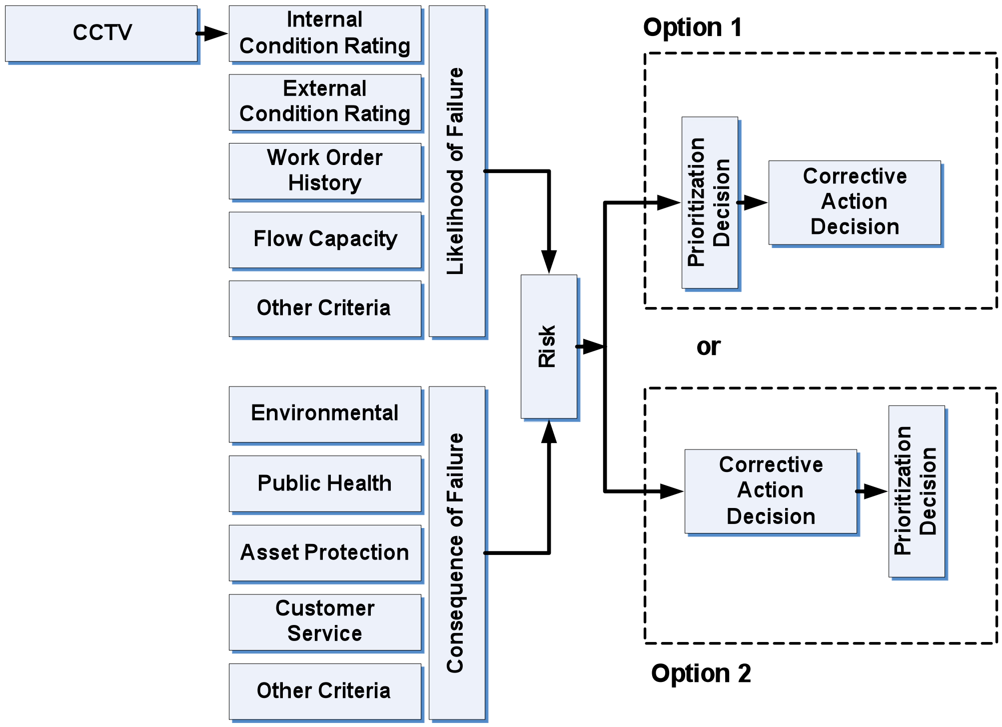

Figure 3-6. Example long-term risk-based prioritization decision framework.

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Appendix A. Utility Case Studies

Case Study on Implementation of New Data Management System – City of Fort Worth Water Dept., Fort Worth, Texas

This case study discusses the experience of the City of Fort Worth, Texas, in transitioning to a new standardized coding system and data management software.

Lessons Learned

The City of Fort Worth Water Department (FWWD) has been very satisfied with the implementation of its new standardized coding system adapted from PACP, digital video inspections and data management software. Advantages of the new system include:

- **100% digital videos and photos and improved querying**. Prior to the new system, staff had to manually search for VHS tapes on a shelf and fast forward through the tape to find points of interest. FWWD is now able to easily search for any inspection and quickly access all information.
- **Historic records**. It is advantageous to have access to data from multiple inspections of a single pipe segment and inspections performed over an extended period of time. These data can be used to compare the results of past inspections to the results of current inspections as part of condition assessment.
- **Exporting of records**. The new software has made it much easier to export inspection records and recordings for review by developers and engineers.
- **Standardized defect coding**. The implementation of a standardized defect coding system has greatly improved the consistency of inspection data. This has led to more efficient cleaning and maintenance procedures.

One drawback is a need to routinely replace electronics in the inspection vehicles due to the harsh conditions to which equipment is exposed. FWWD has also needed increased resources to provide more information technology support to maintain the software and to provide additional training for CCTV operators.

FWWD recommends that utilities select CCTV inspection software that is non-proprietary, open architecture based and not developed by the CCTV camera manufacturers.

FWWD also recommends that if a small or medium-sized community plans to have more than one inspection vehicle, it should plan to standardize the electrical components. CCTV vehicles are a harsh environment for electronics, and FWWD has noticed hardware (motherboards, fans, video capture cards, etc.) failures occurring more frequently than anticipated. The solution has been to purchase the components, build the computers and replace the existing computers once every two years regardless of their condition.

With respect to personnel training, FWWD realized that more IT support was needed within the department to help with troubleshooting and maintenance of the software. The change in procedure also necessitated training for CCTV operators in the use of the new computer-intensive techniques. Also, the expense of purchasing licenses, maintaining a dedicated server, and training personnel is greater than the cost of FWWD's previous system. Utilities will need to weigh the benefits of improved data management against additional expenses.

Background

FWWD provides drinking water and wastewater services for the community of Fort Worth, Texas, and 21 surrounding communities. The FWWD sewer collection system serves a population of approximately 660,000 people with approximately 208,000 service connections.

Initial construction of FWWD's collection system began in 1906 with multiple brick sewers. A large expansion of the collection system took place in the 1940s with the installation of primarily vitrified clay pipe. Throughout the following 60 years, pipelines were added to the collection system as the local population grew. In 1962, FWWD constructed a 96-in. diameter sewer main, which is still the largest pipe in the system. The current collection system spans a total of approximately 3,000 miles and has an average age of 29 years. The collection system is a completely separate system with an average daily flow of 120 million gallons per day (MGD). The collection system consists of eight major drainage basins each of which is divided into 66 sub-basins averaging 237,000 linear ft of pipe. These sub-basins are further divided into 325 sub-areas with an average 44,000 linear ft of pipe.

Historical CCTV Inspections and Defect Coding

FWWD initially instituted its CCTV program in the mid 1990s with the objective of inspecting the entire system once every eight years. Historically, CCTV inspection was used for a variety of purposes such as determining pipe condition, aiding in planning maintenance strategies, evaluating the effectiveness of its cleaning program, performing post SSO evaluations, performing inspection of new construction and finding customer service lateral tap locations.

FWWD personnel perform all inspections of pipes with diameters of less than 20in. For pipes with diameters greater than 20 in., FWWD relies on contractors to perform CCTV, sonar and laser inspections.

Initially, FWWD made no allowances for CCTV software. When purchasing CCTV vehicles, the utility did not specify any options so the vendors made equipment decisions. Inspection records were not saved, and the analog VHS tapes were simply indexed and manually filed. To find a specific CCTV inspection, office personnel would search for a tape and then fast forward and rewind through the footage. This process resulted in shelves overfilled with inspection videos and no efficient method for retrieving historical inspection records. At times, FWWD personnel found it easier to just re-inspect the pipe segment.

Current CCTV and Defect Coding

In fall 2003, FWWD changed from analog video to digital video, implemented a new standardized coding system and installed new data management software. An internal defect coding system was created based on a 1 to 5 rating system for multiple pipe defects. Prior to this, the utility had not used a defect coding system.

FWWD did not select a PACP-certified defect coding system because it was believed that the system is too rigid, too complex and too cumbersome. There was concern that the PACP ratings would not be consistently produced by their operators. Darrell Gadberry of FWWD said the following in an e-mail message:

> "I have talked to a lot of operators, technicians and managers regarding PACP. Managers love it because they think they have a standardized CCTV program in place. Operators hate it due to the extremely large amount of defect observation codes and rating variables. Therefore they [operators] memorized a handful and rarely use the others. In

> some cases, the observation codes are not specific enough for their needs/requirements. Since there is no consistency between each inspection and/or operator, there is very little benefit for the technicians" (Gadberry, 2009).

For example, PACP coding has several different observation codes for roots in the pipe. When identifying a root problem, different personnel may use different codes. The use of different PACP codes by operators may then cause difficulties when querying for root problems. If the user does not construct the query using the same multiple observation codes that were used to code the defects, the user will not find all instances of root problems.

The internal defect coding system that FWWD created and implemented uses coding similar to PACP, but the coding system is more streamlined and better tailored to FWWD's needs. For example, the coding system uses 75 codes compared to 200 codes for the PACP coding system. The coding system assigns ratings from 1 to 5 for each section of pipe inspected, with a rating of 1 representing the best condition and a rating of 5 signifying the worst. The 1 to 5 rating can be given for each observation within a pipe segment. Each observation is assigned a code, which is simply an abbreviation. The observations are broken down into six categories: common text, operation and maintenance (O&M) issues, pipe defects, tap connections, service lateral, and grade/alignment. Table A-1 gives a list of observation codes used by FWWD along with specific code descriptions and ratings (FWWD, 2007).

Even with this standardized coding system, FWWD management has noticed some inconsistencies among operators. In an attempt to alleviate these inconsistencies, FWWD now employs two technicians who are strictly dedicated to CCTV inspection review and assessment.

Table A-1. Summary of Fort Worth defect codes

Code	Code Description	Severity Ranking				
		1	2	3	4	5
G	Grease	N/A	Less than 10% of pipe diameter	10% to 20% of pipe diameter	20% to 30% of pipe diameter	More than 30% of pipe diameter
R	Roots	Less than 10% of pipe diameter	10% to 20% of pipe diameter	20% to 30% of pipe diameter	30% to 40% of pipe diameter	More than 40% of pipe diameter
OB	Obstruction	Less than 10% of pipe diameter	10% to 20% of pipe diameter	20% to 30% of pipe diameter	30% to 40% of pipe diameter	More than 40% of pipe diameter
DE	Debris	Less than 10% of pipe diameter	10% to 20% of pipe diameter	20% to 30% of pipe diameter	30% to 40% of pipe diameter	More than 40% of pipe diameter
CC	Crack, Circumferential	Hairline	Minor	Moderate	Major	Severe
CL	Crack, Longitudinal	Hairline	Minor	Moderate	Major	Severe
B	Pipe Broken	Hairline	Minor	Moderate	Major	Severe
H	Hole in Pipe	Less than ½ in.	½ in. to 1 in. diameter	1 in. to 2 in. diameter	2 in. to 3 in. diameter	More than 3 in. diameter
X	Collapse	N/A	N/A	N/A	N/A	Complete failure imminent
I	Infiltration/ Inflow	N/A	N/A	Dripping	Running/steady stream	Gushing/pouring
J	Joint Offset/Separated	N/A	N/A	Minor	Moderate	Severe
SW	Surface Deterioration	N/A	N/A	N/A	Heavy deterioration, major aggregate projection.	Heavy deterioration, major aggregate projection is beyond repair
E	Encrustation	N/A	Minor	Moderate	Major	Severe
D	Pipe Deformed	N/A	Minor bumps, folds and wrinkles on the pipe walls	Moderate bumps, folds and wrinkles on the pipe walls	Major bumps, folds and wrinkles on the pipe walls	Major bumps, folds and wrinkles on the pipe, could be damaged during cleaning

Source: FWWD, 2007

Note: Other codes include break-in tap connection (TB), factory tap connection (TF), service lateral defective (SLD), pipe material change (MC), diameter change (DC), camera underwater (CU), camera emerged (CE), upward change in gradient (LU), downward change in gradient (LD), line bends left (LL), and line bends right (LR).

Data Management and Inspection Strategy

FFWD selected its data management software (Inspect IT by Infrastructure Technologies) for several reasons:

- The ability of Structured Query Language (SQL) to manage, standardize, and query data; manage reports; and link to CMMS or GIS.
- The ability to store multiple inspections of the same pipe segment over an extended period of time.
- The ability to use the software in lieu of CMMS.
- The ability to coordinate the software with ESRI GIS software.
- The ability to have all data maintained on a single dedicated server.

CCTV, sonar, and laser inspections are captured digitally and stored on a dedicated SQL server. FWWD maintains an extensive archive of over 19,000 digital videos and 27,000 digital photos on its server. In total, its digital library holds approximately 3.4 terabytes of data.

FWWD also uses ESRI's ArcView software and IBM's Maximo asset management software for its GIS and CMMS, respectively. FWWD is able to link inspection records to ArcView to create asset-based datasets for all pipe segments within the collection system. The GIS datasets also include record drawings and construction information. This has allowed FWWD to monitor pipe age and type when conducting and scheduling inspections. The Maximo software is used to coordinate sewer inspections and maintenance with other City of Fort Worth departments.

FWWD now prioritizes inspections to focus budgeted resources according to need. FWWD calculates the following performance indicators for each sub-area of the collection system on an annual basis:

- SSOs per 100 miles.
- Stoppages/blockages per 100 miles.
- Customer complaints per 100 miles.

Using this process each year, FWWD selects approximately 285 miles of sanitary sewer for cleaning, television inspection and condition assessment. Each sub-area is identified in the FWWD GIS dataset, which is used to create work orders in FWWD's CMMS. Each cleaning and inspection work order is specific to one sewer segment.

Inspection frequency is based on the known sewer condition. A 4-year frequency is used for sub-areas in the worst condition; a 4-to 6-year frequency is used for average condition; and an 8-year frequency is used for the best condition. This method also minimizes the possibility of unnecessary inspections damaging old clay pipes, especially those of small diameter. Table A-2 summarizes inspections conducted from 2004 to 2008.

Table A-2. Summary of pipe inspections conducted 2004-2008

Pipe Material	Pipe Size (in.)	Inspection Length (miles)
Cast Iron	6 to 18	6.27
Concrete	6 to 72	369.15
Cured in Place, Lined, high-density polyethylene (HDPE), etc.	6 to 42	14.66
Ductile Iron	6 to 42	38.16
Polyvinyl Chloride	6 to 36	395.41
Vitrified Clay	6 to 27	167.38

All inspection records associated with the project are exported and linked to the original GIS dataset. A visual observation of all O&M, structural and capacity recommendations is performed to determine the project's effectiveness.

At the completion of the project, a standardized two-page summary is prepared along with associated tables and maps documenting all system deficiencies and recommendations. All O&M recommendations are addressed by FWWD. The structural and capacity recommendations are included in the FWWD's Capital Improvement Program (CIP). An example of a sub-area summary report can be found in Appendix D.

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Case Study on Using a Risk Assessment Approach for a Sewer Pipe Inspection Program – Seattle Public Utilities, Seattle, Wash.

This case study discusses development and implementation of a sewer pipe risk model to analyze costs and benefits of CCTV inspection.

Lessons Learned

Seattle Public Utilities (SPU) has found the application of a sewer pipe risk model to be a worthy investment. SPU determined that there was a critical need for risk assessment when a collection sewer pipe collapsed and caused a sewage backup at a city hospital. At the time, all system pipes were scheduled for inspection on a 30-year cycle, and the lack of current pipe condition information created a reactive mode of operation.

The main benefits of the risk model are the information gained from risk assessment and the automation of the decision process. Some utilities have found that it is not cost-effective to inspect all pipes. Risk assessment can be used to identify and prioritize pipes that present comparatively greater risks to public health and the environment. The automation of this risk assessment process is necessary for any system with a complex network of pipes.

Application of SPU's risk model has resulted in unforeseen benefits. Modeling results helped SPU realize that some model input data were incorrect. For example, GIS attributes including pipe elevation data were suspect in about 20% of pipes. With Seattle's hilly terrain, pipe elevation and slope are critical parameters. Since GIS data are also used for SPU's hydraulic model, data corrections made as a result of the sewer pipe risk modeling project also helped to improve the accuracy of hydraulic model output.

Background

SPU is a municipal utility owned by the City of Seattle. It provides retail water, wastewater and drainage and solid waste services to approximately 700,000 Seattle residents. Approximately 112 to 115 MGD of wastewater is collected from the SPU system and treated at King County's West Point treatment facility. SPU has more than 2,000 miles of pipe with an average age of almost 75 years. Approximately one-third of the system has combined sewers and two-thirds consist of separate sanitary sewers. Wastewater collection pipe ranges in diameter from 6 in. to 12 ft. Prior to 1950, sewers were primarily constructed with vitrified clay, whereas concrete has been the predominant material of construction since 1950. The sewer pipe infrastructure has a net worth of approximately $2.5 billion (2007 dollars).

SPU started performing CCTV inspection of sewer pipes in the late 1960s. Today, inspections are conducted using in-line digital cameras, other equipment, and trucks—all owned by the utility. SPU also owns one zoom camera and uses its inspection results (e.g., presence of tree roots inside pipe) to adjust pipe maintenance schedules as warranted. It has not developed a unit cost comparison of the different camera technologies the utility has used. SPU can store information from the digital CCTV cameras much longer and in a much smaller space than it could information from the older, analog cameras, and the analog videotapes degraded after 7 to 10 years. The digital inspection data are easily accessed by more utility staff members via links from the GIS and computerized maintenance management system. SPU uses a PACP-certified method for coding pipe defects with Granite XP asset inspection and decision support software (http://www.cuesinc.com/).

Since the inception of the CCTV inspection program, all sewer pipes have been inspected on a 30-year cycle regardless of age, condition, material of construction, location or diameter. This approach to assessing pipe condition has two major flaws (Martin, 2004). First, the infrequent CCTV inspections seldom identify potential pipe failures, and second, inadequate resources are allocated to high-risk pipes (pipes that have the potential for high financial, environmental and social failure costs to the utility and the greater community).

In 2001, SPU developed an asset management program to address several concerns including aging infrastructure, a lack of information on pipe condition, stricter environmental regulations and public scrutiny of recent rate increases. For sewer assets, the immediate goal of the asset management program was to minimize risk of infrastructure failure. The initial steps in implementing this program included establishing an inventory of pipe infrastructure and developing a modeling tool to support a risk-based pipe replacement and rehabilitation program.

Sewer Pipe Risk Model

In 2003, a sewer pipe risk model originally developed by Hunter Water Australia (http://www.hwa.com.au) was adapted and applied to SPU's sewer network in order to calculate the risk cost of failure for individual pipe segments and to calculate the total annualized cost to the utility over the period between CCTV inspections. The risk cost of failure is determined by multiplying the estimated consequences of failure by the estimated likelihood of failure. SPU uses the risk assessment and its benefit-cost ratio to help select pipes for inspection and maintenance.

To estimate the consequences of pipe failure, the model extracts GIS attributes for each pipe (i.e., elevation, installation date, material of construction and proximity to geologic or structural features) and uses this information to calculate the financial, social and environmental costs such as the factors listed in Table A-3. For example, if the sewer pipe is located underneath a building, a multiplier is automatically applied to the cost formula due to the added repair cost.

Table A-3. Factors that increase consequences and costs of pipe failure

	Location-Specific Factors That Increase the Cost of a Sewer Failure		
Baseline Generic Financial Costs for Repairing Sewer Failure	**Financial Factors**	**Environmental Factors**	**Social Factors**
Labor	Under a body of water	Property damage	Unfavorable publicity
Equipment	Under railroad tracks	Regulatory non-compliance	Social disruption
Material	Under a building	Environmental damage	Damage to public health
Shoring	Within a known slide area		Regulatory non-compliance
Dewatering	Within a wetland area		
Bypass pumping	On a steep slope		
Administration	High-capacity sewage pipe		
	In dense urban area		

Source: Martin, 2004

To estimate the likelihood of pipe failure, the model uses predictive failure curves that are specific to each pipe based on age and material. This method assumes that pipe failure is due to material deterioration and does not occur before the pipe is 20 years old. Model inputs are summarized in Table A-4. An example predictive failure curve for vitrified clay pipe is shown in Figure A-1. These failure curves are generated using a normalized Weibull-type distribution. More information on Weibull distributions and curves can be found at http://www.weibull.com/. SPU received "off-the-shelf" sewer pipe curves from Hunter Water Australia.

Table A-4. Asset life information for SPU sewer pipe

Material of Construction	First Failure[1] (Years)	Remaining Life (Years)	Total Life (Years)
Vitrified clay	20	100	120
Concrete	20	60	80
Pipe relining	20	30	50
Polyvinyl chloride	20	80	100
Asphaltic concrete	20	60	80
Brick	20	60	80
Ductile iron	20	60	80
Cast iron	20	60	80
Corrugated metal pipe	20	40	60

[1] Assumes that pipe failure is due to material deterioration and does not occur before the pipe is 20 years old.
Source: Martin, 2004

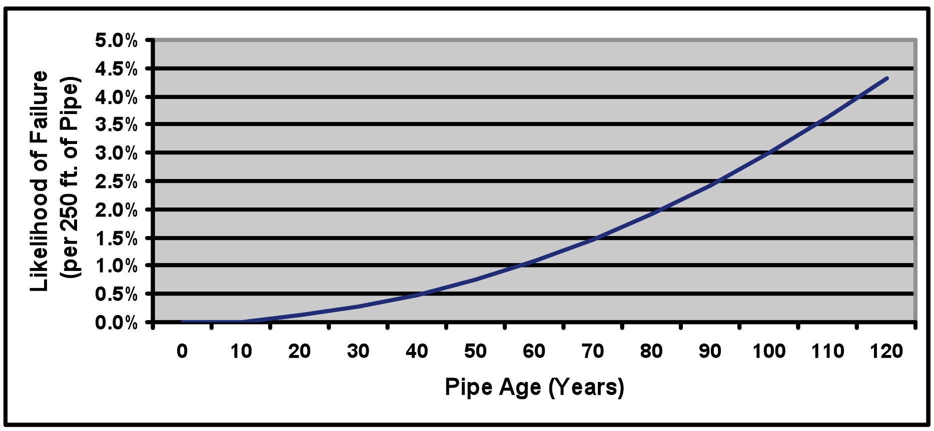

Figure A-1. Predictive failure curve for vitrified clay pipe. Source: Martin et al. (2007). Reprinted with permission.

The risk model, developed using a Microsoft Excel spreadsheet, is based on system-specific attributes and causative factors. What causes pipe failure in one system may not be a critical factor in other systems. For example, steep slopes are a major factor in Seattle, while a city on the Great Plains may have other, more critical factors. Therefore, it is important that the model developer is familiar with the system design and operating parameters.

Risk modeling conducted in 2004 showed that the cost of conducting CCTV inspection on low-risk pipes exceeded the benefit gained by performing condition assessment, preventing a point failure (Martin, 2004). Therefore, SPU decided to perform CCTV inspection only on high-risk pipe (15% of total pipe) using a 5-year inspection frequency. Low-risk pipe was allowed to run to failure without CCTV inspection and repaired reactively. It is important to note that SPU's decision to run pipes to failure is not a universal recommendation but a utility-specific decision. Utilities that are operating under a consent order are not allowed to run pipe to failure. The following example illustrates the 2004 modeling results (Martin, 2004).

Example of Risk Modeling by SPU (Martin, 2004)

- 87-year-old pipe at 12-ft depth.
- Point repair costs predicted by model: $36,000.
- Probability of failure in the next 5 years: 5.9%.
- Risk cost of repair in the next 5 years: $36,000 x 5.9% = $2,100.
- Estimated life cycle cost of CCTV inspection assuming a 5-year frequency: $600.
- Risk cost > CCTV inspection cost (by a factor of 3.5).
- SPU's conclusion: Based on cost-benefit analysis, this pipe is high risk and should be inspected.

In 2007, SPU conducted an analysis to verify the accuracy of the existing predictive failure curves using actual sewer pipe failure and repair records (Martin et al., 2007). Based on anecdotal field reporting, CCTV inspection data and the number of scheduled and emergency repairs, the existing curves were suspected of over-predicting failure of most pipes and of poorly characterizing the failure modes of different pipe materials. The 2007 analysis included a review of 15 years of point repair data (1989 – 2004) for vitrified clay and concrete pipes, which represent more than 90% of SPU's sewer pipes. Study results indicate that vitrified clay pipes and concrete pipes incurred point failures at much lower rates than predicted by the existing failure curves. In the early 2000s, pipe failures due to material deterioration triggered about 150 annual repairs, compared to 800 annual repairs estimated by the predictive failure curves to be needed.

The 2007 analysis also found a statistically significant correlation between certain local conditions (steep slopes, clay soils and fill soils) and increased potential for pipe failure (Martin et al., 2007). For example, 86 actual pipe failures have been identified via inspection in 164,308 ft of clay pipe that is located on steep slopes. Based on pipe age, the existing predictive failure curves estimated that 50 failures would occur in these pipes. The observed failures exceeded the 95% confidence level of the prediction, therefore the model was judged inadequate.

As a result of this analysis, SPU identified the following action steps (Martin et al., 2007):

- Pipes on steep slopes, in clay or in fill should be assigned higher likelihood of failure multipliers in the risk model, resulting in higher risk scores and more frequent inspections in the future.
- Concrete pipes should be assigned a conservatively high predicted failure rate in the model in order to accelerate the inspection frequency because the predominant failure mode is expected to shift to structural failure in the near future.
- SPU will continue to conduct strength testing of existing sewer pipe segments to provide information on structural degradation trends of the sewer pipe network.

New failure curves were customized for SPU based on actual sewer pipe failure data and CCTV inspection data (Martin et al., 2007). Inspected pipes were first categorized according to their failure history. For Type 1 failures (pipes that failed prior to their first inspection date), the pipe's service life is not known exactly but can be estimated based on known dates for pipe installation and inspection. For

Type 2 failures (pipes that failed during the period between the first and second inspections), the pipe's service life can be estimated based on known dates for the two inspections, a narrower window than Type 1 failures. Pipes were then analyzed using a statistical parameter estimation method known as Maximum Likelihood Estimation to generate the new curves. This method finds the most likely failure curve for a dataset. The new failure curves are shown in Figure A-2 as a comparison to the existing curves.

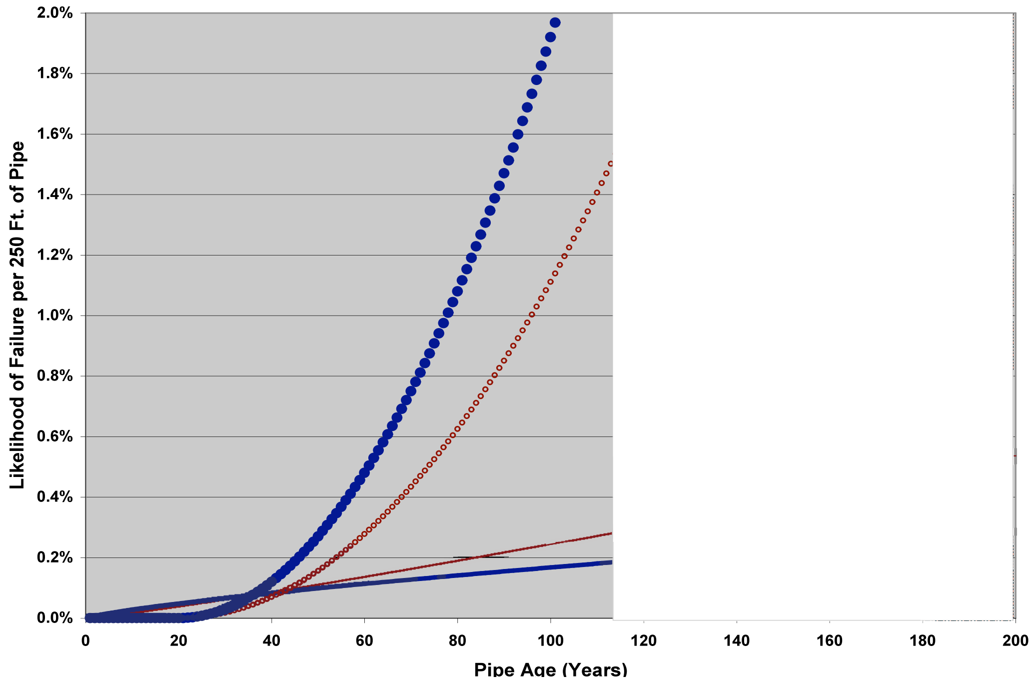

Figure A-2. Comparison of failure curves for vitrified clay and concrete pipe. Source: Martin et al. (2007). Reprinted with permission.

Recently, EPA conducted a system audit and determined that SPU should conduct CCTV inspections of all collection system piping within the next 6 to 7 years. To meet EPA requirements, SPU will conduct these system-wide CCTV inspections using the risk model to establish a risk-based inspection schedule. SPU will continue to improve the inspection program, balancing the need to maximize ratepayer value while meeting EPA requirements.

References

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Data Management Case Study – Huntsville, Ala.

Lessons Learned

Prior to applying an advanced asset management software tool, the City of Huntsville had no direct link between CCTV data and GIS data, which made locating and evaluating inspection data a difficult task. Huntsville has learned that it is important not only to link CCTV data to a map, but to also to integrate CCTV data with other inspection and repair data. When viewed together, the various data help “tell the story” of an asset and its condition over time.

While implementing this software tool, the city found many discrepancies in existing GIS and condition assessment records. These discrepancies were readily identified when GIS records and condition assessment records were compared. At first, this comparison created additional work to resolve discrepancies in existing records. However, the end result was a more accurate and accessible database of historical system conditions. Prior to implementing a similar program, other utilities should review the type of data needed for their asset management programs, including CCTV inspection data, and make sure that the asset numbers used are consistent with available GIS data.

Although the city has not yet achieved reductions in the cost of CCTV inspections or improved performance of CCTV crews as a result of implementing the new data management software, the city expects to realize cost reductions in the future as staff members become more proficient at data analysis and decision making related to prioritizing sewer lines for inspection. The new software has improved the accessibility to and dissemination of inspection data among city staff.

The city has also found that data management objectives change and expectations increase as staff members become familiar with the new software product and as initial objectives and expectations are met. The key is finding a solution flexible enough to change direction with the city’s evolving needs.

Background

The City of Huntsville provides sewer service to a total population of 170,000 within the city limits. It also serves the City of Triana and a small portion of the City of Madison. The average daily flow is about 22.7 MGD and is distributed to five wastewater treatment plants.

The first significant parts of the collection system were built in the late 1950s and early 1960s. Currently, the collection system includes over 1,250 miles of sanitary sewers, with an average age of 28 years. The system does not include any combined sewers. Sewers are constructed of a variety of materials, including vitrified clay, polyvinyl chloride (PVC), ductile iron, cast iron and concrete. Sewers range in diameter from 6 to 60 in.

Huntsville conducts CCTV inspections using two in-house crews. The inspections cost $0.95 per foot of pipe. A local contractor has also been retained for on-call work, and other contractors are used periodically as needed. The city does not use outside contractors frequently enough to establish typical unit costs. The city has conducted CCTV inspections for many years and continues these activities as an integral part of its asset management program. The average inspection frequency for sanitary sewers is about seven years.

CCTV inspections are conducted for a variety reasons, including acceptance of new sewers, O&M, and condition assessment. New sewers are inspected prior to acceptance and prior to the expiration of their warranty period. Existing sewers are inspected to investigate blockages and overflows, identify sources of I/I and facilitate repairs within the system. Sewers are also inspected in conjunction with other public works activities, such as road resurfacing projects.

CCTV inspections are conducted using analog-type cameras. Video images are recorded in a digital format on the CCTV trucks. The city has no digital or zoom cameras; however, it has taken an important step by incorporating CCTV inspection data and digital video files into a GIS-based application which allows managers and engineers to quickly review CCTV inspections in context with other inspection and repair data. Now, CCTV inspection data and video are easier to access, examine and compare with related data. This allows managers and engineers to better understand the condition of the system and plan and manage O&M and rehabilitation programs.

Summary of Data Management System

Pipe defects are coded in accordance with the PACP-certified inspection protocol. This provides data reliability. A second level of data reliability is the ability to validate that the CCTV data matches GIS data. CCTV inspection data are imported into a commercially available GIS-based asset management software application named InfoNet, developed by Wallingford Software (http://www.wallingfordsoftware.com/products/infonet/). Data are imported into InfoNet by city personnel via a PACP-compliant database. The import process uses several data queries to assess data quality and identify inconsistencies with existing GIS data. InfoNet is also used to import GIS data from the city's GIS Department and other inspection data and repair records from internal and external sources.

The city began using InfoNet in 2006, and it was first used to maintain and evaluate manhole inspection and smoke testing data from an outside contractor. Supporting CCTV inspection data from in-house crews were then added to develop a more complete condition assessment of the inspected areas. Since then, the use of InfoNet continues to expand.

Software/Hardware Requirements

Windows 2000 or XP is required to run InfoNet. Ten gigabytes of local free disk space are recommended for optimal use. The InfoNet master database is often maintained on a server and accessed by multiple users. Huntsville has not encountered any data storage limitations to date.

Software training is recommended for all new users, and further training is recommended for more advanced users. Annual software support includes software updates, as well as telephone and Web-based support provided by technical services representatives based in Fort Worth, Texas.

Costs

InfoNet user and viewer licenses are available, and the unit cost varies with the number of licenses that are purchased. Huntsville currently owns one user license and four viewer licenses. The user license was purchased in 2006 for about $15,000, and the annual support fee is about $2,500. The viewer licenses were purchased for about $6,000 each, and the annual support fee is about $900 per viewer license.

Advantages:

- "Off-the-shelf" software application.
- View CCTV inspection data in GIS-based environment.
- View CCTV inspection data in context with data from other sources.
- Powerful structured query language functionality to analyze data.

Disadvantages:

- Requires more proactive attention to maintain integrity of GIS data.
- May require minor modifications to existing data gathering procedures.
- May overwhelm new users until training is completed.

The InfoNet software application is now used by the Huntsville to maintain all CCTV inspection data and actively manage its in-house pipe cleaning program. With the addition of inputting sewer pipe cleaning records into InfoNet, the utility expects that this information will soon begin to drive CCTV inspection work. The application also serves as a repository for other inspection and repair data, including:

- Manhole inspection.
- Smoke testing.
- Sewer cleaning.
- Root control.
- Repair/rehabilitation.
- Customer complaints.
- SSOs.

CCTV data are used to help direct grease management and root control efforts, as well as on-going I/I reduction programs. CCTV data are also used to plan pipe replacement, pipe bursting and cured-in-place lining projects.

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Case Study on Comparison of In-House vs. Commercial Data Management System – Metropolitan Government of Nashville and Davidson County – Metro Water Services

This case study discusses the experience of Metro Water Services (MWS) (Nashville, Tenn.) in changing from an in-house data management and defect coding system to a PACP-certified commercial software product.

Lessons Learned

The change from an in-house data management and coding system to a commercial system and standardized coding has yielded several benefits. Under the new system, inspection data are now quickly uploaded and available to all MWS employees within 24 hours of inspection and hence duplicative inspection efforts are avoided. The Granite XP software allows MWS schedulers to know daily exactly which sewer lines have been inspected, and it eliminates the need to request hard copies of inspection data and manually update paper maps. Inspection results have been much more consistent with the addition of PACP coding. Initially, use of the PACP coding system decreased the department's productivity due to the staff's lack of familiarity with the system. As the staff has adjusted to the new system, productivity and efficiency have increased. The one disadvantage noted is that the PACP coding can be too detailed, making it difficult to get complete information when querying for problems.

Introduction and Background

Sewer construction in Nashville began in 1823 with the installation of brick and clay pipes to convey both storm water and sanitary sewerage to the Cumberland River. In 1884, a cholera epidemic precipitated the mass construction of sewers in Nashville. As Nashville and Davidson County's population grew, so did the sanitary sewer system. By 1950, the system had grown to nearly 400 miles of sanitary sewer serving a population in excess of 300,000. During the 1980s, Davidson County began an aggressive sewer expansion program to provide sanitary sewer service for the more densely populated areas of the county.

MWS is a department of the Metropolitan Government of Nashville and Davidson County (MGNDC), which provides drinking water, wastewater and storm water services. Today, MWS's sewer system serves an area of approximately 739 square miles. The system has approximately 2,740 miles of gravity sewer lines and 150 miles of force main. The gravity sewer lines range between 6 in. and 16 ft in diameter, with the majority of pipes having a diameter of 36 in. or less. The force mains range from 6 in. to 36 in. in diameter. A summary of pipe size and corresponding mileage is shown in Table A-5 (MGNDC, 2006).

Table A-5. Sewer system inventory

	Pipeline Length (miles)			
Type of Pipeline	**≤8 in.**	**10 in. to 24 in.**	**> 24 in.**	**Total**
Gravity Sewer	2,150	450	140	2,740
Force Main	60	60	30	150

MWS's collection system uses many types of pipe including vitrified clay, brick, PVC, concrete, cast iron and ductile iron. The system serves approximately 172,000 residential, commercial and industrial customer connections and a total population of 660,000. Approximately 92% of service connections are residential. The remaining 8% are commercial and industrial. There are also approximately 22,000 customer accounts in satellite municipalities or utility districts (MGNDC, 2006). Counties, municipalities and entities served by MWS include Davidson, Madison, Goodlettsville, Nolensville/College Grove and Lakewood.

MWS maintains and operates three wastewater treatment plants (WWTPs): Central WWTP, Dry Creek WWTP, and Whites Creek WWTP. The average daily flow of wastewater transmitted to the three wastewater treatment plants from August 2005 to July 2006 was 120.7 MGD (MGNDC, 2006). Estimated average daily flow for 2009 was 129.3 MGD. A large majority (93%) of MWS's sewer system is solely dedicated to sanitary sewerage, with a small amount (7%) of combined sewers located in downtown Nashville.

History of CCTV Use by MWS

MWS began using CCTV in the late 1960s to inspect gravity sewers. The utility first used a trailer-mounted CCTV unit that employed a manually operated winch to move the camera between manholes. MWS uses CCTV inspection for many reasons, including:

- Locate defects contributing to leaks during wet weather.
- Identify rehabilitation needs.
- Inspect after clearing line blockage.
- Identify restrictions and other causes of SSOs.
- Identify service locations.
- Investigate customer complaints.
- Conduct routine maintenance.

Currently, Nashville has six cameras with pan and tilt features and two zoom cameras. The city is in the process of replacing one camera that is 10 to 15 years old. MWS currently has a fleet of six CCTV truck units, which is maintained and operated by in-house staff. All inspection personnel have received full PACP Condition Grading System certification in order to ensure that standards are maintained. MWS uses outside contractors to inspect collection sewers larger than 60 in. in diameter.

Data Management

Inspection data were formerly documented using a labor-intensive process employing VHS tapes and handwritten inspection forms. The information was then coded in a separate step, which subjected the data to potential transcription errors. There was no ability to query historic VHS tapes to compare historic inspections of pipe segments or possibly compare inspections of similar pipe materials.

The department's first CMMS consisted of a Microsoft Access database, which allowed users to input, view, organize and code inspection data. MWS incorporated an internal (non-standardized) defect coding system with the database. The internal coding consisted of a 1 to 5 ranking system, with the number 1 meaning "like new condition" and the number 5 signifying "emergency repair needed." In addition, MWS scanned hand-written CCTV reports for inclusion in the database. Other information tracked in the CMMS includes date, time and location of routine cleaning activities; specific lines cleaned; equipment used; identity of cleaning crew; presence of roots, grease or debris; any specific problems; size, material and length of pipe; and manhole status.

The data management and coding system was designed in-house in the 1990s, based on industry standards at the time. The system served MWS well, but did not optimize the possibilities available with the current state of the technology. MWS recognized the need to expand its database management to aid in condition assessment. In 2006, MWS completed a CMOM report, allowing MWS to evaluate its internal processes and programs. MWS recognized that its current system had several problems:

- The internal defect coding lacked consistency; a segment of pipe inspected by several employees could be given different ratings by each person.
- Data could not be easily viewed by all personnel; most MWS personnel had to file a request to obtain any information from the database.
- MWS was not able to use digital video technology that was available; instead, it was limited to scanned still photographs.

The CMOM report included the following recommendations regarding CCTV inspections, data management and defect coding:

- Develop and implement standard line condition codes (1 to 5) for use when televising sewer lines. These codes will be manually recorded on TV Inspection Reports.
- Evaluate the software available for entering standard defect codes from guidelines into CMMS.
- Develop a written standard method of prioritization of all assessment practices.
- Evaluate ways to prioritize the frequency of CCTV inspection for various sewer categories. For example, new PVC sewers may be inspected less often than old clay and brick sewers.
- Purchase software for TV units that will allow priorities to be entered into the CMMS.

MWS has made major changes to its sewer inspection program in the past three years. MWS replaced its in-house data management software and inspection coding system with the commercial Granite XP software (from CUES) and a Hansen-based CMMS, using PACP criteria that provide a standardized method for defect coding. The new platform provides MWS with the ability to conduct queries such as comparing multiple inspection results of a particular pipe within the past five years. Query results are available very quickly and can help MWS determine the root cause of a pipe defect (e.g., pipe material, pipe age, installation conditions).

Granite XP is a flexible and customizable data collection and management software platform that integrates CCTV data with MWS's asset and maintenance management data (Hansen software) and GIS data (ESRI's ArcGIS software). Hansen provides a wastewater network browser, which stores information and allows it to link items such as maintenance records, complaints, work orders and inspection reports. The combination of Granite XP and Hansen software permits users to navigate particular assets and view all inspections. A work order is generated in Hanson and required resources are selected (labor, equipment, materials). The GIS information is queried and the inspection can proceed. The data are saved and coded directly into the system. This automates the entry information and provides the utility with the information needed for decision making. Granite XP has a business licensing agreement with Hanson and ESRI to work directly with both software platforms.

GraniteXP has many features that MWS considered substantial improvements over its previous system, including the ability to:

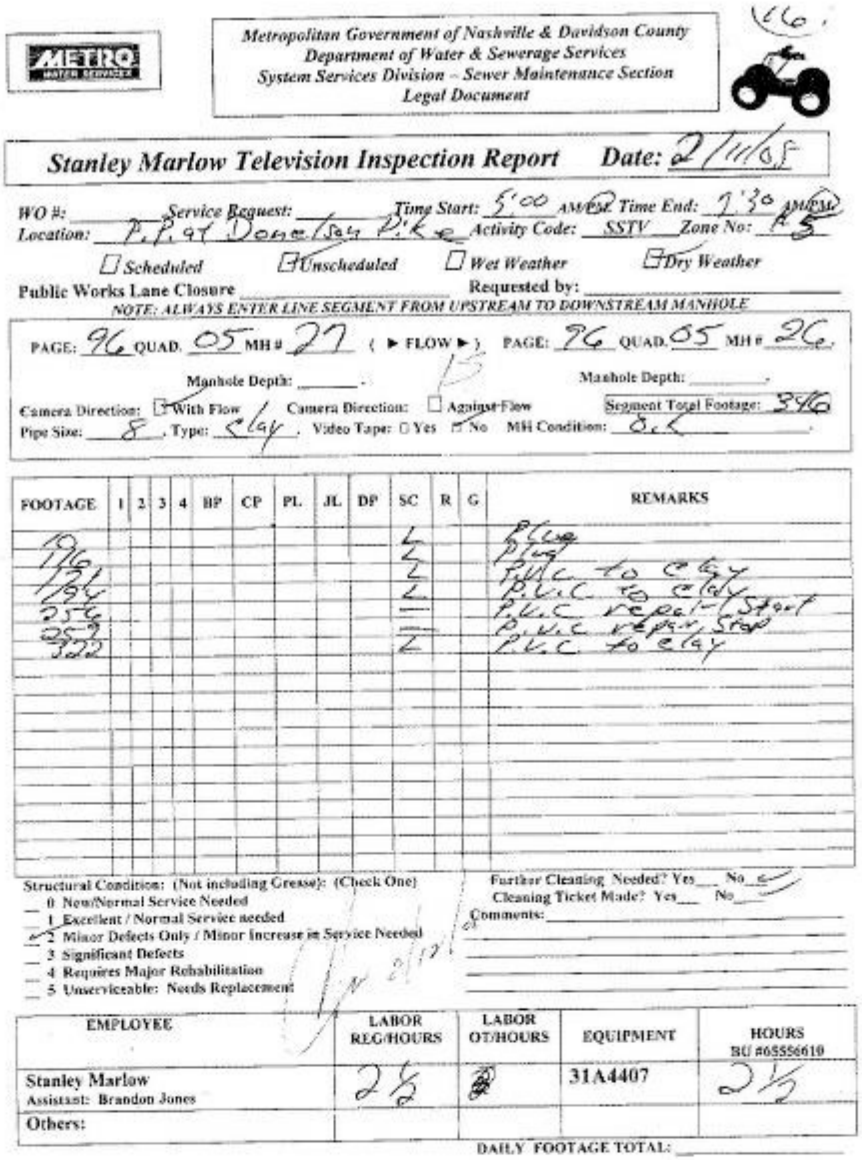
- Import ESRI asset data into Granite XP from a master GIS database.
- Create custom reports that can be saved in PDF, HTML or ASCII file format.
- Search using keyword and filtering capabilities by projects, assets, inspections and observations.
- View video and still images simultaneously.
- Select an observation on a pipe graph and instantly access that point in a video.

Granite XP has four editions available to meet the needs of the individual users. A brief description of each edition is given below (further information can be found on the Internet at http://www.cuesinc.com/Granite-XP.html):

- The Inspection Edition is designed for field use and is often integrated with camera systems to capture, assess and store inspection data. MWS has five Inspection Edition licenses, allowing the CCTV crews to upload and submit each day's inspection data on a flash drive.
- The Enterprise Edition allows users to manage inspection information and create customized reports, videos, still pictures and database files. It can be useful for preparing data for applications such as GIS and PACP coding. MWS has one Enterprise Edition license, allowing a staff member to maintain, update and manage the system.
- The Engineering Edition allows users to modify and review data, synchronize inspections, capture images from playback and generate reports. MWS's three Engineering Edition licenses allow selected personnel to input daily CCTV data obtained by the inspection crews.
- The Viewer Edition allows users to review and share field data and generate reports. MWS has licensing for over 50 Viewer Editions.

MWS has found its licensing to be sufficient to meet the department's needs. Every MWS employee has instant access to view anything within Granite XP. Although Granite XP allows for internet transmission of data through a wireless server, MWS has chosen to use flash drives instead.

Figures A-3 and A-4 are examples of reports prepared using the in-house system and Granite XP, respectively. Compared with the older handwritten version, the Granite XP report presents inspection data in a concise, consistent, easy-to-read format. The report can be quickly viewed by the reader for the most crucial information, improving efficiency.



METRO WATER SERVICES

Metropolitan Government of Nashville & Davidson County
Department of Water & Sewerage Services
System Services Division – Sewer Maintenance Section
Legal Document

Stanley Marlow Television Inspection Report Date: 2/11/05

WO #: ____ Service Request: ____ Time Start: 5:00 AM/PM Time End: 7:30 AM/PM
Location: P.P. 97 Donelson Pike Activity Code: SSTV Zone No: A5

☐ Scheduled ☑ Unscheduled ☐ Wet Weather ☑ Dry Weather

Public Works Lane Closure ____ Requested by: ____

NOTE: ALWAYS ENTER LINE SEGMENT FROM UPSTREAM TO DOWNSTREAM MANHOLE

PAGE: 96 QUAD. 05 MH # 27 (► FLOW ►) PAGE: 96 QUAD. 05 MH # 26

Manhole Depth: ____ Manhole Depth: ____

Camera Direction: ☑ With Flow Camera Direction: ☐ Against Flow Segment Total Footage: 346
Pipe Size: 8 Type: clay Video Tape: ☐ Yes ☑ No MH Condition: O.K.

FOOTAGE	1	2	3	4	BP	CP	PL	JL	DP	SC	R	G	REMARKS
19										L			Plug
176										L			Plug
181										L			PVC to clay
184										L			P.V.C to clay
256													P.V.C repair Start
259													P.V.C repair Stop
322										L			P.V.C to clay

Structural Condition: (Not including Grease): (Check One)
- 0 New/Normal Service Needed
- 1 Excellent / Normal Service needed
- ✓ 2 Minor Defects Only / Minor Increase in Service Needed
- 3 Significant Defects
- 4 Requires Major Rehabilitation
- 5 Unserviceable: Needs Replacement

Further Cleaning Needed? Yes__ No ✓
Cleaning Ticket Made? Yes__ No__
Comments: ____

EMPLOYEE	LABOR REG/HOURS	LABOR OT/HOURS	EQUIPMENT	HOURS BU #65556610
Stanley Marlow Assistant: Brandon Jones	2½	2	31A4407	2½
Others:				

DAILY FOOTAGE TOTAL: ____

Figure A-3. Sample inspection report for in-house data management system. Image courtesy of Nashville MWS.

CUES, Inc.
3600 Rio Vista Avenue
Orlando, FL 32805
Phone: 407-849-0190
Fax: 407-425-1569

GraniteXP Observation Report with Still Images

Mainline ID:	Project Name:	Started:	Weather:	Operator:
SMH-075-14-090 - SMH-075-14-080	HERMITAGE	12/3/2008 8:00:41 AM		BOWME

Upstream node:	Downstream node:	Length:
075-14-090	075-14-080	242.4

Comments

Observations

Distance	Length	Code	Reversed	Clock Pos.	Severity	Comment
6.0		START DS	No	/		
34.1		TFA	No	9 /		
75.2		TFA	No	9 /		

Observations

Distance	Length	Code	Reversed	Clock Pos.	Severity	Comment
148.1		B	No	3 /	04	

Distance	Length	Code	Reversed	Clock Pos.	Severity	Comment
242.4		STOP	No	/		

Figure A-4. Sample inspection report created using GraniteXP software. Image courtesy of Nashville MWS.

The PACP, developed by NASSCO, provides a mechanism for creating reliable descriptions of pipe conditions. The goal of PACP is to provide the ability to quantitatively measure the difference in pipe condition between one inspection and subsequent inspections, and to prioritize among different pipe segments. PACP uses a basic coding method based on a grade of 1 to 5. A grade of 1 is assigned to pipes with only minor defects, and a grade of 5 is assigned to pipelines with defects needing immediate attention. Table A-6 gives the grades and corresponding descriptions within the PACP system.

Table A-6. PACP defect grades

5	Immediate Attention	Defects requiring immediate attention.
4	Poor	Severe defects that will become grade 5 defects within the foreseeable future.
3	Fair	Moderate defects that will continue to deteriorate.
2	Good	Defects that have not begun to deteriorate.
1	Excellent	Minor defects.

MWS is currently on schedule to inspect all of their sewers within an 8-year period. Due to the recent deployment of Granite XP software and implementation of PACP coding, MWS has not finished the first full round of inspections.

MWS has historically used a comparison of identified defects with the cost/difficulty of the anticipated rehabilitation. For example, when a single pipeline defect is identified, MWS will call for a point repair to physically correct the defect. Utility staff will typically do two point repairs on a line segment, but once three or more defects are noted, MWS moves towards rehabilitation of the entire line. Entire pipeline rehabilitation is typically done with cured in-place liners, although other methods have been used in the past. The service line from the mainline sewer to the property or easement line is rehabilitated at the same time. MWS has occasionally rehabilitated a line with only one or two defects if the line is under a busy roadway where the dig and repair methodology is costly and has a high impact on the public. The new software and coding system has not changed MWS's approach to rehabilitation, but it has facilitated the process. The Granite XP software has made it easier to search for pipes that are in need of repair. The use of a standardized defect coding system such as PACP coding allows MWS staff, consultants and other external data users to easily compare MWS with other systems data without need to learn their particular defect coding system.

Since the conversion to Granite XP and PACP coding, MWS has noticed a substantial increase in consistency and efficiency. Listed below are several reasons for the noted increase.

- **Improved turnaround time on data:** Inspection crews bring in their flash drives at the end of each business day and upload data to the system. This allows all videos, still photographs and condition reports to be available to all MWS personnel within 24 hours of an inspection.
- **More efficient inspection scheduling:** The Granite XP software allows MWS schedulers to know exactly which sewer lines have been inspected on a day-to-day basis. Inspection crews no longer double up on inspections because of the time delay of inputting data and using it for daily operations. Under the previous system, a paper map was used to track completed inspections. Sewer lines not marked on the map were considered available for inspection. In some instances,

maps were not kept current with inspections, resulting in the re-inspection of sewer lines that had been recently inspected.

- **Instant access of database:** All MWS personnel now have instant access to all information within the database from their computer. In the past, MWS personnel had to request database information and wait for it to be printed and distributed.
- **Standardized coding:** The PACP coding and the corresponding personnel certification have greatly improved the consistency of the CCTV inspection reports.

As part of its Corrosion and Odor Control Program, MWS uses its CCTV inspection program to monitor pipe corrosion from industrial entities. MWS compares CCTV data from previous inspections to locate areas experiencing unusual levels of corrosion. In addition, MWS is attempting to track the origin of corrosive damage within the sewer collection system and is working on a program that will ensure the accountability and responsibility of industrial entities that may be damaging the system.

Considerations for New Users

MWS cautions potential new users to expect a significant drop in productivity when first implementing a new CMMS and defect coding system. Although MWS staff is highly experienced, the change of both a new software package and a new coding system initially caused confusion. Employees would need to reference software and PACP manuals in order to complete tasks that had previously been completed in moments. MWS noted that productivity increased relative to the old system once its personnel adjusted.

MWS would also advise any utility interested in implementing a new data management system to provide software training to multiple employees. MWS initially assigned one staff member to be solely responsible for managing the entire database. MWS has since realized that this was a mistake and has begun training several other staff members.

The only disadvantage to the new system of data management noted by MWS is that the system can be too detailed. Within the PACP system are multiple levels of coding for defects such as roots, cracks, and breaks. This has created complications in querying for problems. For example, if the user performs a search for "roots," only a small portion of the actual root problems within the collection system may be identified. The others defects may be categorized as "root balls," "root clusters," or another detailed name that describes the same problem. MWS is currently working to adjust its queries accordingly.

References

Metropolitan Government of Nashville and Davidson County, Tennessee (MGNDC). (2006). *EPA CMOM Self-Assessment Report.*

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Case Study on Use of Digital Scanning and Zoom Camera Technology – City of Hamilton, Ontario, Canada

This case study discusses the experience of the City of Hamilton in using digital scanning and zoom camera in its sewer condition assessments.

Lessons Learned

The City of Hamilton makes strategic use of a variety of sewer inspection methods to provide information for making decisions on infrastructure management. Zoom cameras are used for system-wide inspections and are useful for selecting pipes that need more detailed inspection. Although a zoom camera provides less detail than CCTV, it is an acceptable tradeoff for its lower cost and faster inspection time. For pipes requiring additional inspection, an array of methods is available, including digital scanning. The level of detail acquired by scanning is superior to CCTV. However, Hamilton has only used digital scanning to a limited degree because of the cost and pipe size limitations. Hamilton recently received indications that its contractors may now be able to scan larger pipes, and may also be able to offer costs comparable to CCTV. This may increase the role that digital scanning plays in Hamilton's inspection strategy. Hamilton's experience shows the value of selecting methods with different costs and different levels of detail according to need. The city's ongoing experience also illustrates that newer technologies such as digital scanning will continue to evolve, and the costs of such technologies may become competitive with traditional CCTV.

Background

The City of Hamilton's Water and Wastewater division provides drinking water and wastewater services to a population of 520,000 in Hamilton, Ontario. The system handles, on average, 111 MGD, with a maximum peak flow of about 159 MGD. The system has a total of 2,700 km (1,678 miles) of sanitary, combined and storm sewers. The 21% of the system (580 km or 360 miles) is combined; 41% (1,100 km or 684 miles) is sanitary sewer and 38% (1,020 km or 634 miles) is storm sewer. The system also has 45 km (28 miles) of force mains. The system dates back to 1850; its average pipe age is approximately 59 years. The system has many deep, critical sewers of large diameter. Pipe materials include clay, concrete, reinforced concrete and brick. Pipe diameters range from 200 mm (8 in.) to 2,500 mm (100 in.).

Overall Inspection Strategy

Zoom camera technology is used to scan the entire system, and inspection results are then used along with Hamilton's risk-based decision management strategy to prioritize pipes for further inspection. The selection of additional inspection technologies depends on the level of accuracy and detail needed for the particular pipe under consideration. A number of additional technologies are used after the completion of baseline zoom camera inspections: CCTV, sonar, laser and digital scanning (limited application). New technologies applicable to wastewater applications are actively investigated and their limitations considered. Several inspection methods may be needed in order to achieve the desired level of accuracy for assessing the condition of critical pipes. The use of advanced technologies such as sonar and laser can be expensive ($15 – $30 per meter or $4.57 – $9.14 per foot, in Canadian currency).

Experience with Digital Scanning

In 2006, Hamilton participated in a pilot test of digital scanning using the SSET system manufactured by Blackhawk-PAS. This product is no longer available commercially, and technical support is no longer available. At the time of the pilot test, SSET was the only available digital scanning system. New products have since emerged in North America (PANORAMO, Digisewer). Since performing the pilot test, Hamilton has used digital scanning twice on critical pipes (15 in. (375 mm) clay pipe and 24 in. (600 mm) concrete pipe) and has been very satisfied with the results. The digital scanning inspection was performed by a contractor. Pipe defects observed during the inspection are coded using the WRc third edition defect coding standard. Data are stored and maintained in a CMMS. Staff training is the same as for CCTV; inspectors must be NAAPI (North American Association of Pipeline Inspectors) certified, which entails training in defect coding in much the same way as PACP.

SSET uses a fisheye lens mounted on the front of a crawler or tractor unit. The annular segment around the edges is scanned and used to produce an unfolded view of the pipe. The unit travels through pipe at a constant speed of about 13 ft per minute (additional information can be found on the Internet at http://www.hydromaxusa.com/sset.html). White LEDs are used for a light source, providing a bright light that is close to natural light (Karasaki et al., 2001). The unit also includes an inclinometer and a gyroscope, which permit recording of vertical and horizontal movements, helping to accurately locate the unit within the pipe (Knight et al., 2009). This facilitates tracking of defects through time. Digital scanning produces a high level of imaging, picking up more detail than CCTV. It permits the reviewer to code defects that might not be visible with CCTV. This greater detail also allows a better understanding of the significance of a defect, rather than only documenting its existence.

The primary drawback with the SSET equipment has been that its effectiveness is limited to small pipes. Hamilton has only successfully inspected pipes up to 600 mm (24 in.) in diameter. Although the SSET system has been most effective in small pipes, highly detailed inspections are not needed for the smaller pipes because their cost of failure is lower than that of larger diameter pipe. The additional cost of performing digital scanning has not been justifiable. In larger, more critical pipes, a greater level of detail is needed, but SSET is not effective in these larger pipes due to problems with focal length. Based on communications with Hamilton's contractor, digital scanning is now being used for pipes up to 5 ft in diameter. One issue remains: SSET has problems with pipes that are not circular, and many of Hamilton's larger, critical pipes are oval in shape.

Cost has driven Hamilton's decisions regarding the use of digital scanning rather than CCTV. In its experience, the field costs are not greatly different than for CCTV because the digital scanner moves more quickly through the pipe. However, the net cost was greater due to the data processing conducted in the office. With CCTV, defects are observed and coded in the field. With digital scanning, images are reviewed and coded in the office, increasing the overall time and labor cost associated with this technology. Utilities considering digital scanning are encouraged to compare the costs of digital scanning versus CCTV and make sure that any potential added costs can be rationalized. The cost of inspection should be weighed against the cost of pipe failure. If net costs are as low as for CCTV, then digital scanning would be the method of choice due to its superior level of detail. Hamilton's contractor recently indicated that digital scanning may now have a cost comparable to CCTV. The improved cost, along with an improved ability to inspect larger pipes, may enable Hamilton to use digital scanning in more of its system. Hamilton will be exploring this possibility.

Experience with Zoom Camera Technology and Comparison to CCTV

Based on 10 years of experience, Hamilton has found zoom cameras to be a very effective and economical inspection method and uses the results to decide where to employ CCTV and other advanced inspection methods. As of May 2008, zoom camera inspections had been completed on 1,441 km (about 895 miles) of main pipelines (about 55% of the network) (Bainbridge and Krinas, 2008). Although zoom camera technology provides a lower level of detail than CCTV, Hamilton has found that it identifies enough pipe defects to provide a basis for focusing CCTV and other inspection work.

Unlike CCTV, a zoom camera does not move through the sewer system. It is lowered into a manhole chamber, where it remains stationary, rotating 360° along its vertical axis. It is used to inspect all the sewers that enter the manhole chamber. Each pipe segment gets viewed twice, once from the manhole at each end, resulting in two ratings for each pipe segment. As with CCTV, Hamilton's zoom camera defect coding is completed using the WRc third edition.

The viewing distance depends on such factors as pipe deflection, debris, and other obstructions. Based on zoom camera inspection of 23,566 manholes and associated piping in Hamilton, Bainbridge and Krinas (2008) found the average inspection distance was 30 m (98 ft); the associated range of pipe sizes was not provided. The zoom camera cannot see around horizontal deflections (i.e., bends) in pipes; therefore, if there are a significant number of bends without access points, the utility of the zoom camera may be limited. Sewers do not need to be cleaned in advance of a zoom camera inspection.

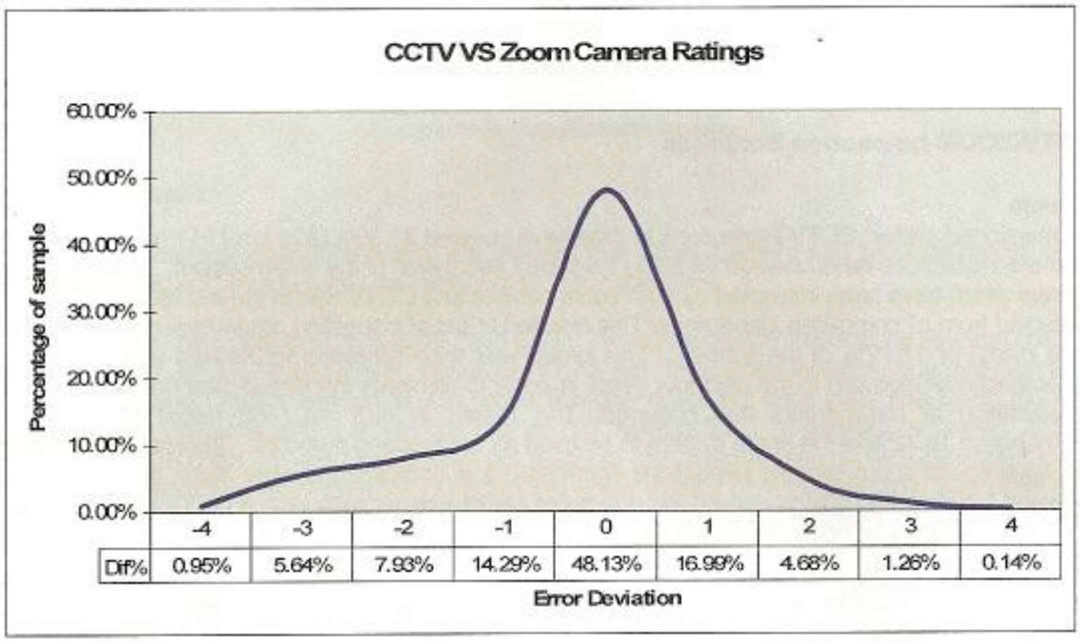
Table A-7 compares the average price and other parameters for CCTV vs. zoom cameras. The zoom camera technology is several times cheaper than CCTV, and it can inspect pipes much faster. Using a zoom camera, Hamilton's system can be surveyed in less than half the time that would be required for traditional CCTV.

Table A-7. Comparison of traditional CCTV with zoom camera technology

Technology	Adjusted Inventory, m (miles)	Average Price/m (Canadian dollars)	Funding Requirements (Canadian dollars)	Average Production Rate (Meters/day/crew)	Time Required to Inspect 100% of Sanitary Sewers (years)[a]
Traditional CCTV	2,566,000 (1,594 miles)	$5.74	$14,728,840	700 m (2,297 ft)	10.0
Zoom Camera	2,566,000 (1,594 miles)	$0.977	$2,506,982	1,875 m (6,152 ft)	3.8

Source: adapted from Bainbridge and Krinas, 2008, and used with permission
[a] Based on 365 work days per year.

Hamilton has been able to compare the results of inspections in pipes that have undergone both CCTV and zoom camera inspection. This analysis provides some understanding of how the two methods differ. Figure A-5 shows the results of a statistical analysis of condition ratings from CCTV and zoom camera inspections. It was found that zoom camera and CCTV inspections resulted in the same ratings (zero on the X axis in Figure A-5) approximately 48% of the time. The assessments differed by a condition rating of 1 about 31% of the time.

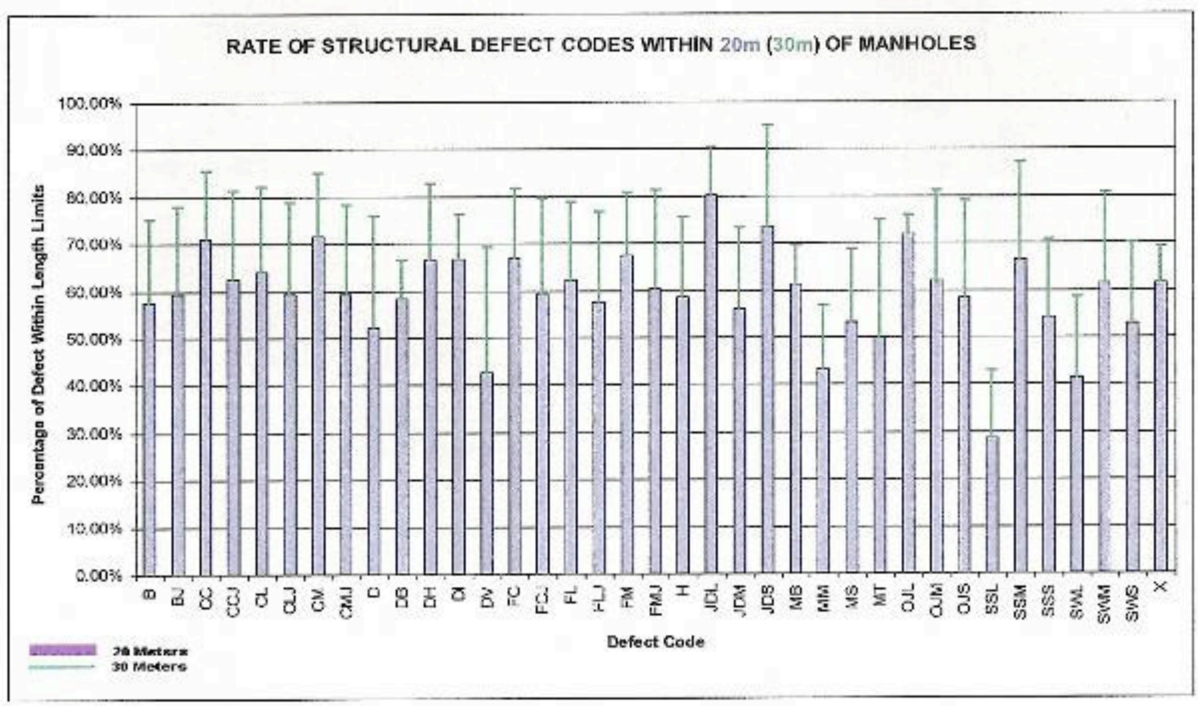


Source: Bainbridge and Krinas (2008). Reprinted with permission.

Figure A-5. Comparison of CCTV and zoom camera inspections.

As another means to assess the accuracy of zoom camera technology, CCTV data were used as a basis to determine how many defects were located within the zoom camera's functional range. Figure A-6 (Bainbridge and Krinas, 2008) shows the percentages of defects located within 20 m (66 ft) (purple bars) and 30 m (98 ft) (green lines) of manholes. The x-axis indicates the defect type. About 59% of defects were found within 20 m (66 ft) of manholes and 76% were within 30 m (98 ft). This analysis provides some indication of the percentage of defects that are likely to be detected because of their proximity to the camera.

Bainbridge and Krinas' (2008) analysis suggests that zoom camera technology may not be as accurate as CCTV. However, Hamilton has found the level of accuracy sufficient for its sewer management strategy. Hamilton's zoom camera inspection program has resulted in more than 5,000 work orders and beneficial economic and social impacts.



Source: Bainbridge and Krinas (2008). Reprinted with permission.

Figure A-6. Pipe defect location.

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Case Study on Application of Truck-Mounted Zoom Cameras – Hillsborough County Water Resource Services, Florida

This case study focuses on the experience of Hillsborough County Water Resources Services (WRS) in using a truck-mounted zoom camera along with in-line CCTV as part of a two-year comprehensive manhole and gravity sewer inventory and condition assessment project.

Lessons Learned

WRS has gained valuable experience from its successful condition assessment project. Lessons learned include the following:

- If a large-scale project assessment is proposed, a pilot project demonstration of the field and office procedures should be conducted to ensure that proper procedures and appropriate quality assurance and quality control data protocols are in place.
- Using zoom camera technology as the first step in field review has proven to be effective, both for acquiring technical data in a timely manner and for maximizing cost benefits.
- Regular communication with customers is critical for large-scale field-intensive projects. It is important to clearly define the authority the contractors have in the field in dealing with customers.

Utility Background

WRS provides water, wastewater, and reclaimed water services to approximately 483,000 customers in unincorporated Hillsborough County, Fla., with minor overlap areas with the cities of Tampa and Temple Terrace. Located northeast of Tampa Bay on the central Gulf Coast of Florida, WRS was formed in the 1970s by purchasing and centralizing many small franchise utilities. In the early 1980s, WRS undertook a major construction program to regionalize the system into two service areas, eliminating many franchises. At the time the project was initiated, the county was growing at an annual rate of 3 to 4 %. WRS currently manages infrastructure worth more than $1.2 billion.

The county's wastewater systems consist of one secondary wastewater treatment plant and six advanced wastewater treatment plants with more than 692 pumping or lift stations. The annual average daily flow is 36.4 MGD. The collection system includes 655 miles of force mains and approximately 1,268 miles of gravity sewer pipelines ranging from 4 to 42 in. in diameter. The sanitary system is 100% separate from the storm water system. Although parts of the system are very old, the average age of the entire system is close to 25 years, with a remaining useful life of 15 to 20 years. Eighty percent of the gravity sewers are constructed of PVC and 20% are vitrified clay pipe (VCP). The system also includes approximately 31,045 manholes constructed of pre-cast concrete (88.3%) and brick (10.2%) (Kirby et al., 2008). The PVC pipe has an average age of approximately 20 years and an estimated remaining useful life of 40 to 50 years. The average age of the VCP pipe is approximately 40 years.

In 1998, WRS decided to change from a reactive run-to-failure management approach to a proactive approach. A 20-year capital improvement program was established through rate increases and refinancing plans in order to rehabilitate, repair or replace assets known to be at imminent risk of failure. In 2003, WRS began development of a Comprehensive Asset Management System (CAMS) program to address its aging infrastructure, to develop a proactive maintenance program and to address the problem of having a wide assortment of software systems that did not communicate with each other. A CMMS was selected as the backbone of the CAMS. In order to populate the CMMS with accurate and comprehensive data, inventory and assessments of all WRS assets were undertaken. The evaluation was broken down into two parts: above-ground assets at plant or pump station sites, and linear assets of the collection and distribution system. The assets were further broken down into manholes and gravity pipes; hydrants, valves and large meters; plant and pump station equipment; and pressure pipes.

Project Objectives

In May 2006, the utility began a two-year comprehensive manhole and gravity sewer inventory and condition assessment project. The principal objectives of the project were to:

- Locate all manholes (on road, off road, and in easements) and cleanouts with survey-grade GPS coordinates.
- Inspect all manholes and pipelines.
- Find the immediate maintenance and structural needs.
- Clean and obtain detailed information about structural defects in manholes and pipelines requiring attention in the short term.
- Establish the maintenance and structural condition of each asset.
- Provide GIS and CAMS attributes in a format easily integrated into the existing software databases.

Project Approach and Planning Steps

Knowing that the collection system was relatively new and constructed mostly of PVC pipe, WRS anticipated that its gravity sewer system was generally in good condition. Based on CCTV inspections conducted from 1973 to 1998 using analog cameras, WRS estimated that only about 20% of the gravity sewer system would require maintenance or structural improvement.

An investigation of new inspection technologies was conducted to see if costs and time could be saved by employing new technologies or condition assessment processes. WRS chose to use a combination of zoom camera and in-line CCTV inspection technology and to use a third-party inspection company, InfraMetrix LLC of Tampa, to locate immediate maintenance and structural defects and to document with video the maintenance needs and structural condition of manholes and pipelines. According to InfraMetrix, inspection with zoom camera technology was four times faster than conventional in-line CCTV and was less expensive. Conventional in-line CCTV was used to inspect only pipelines that had failed or where failure was imminent and to provide important condition information for future maintenance and capital planning.

Prior to initiating fieldwork, InfraMetrix developed an implementation plan that included descriptions of the project procedures and protocols. The plan was submitted for county approval. The implementation plan was tested on a pilot scale to demonstrate the efficacy of the field and office procedures and to allow the WRS to modify the plan before a significant amount of data were collected. The pilot program began in September 2006 and involved inspections of 1,000 manholes and connecting pipelines.

One of the greatest challenges of the project was to develop and implement an efficient and effective strategy for data management. During the pilot project, daily procedures and software applications were developed to manage collected survey, inspection and condition assessment data. To ensure compliance with existing county systems, InfraMetrix conducted a number of data source reviews and process design sessions with WRS and its program manager. Using input from these sessions, procedures were developed to manage data for the duration of the project (Kirby et al., 2007). Quality assurance/quality control (QA/QC) protocols were applied to the survey-grade GPS coordinates, and in-house QA/QC procedures were performed to check the quality of physical characteristic, inventory, and condition of the data. Based on the results of the pilot project, minor refinements were made to customize the field and office procedures to best fit the county's needs (Kirby et al., 2007).

Inspection Program

The assessment portion of the project included inspection of gravity sewers with zoom camera and standard in-line CCTV inspection technology, where warranted, to collect physical attribute and condition data. The initial inspections were conducted using zoom camera technology from street level. Manholes and pipelines located within the right-of-way and within 400 ft of the right-of-way were inspected using truck-mounted zoom camera inspection equipment (see Figure A-7). Manholes and pipelines located more than 400 ft beyond the right-of-way were inspected using a tripod mounting for the zoom camera instead of the truck-mounted boom and mast.

Source: CUES, Inc. (2009). Reprinted with permission.

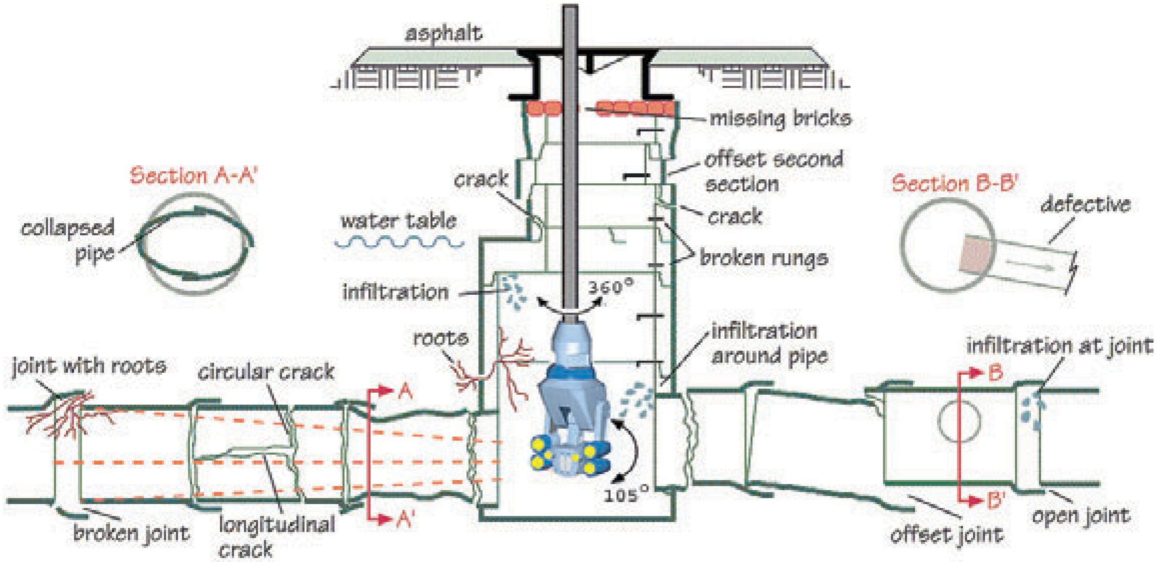
Figure A-7. Truck-mounted zoom camera.

Source: CUES, Inc. (2009). Reprinted with permission.

Figure A-8. CUES-IMX optical zoom camera.

The CUES-IMX camera (Figure A-8) has a 25:1 optical zoom lens that is stabilized and remotely controlled by a telescopic boom. The camera mounting fork is designed to pan the camera head 360° continuously, tilt mechanically 45° up or 90° down and tilt optically 166°. The CUES-IMX system includes the camera, high-intensity discharge (HID) lighting heads, mast system and controller. According to vendor literature, the CUES-IMX camera can view up to 75 ft of 6-in. diameter pipe segments; however, the reader is advised to verify such claims with field data. More information on the technology can be found on the Internet at http://www.inframetrix.com and http://www.cuesinc.com.

Figure A-9 shows how the zoom camera is inserted in the manhole and the types of pipe defects that can be identified.



Source: InfraMetrix LLC (2008). Reprinted with permission.

Figure A-9. Examples of pipe defects identified with zoom camera technology.

The software and GPS equipment in the zoom camera truck are used to create sewer maps in the field, locate defects, and capture video and photographic documentation of the condition of the sewer system. Inspection data are geo-referenced to GPS coordinates collected in the field. Video records of manholes or other vertical structures and pipelines are provided on graphically indexed CD-ROMs, DVDs, or hard drives linked to the GIS maps.

According to the vendor, the cost to inspect manholes or other buried structures starts at $45 per structure. Prices vary based on location, depth, and required deliverables. Because zoom camera inspections do not require confined space entry or pipe cleaning prior to inspection, more pipe footage can be inspected for less money than by using other inspection methods. The vendor claims that pipeline inspection with zoom camera technology can be performed for about one-third of the cost of in-line CCTV. A utility should budget $1.00 to $2.00 per linear ft for a system-wide gravity sewer assessment. This cost will cover collecting GPS coordinates for manholes, mapping, inspection of manholes and pipelines by zoom camera, data management (creating/updating GIS and work order management databases to include physical characteristic data and condition data), cleaning and performing in-line CCTV inspection of pipelines that require immediate attention and prioritizing future inspection, maintenance, and repair/rehabilitation activities.

Following completion of the pilot-scale program, the countywide program was initiated in January 2007, beginning in the northern- and southern-most extremities of the county and moving toward the center. Five work crews inspecting an average of 30 manholes and connecting pipelines per day per crew were needed to complete the project in the two-year timeframe. According to InfraMetrix, a two-man crew can inspect approximately one mile of pipe per day with manholes and about two miles of pipe per day without manholes. A typical manhole and pipeline inspection can be performed in 15 to 20 minutes, according to the company.

To determine the internal condition grade for each pipeline, a team of PACP-certified viewers reviewed the manhole and pipeline videos produced from both zoom and in-line CCTV cameras. The viewers considered safety issues, structural defects, evidence of previous I/I, active infiltration sources, and debris accumulation recorded by the video cameras to determine an internal condition grade for the manholes and pipelines. This assessment was done in accordance with the defect codes for a modified MACP for manholes and PACP for pipelines developed by NASSCO. Each manhole and pipeline was given an internal structural condition grade and an O&M and construction condition grade. Data were stored using SPL Enterprise Asset Management Software.

An external condition grade was assigned to each manhole and pipeline considering soil conditions, evidence of surcharging, depth to water table, evidence of previous failure, pipe slope and depth, evidence of subsidence, evidence of corrosion, location (e.g., grass, pavement, near wetlands), evidence of surface depression, and difficulty to access.

All pipelines determined to have a PACP condition grade of 3 or higher were recommended for cleaning and further inspection with conventional inline CCTV equipment. These recommendations were submitted monthly to the county's program manager for review and approval of the work. These pipelines were cleaned and inspected during the project, resulting in no pipelines with an O&M grade equal to or greater than 3 at the completion of the project. Approximately 1,500 manholes were scheduled for rehabilitation.

The sewer system was found to be in better condition than expected. This resulted in significant savings, which allowed InfraMetrix to provide additional support including:

- Developing a standardized manual that includes procedures for data collection, cleaning and CCTV, and emergency responses.
- Providing recommendations for job codes for generating work orders from the MACP and PACP defects.
- Developing a methodology for prioritizing future maintenance and capital improvements.
- Determining useful life and remaining life for the manholes and pipelines.
- Providing manhole and pipeline improvement recommendations.
- Presenting the findings and conclusions in a report on maintenance and capital planning.

The project was completed approximately $1 million under budget. These funds were set aside to pay for the rehabilitation of manholes and pipelines assigned a structural condition grade of 4 or 5. WRS estimated that it saved approximately $11.4 million and 3,200 crew days with the inspection approach combining zoom camera technology and in-line CCTV.

The video information and physical characteristics captured in the inspection data were used to develop proactive O&M and capital improvement programs for pipe renewal and replacement and to improve the accuracy of hydraulic models. As an added bonus, the video inspection files provide an accurate visual condition assessment that can be used in case a hurricane leads to debris accumulation or structural damage in the sewer system. The information can be used when applying for Federal Emergency Management Agency (FEMA) disaster reimbursement.

The schedule and inspection frequency of future manhole and pipeline inspections are based on the risk of failure. This risk evaluation is based in part on a risk score, calculated by multiplying the condition grade by a criticality factor. The criticality factor ranges from 1 to 9 and indicates the severity of the consequence of failure. It takes into account a variety of factors such as depth of the pipe, the overlying street and traffic conditions and the type of service (e.g., hospital, school). The system also has a built-in "fudge factor" in case there is a compelling reason to change the criticality that is not already included in the criticality factor. Once the risk score is calculated, it is used along with other information such as pipe age and material to prioritize and schedule inspections as well as O&M and capital needs for the future.

Problems Encountered and Resolved

During this two-year comprehensive manhole and gravity sewer inventory and condition assessment project, several problems occurred in gaining access to private property and locating buried manholes. County staffers were brought in to assist in gaining access; multiple attempts to contact residents were needed in some cases. Specific problems encountered and recommended actions are listed below.

- Cleaning operations may result in customer claims – must be responsive to customer concerns.
- High flows may limit inspection – must anticipate working at night when flows are low.
- Private pumping stations connected to public sewers produce unexpected flows at unexpected times – must be patient and plan ahead.
- Manholes may be located under sheds, fences and pool decks within backyard easements and buried under pavement – allow enough time to locate and uncover manholes.

WRS also found grease to be an ongoing problem. Pipelines that had to be cleaned due to grease build up were likely to need cleaning in a relatively short time to prevent blockage. Some areas were more prone to this buildup than others.

Considerations for New Users

WRS recommends that utilities define project objectives as early as possible. Establishing a thorough scope and standards in the planning stages will minimize changes through the life of the project. WRS did make some relatively minor changes to the scope of contractor duties after the start of the project. These included taking still photos of defects to assist line maintenance staff in repairs; defining effort and time for difficult to locate assets needing extraordinary effort; developing a method to add newly completed assets to the scope during the process; and making minor improvements to customer notification. These minor scope changes could have been included in the original project scope.

With dollars being limited for most utilities, a utility might choose to survey representative areas for analysis and develop predictive methodologies based on information gathered. However, in the long term, it is recommended that all assets be inspected. When the county initiated this program, minimal data were available from similar projects. As more utilities pursue this type of system analysis, more information is becoming available to help in the planning.

Conclusion

According to WRS staff, the main project objectives were met. WRS developed an inventory of system assets including their location and physical condition. The county now has good asset data that can be used to prioritize current capital and operational needs and to plan for future maintenance and capital needs.

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Data Management Case Study – Northern Kentucky Sanitation District No. 1

This case study describes the enhancements to the District's data management system and the improvements implemented in data flow from field collection through analysis.

Lessons Learned

Northern Kentucky Sanitation District No. 1 (District) was eager to show progress in making collection system improvements to support their CMOM program. In 2006, the District accelerated the pace of field evaluations and system improvements. At the same time, planning was initiated and improvements were made to the data management system (DMS). The District realized that large amounts of valuable data were being collected, but data analysis and identification of correction actions were not being performed in an efficient manner. The District also realized that field tasks were being duplicated in the office, which was both frustrating and costly.

The lesson that became evident was the value the DMS provided in the execution of fundamental work. DMS improvements were given a higher priority and specific data flow logic was carefully reviewed in order to:

- Ensure that the correct data were being captured in the field.
- Understand what short-term and long-term decisions the data would support.
- Ensure that data were properly stored so that future retrieval would be easy and convenient.

Background

The District's sewer system covers approximately 200 square miles over 33 communities in three counties (Boone, Kenton and Campbell), and serves approximately 98,000 customer accounts and 245,000 customers. The collection and treatment system service area (Figure A-10) is composed of approximately:

- 49,586 manholes.
- 3,769 catch basins in the combined sewer system.
- 1,665 miles of sewer lines (10% combined and 90% separate sewers).
- 141 pump stations.
- 15 flood pump stations.
- Two regional wastewater treatment plants (WWTPs) and eight small WWTPs with a total average daily flow of 36 MGD and a maximum flow exceeding 55 MGD.

The majority of the collection system is 50 to 100 years old, with diameters ranging from 8 in. to 120 in. The common pipe materials are concrete and clay for smaller sewers, and brick and rock for sewers over 48 in. Since the 1970s, PVC has been used for new sewers 4 to 18 in. in diameter. PVC constitutes approximately 25% of the current system.

SourceS

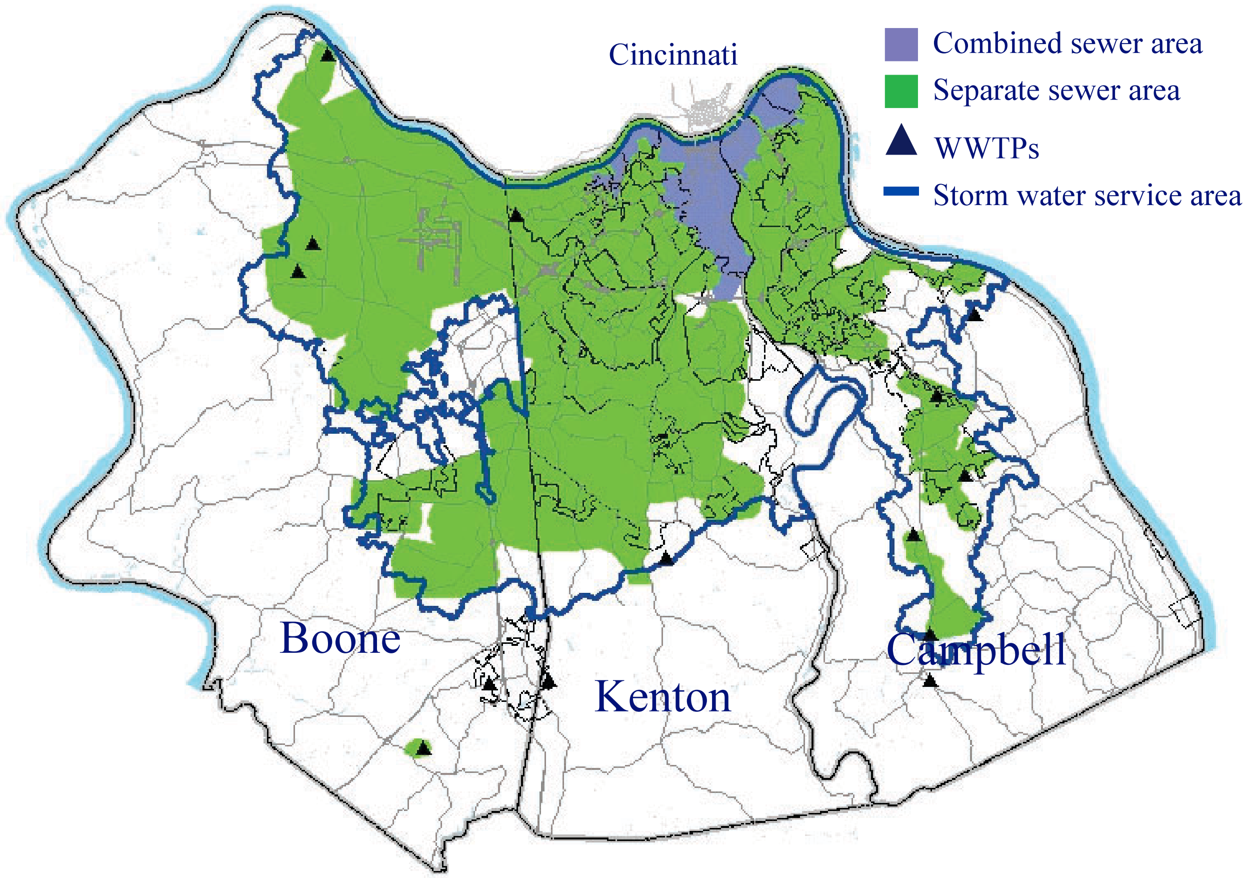


Figure A-10. Sanitation District No. 1's service area.

Data Management for an Asset Management-Based Approach to Corrective Action Prioritization

Sewer System Assessment Program: During its CMOM development, the District decided to develop a more proactive collection system inspection, cleaning, and rehabilitation/replacement program. The District also established a coordinated approach to address both the Nine Minimum Control requirements for the combined sewer system and the CMOM requirements for the sanitary sewer system. In concert with the CMOM self-assessment and the Nine Minimum Control activities, the District began a holistic Continuous Sewer Assessment Program (CSAP) in 2007. This formalized CSAP guides the District's assessment and rehabilitation/replacement work, and many collection system data management activities.

An objective of the CSAP is to take a proactive and coordinated asset management-based approach to assess the infrastructure's condition and manage corrective actions. Through the CSAP, the District can more effectively prioritize and implement system inspection, cleaning, and rehabilitation/replacement. This will enable the identification of wet weather I/I sources, ensure sufficient capacity in both dry and wet weather, and reduce SSOs.

The CSAP is a high-level program consisting of several specific CMOM activities supporting the collection system. Six O&M programs are incorporated into the larger scale CSAP:

- Trouble call.
- Preventative O&M.
- Sonar.
- Sanitary sewer evaluation survey.
- Large diameter sewer assessment.
- Manhole inspection.

Assessment Prioritization Approach: A key component of the CSAP is the prioritization of assets for assessment and subsequent rehabilitation or replacement. Typically, the basin areas where problems are known to exist or where there is a high likelihood of problems should receive the most immediate attention and inspection. Other factors, such as consequence of failure (criticality), also play a key role in prioritization. The CSAP data management system enables basin prioritization to be completed using a comprehensive and easily retrievable dataset. This is preferable to the more traditional pipe age and material projection methods used when data are limited or are not supported by a sophisticated data management system.

The following data categories were selected for each basin to produce a basin score and corresponding basin rank:

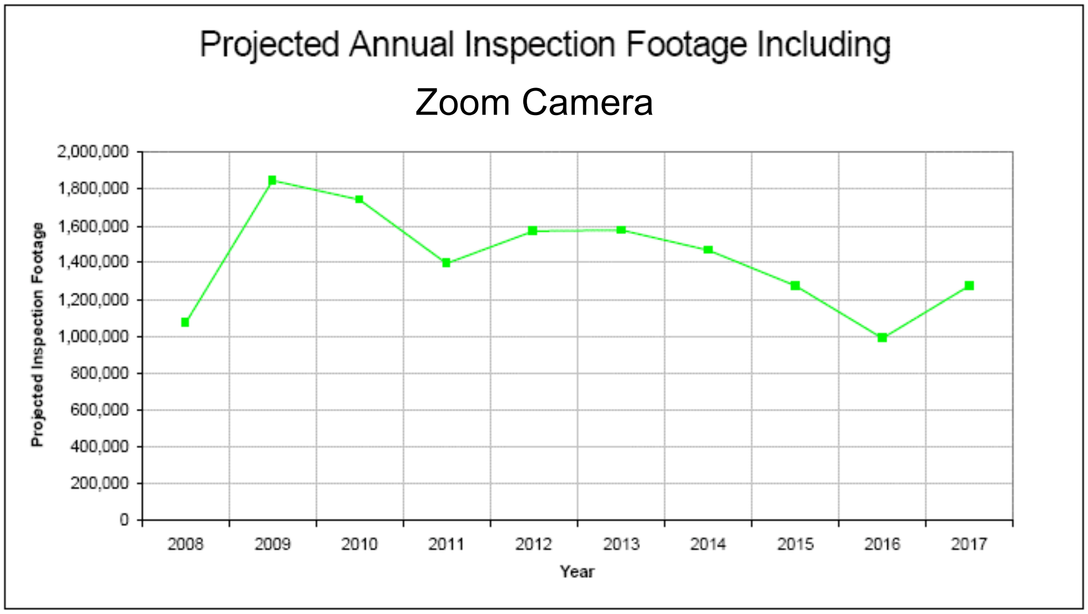
- Service performance priority (measures risks of blockages).
- Structural performance priority (measures risks of collapse).
- Work order history priority (used to estimate frequency of problem occurring).

Although these criteria will dictate most of the sewer and manhole inspections, there are certain assets or groups of assets which require priority inspection, regardless of basin priority:

- All major sewer interceptors and large combined sewers inspected with zoom camera and sonar techniques.
- All sewers within 50 ft of major creeks.
- All sewers downstream of SSOs.
- All sewers in basins that have I/I percentages greater than 10%.

The District is allocating resources in the most cost-effective manner by performing earlier initial inspections and more frequent re-inspection of high priority areas. It is estimated that the entire collection system (approximately 7.9 million ft) will be inspected via CCTV within 10 years, with re-inspection of critical assets occurring throughout the 10-year cycle.

The lower priority sewers and newer sewers are inspected after year five of the program. The CSAP provides the data needed to focus cleaning, rehabilitation and replacement on the sewers with the greatest need. The re-inspection process informs cleaning or rehabilitation decisions, resulting in a more cost-effective program. This approach reduces the risk of service-related overflows compared to a linear inspection and cleaning approach (start at the top of the system and progress downward). An example projection of CCTV and zoom camera needs through the year 2017 is shown in Figure A-11 (2008 CMOM self-assessment report).



Source: Image courtesy of Northern Kentucky Sanitation District No. 1.

Figure A-11. Example District projection of the CCTV and zoom camera needs through 2017.

Basin inspections are divided into three phases based on their priority scores:

- Phase 1 comprises all basins with priority SSOs and other basins with known problems. Priority SSOs have been identified as part of the watershed plans development.
- Phase 2 comprises all other basins with listed SSOs under the consent order with the state and federal regulatory agencies and other basins with problems that are not as concentrated as Phase 1 basins.
- Phase 3 comprises newer basins where available data show few structural or service related problems.

CSAP Data Collection and Management: Each of the six CSAP programs listed above includes an assessment phase using appropriate inspection technologies such as CCTV, zoom camera, smoke & dye testing, sonar, and visual inspection. This is followed by an action phase such as cleaning and rehabilitation/replacement. Data for each of these programs are integrated and designed to support the correction actions.

Collection System Inspection Approach: The primary data used by the District engineering staff for condition assessment are obtained by CCTV and zoom camera inspections. The District operates a fleet of five CCTV inspection vehicles (from a variety of manufacturers), which are fully equipped with cameras, control units, rods, and other items necessary to perform CCTV inspections. This technology enables surveying of pipes ranging from 6 to 48 in. in diameter. CCTV technology also enables District crews to record audio information and observations while observing pipes in the field. Once the video is captured and the data uploaded on the server, the data are converted to a condition score. The resulting score and additional analysis determine whether the asset needs to be placed in the preventive maintenance work program, or if it requires rehabilitation or replacement. District crews use the SCREAM™ defect coding system developed by CH2M HILL. SCREAM™ is not a specific software package, but a condition assessment protocol that allows inspection and testing results to be converted to a numerical score that "ranks" each asset according to structural, O&M, and I/I concerns.

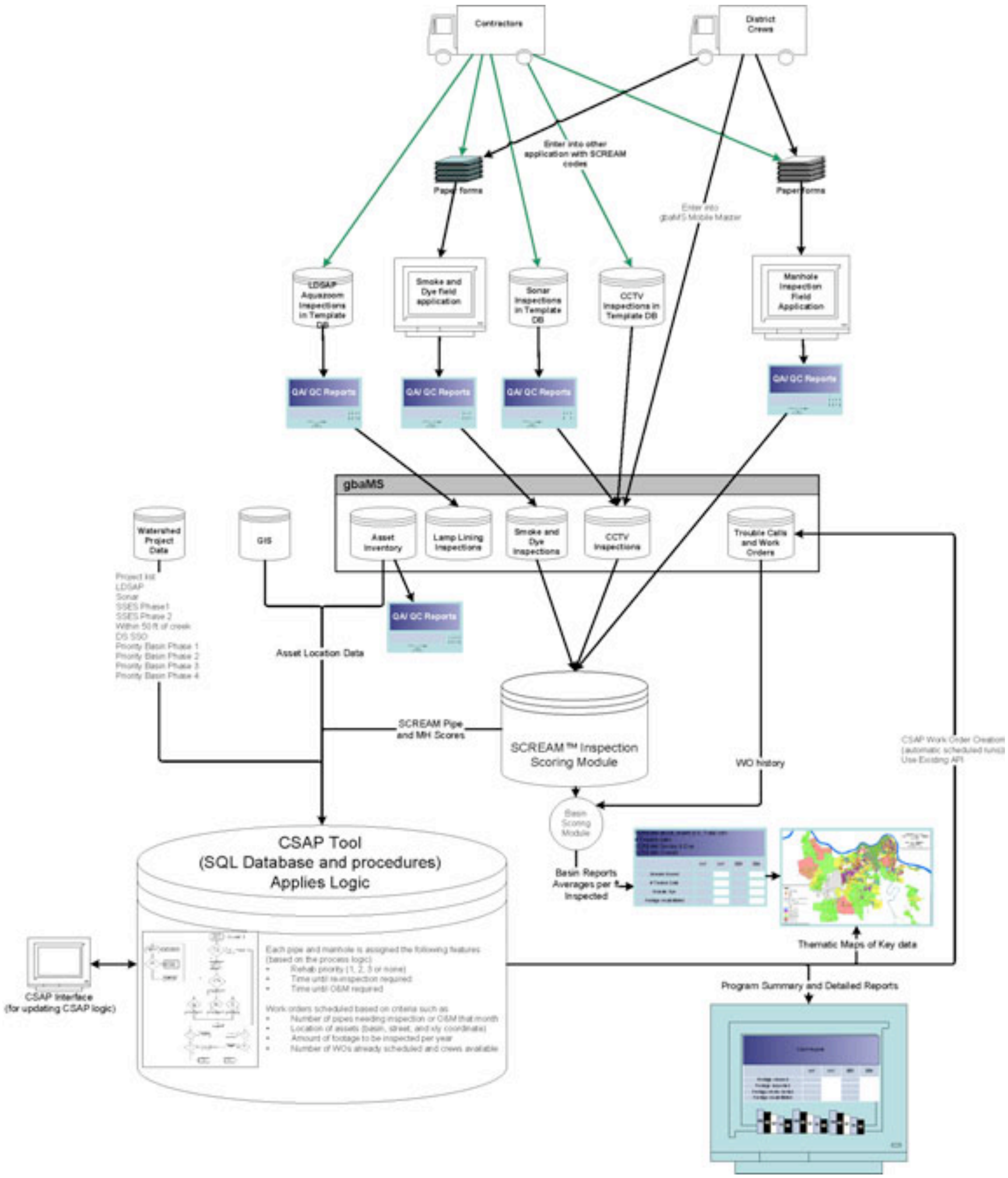
In addition to the CCTV work performed by District crews, large diameter and some smaller diameter sewer lines in the collection system are inspected by contractors using zoom camera screening technology. A zoom camera is a high-powered, high-optical zoom video camera that provides a rapid evaluation of a collection system. The results of the zoom camera screening inspection are used to identify where cleaning or detailed CCTV inspections are needed to further assess defects. In some cases, however, the zoom camera inspection provides sufficient condition information to move forward with rehabilitation/replacement planning, and further CCTV inspection is not necessary.

Engineers use the zoom camera and CCTV results, combined with other information such as the sewer's location, slope, depth and complexity of construction, to decide whether the work will be done with in-house staff or contractors. To help expedite decision making, the District developed an automated corrective action process that models the staff's decision logic for high priority assets. The decision model is a SCREAM™ module that evaluates the type and grouping of defects and identifies initial corrective action decisions. It overlays these suggested corrective actions with the asset's physical condition information in order to produce a more definitive corrective action (e.g., repair, rehabilitation, replacement, or further investigation). Costs are also assigned, which helps the engineering staff prepare capital investment program (CIP), maintenance budgets, and schedules.

Data Collection and Management: gbaMS (GBA Master Series) is central to many daily functions. Therefore, one of the goals of CSAP is to use gbaMS as the primary tool for data collection and automation, with much of the key data integrated with the GIS. The integration of the data with the GIS allows personnel from many different disciplines and backgrounds to view data in the same way, facilitating a standard decision-making process.

Prior to implementation of the CSAP, field data were either collected directly within gbaMS mobile master or were entered on hard copies in the field and then entered into gbaMS by office staff. In the early planning stages of the CSAP, the District recognized the need to improve this data handling process by integrating and automating the movement of field data into gbaMS. Automated future actions and work orders would also need to be generated within gbaMS. The District selected CH2M HILL's SCREAM™ inspection analysis methodology and SQL database integration logic because they allow the results of single or multiple inspection technologies (e.g., smoke testing and CCTV performed on the same asset) to be scored and compared to other assets. The SCREAM™ CCTV and manhole inspection analysis is based on a comprehensive multi-attribute method using logarithmic functions to aggregate and score the array of multiple defects that can occur on a single asset. For Northern Kentucky, CH2M HILL coordinated the SCREAM™ system within the agency's existing use of the gbaMS software.

The SCREAM™ methodology and logic also allow existing CCTV and sonar pipe inspections performed using the NASSCO's PACP CCTV codes to be mapped to the SCREAM™ codes for standardized SCREAM™ scoring. This information can be exported to gbaMS for additional analysis and determination of next actions. An example of how the data are linked among the various applications is shown in Figure A-12.



Source: Image courtesy of Northern Kentucky Sanitation District No. 1.

Figure A-12. District 3's CSAP Data Flow Chart.

Data Software/Hardware: The district uses gbaMS as its CMMS. As noted above, gbaMS is central to the district's daily functions and the district aims to use gbaMS as the primary tool for data collection and automation.

The District uses numerous gbaMS software products for management and maintenance of infrastructure assets. The module-based, customizable applications promote effective data management practices. Other gbaMS modules used include: GIS Master, Sewer Master, Work Master, and Equipment Master. The gbaMS software generates an extensive variety of reports and can export data into spreadsheets. Each of the gbaMS modules provides a wide range of data and work management functions that are completely integrated to assist the district in establishing a maintenance plan, setting priorities, providing timetables, tracking system rehabilitations, and giving direction on effectively maintaining the system. A large number of pre-defined reports are contained within gbaMS and can be modified, or additional reports can be created using Crystal Reports, which is a software application used to design and generate reports. Detailed and summary reports compile the results and are accessed in three ways: through the gbaMS application, the CSAP administrative interface, or reports created with SQL Server Reporting Services and made available through the District's portal ftp site.

For sewer condition assessment, the district uses SCREAM™ software, which provides a standardized defect coding system and a definitive scoring and ranking process, eliminating subjectivity by the operator. Each defect is coded so that it has a category, type and severity associated with the code. The scores for each pipe segment are based on a scale of 1 to 100 for structural, maintenance, and I/I conditions. This allows for a better understanding in assigning relative risks posed by the asset and what corrective actions are needed. The gbaMS and SCREAM™ data reside in SQL 2005 in their own databases, which can share data with each other.

An additional database, CSAP (Figure A-13), was created and serves as a hub, pulling data from gbaMS, SCREAM™ pipe, manhole defect coding databases, and template databases. The template databases are used for storing and reviewing the quality of contractor data collected with NASSCO's PACP system. The CSAP database is used for data compilation, pipe scoring based on the defects within the inspection report, and application of the next action decision-making logic as outlined by the CSAP Process Diagram. The predetermined procedures stored in the SQL server apply the logic and generate the next action to take. Actions might be a list of prioritized pipes and manholes needing immediate rehabilitation or replacement, future sonar and CCTV pipe re-inspections, future cleaning activities at differing intervals or prioritized groups of pipes and manholes that require rehabilitation/replacement as part of a larger scale basin-wide project. An administrative interface allows modification of CSAP logic as needed.

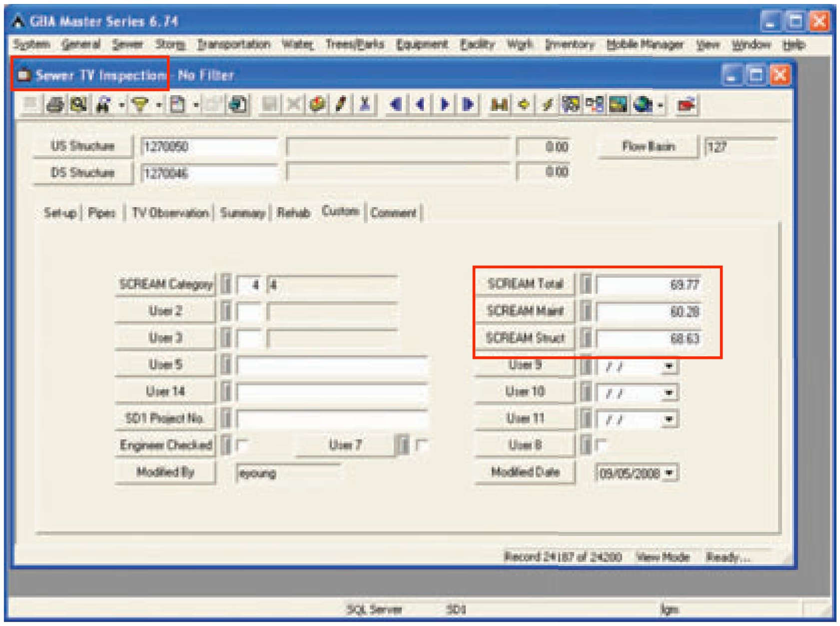


Figure A-13. Example SCREAM™ scoring displayed in gbaMS.

Once the list of prioritized assets is created, the work orders are scheduled from the CSAP database logic for future inspection and cleaning activities. The following information is taken into account in scheduling the work:

- SCREAM™ scores.
- Number of pipes needing inspection or O&M that month.
- Location of assets (basin, street, and x/y coordinates).
- Amount of footage to be inspected per year.
- Number of crews available.

The gbaMS and GIS database(s) were analyzed for relationships and data commonalities. As a result, a data and process flow model was developed to represent the CSAP and GIS data integration.

Based on the initial inspection results, the following actions are taken:

- Sewers with high maintenance scores in need of cleaning are cleaned and scheduled for re-inspection in approximately six months to one year.
- Sewers in good condition with no need for cleaning or repair are scheduled for re-inspection in one, three, or five years depending on the inspection scores for the pipes.
- Sewers with high structural scores in need of repair are brought into the rehabilitation/replacement program to be properly addressed.
- Sewers are scheduled to be rehabilitated or replaced either immediately (collapsed pipe) or as part of a basin-wide rehabilitation/replacement project. These sewers are also coordinated with the District's watershed plans to ensure that watershed plan projects are properly incorporated into the sewers' overall solution.

Utility Comments on Implementing New Databases and New Defect Coding System

The district experienced initial challenges in implementing a new process such as the SCREAM™ codes. Some of the field staff was initially reluctant to make the change. District management resolved this by ensuring that the field staff clearly understood the purpose and benefits of these changes, listening to their responses, and promptly responding to their legitimate concerns. For instance, the engineering staff made every effort to clarify how the field data were converted into usable information to make key decisions on spending the District's limited resources more efficiently.

The District has stressed the importance of leveraging the value of accurate and representative field data throughout the decision-making process. For instance, the CCTV data and analysis process was reviewed and modified to capture data to support specific district policies. An example is the terminology of CCTV codes for the various methods by which service laterals are connected to the mainline sewer pipe. By coding with nomenclature familiar to the field crews, the engineering staff was more assured that CCTV reports would be reliable when deciding how to resolve service lateral issues. At the same time, the crews became engaged in the process by recommending a number of new codes that could be used instead of taking the time to write comments on the inspection form.

The District built automatic and manual quality control checks into the data management process to improve data reliability. As part of the SCREAM™ data handling process, an interim database template included queries that identified data gaps or anomalies for the field crew to resolve prior to uploading the data. This prevented data problems from slowing subsequent engineering decisions. Also, district staff reviews approximately 10% of a contractor's CCTV videotapes to determine whether all the defects are being captured and captured accurately. The district developed a missed-data scoring sensitivity calculator that will predict the impact on the asset's score if a particular defect is not included in the score. Rules were established regarding acceptable missed data, enabling the staff to know when the data scoring would be compromised, and how to provide feedback to the CCTV contractor to minimize future missed data.

Collection of field data is not an activity unto itself, and the district has designed the data collection in stages to be integrated into progress decisions. The District is already leveraging the data management process to make more and better decisions with the same or proportionate less resources and staff.

References

Sanitation District No. 1 Capacity, Management, Operations, and Maintenance (CMOM) Self-Assessment, March 8, 2008.

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Appendix B. Defect Code Systems

Appendix B presents a detailed discussion of PACP and SCREAM™ defect codes. The process of defect coding summarizes observations of pipe defects from CCTV inspections in the form of pipe scores or grades. The defect code systems record defect locations as a function of their distance from a starting manhole, and defect codes are used to represent a variety of CCTV inspection observations.

PACP Defect Codes

The PACP code system organizes defects into five "families": continuous defects, structural, O&M, defects related to construction features and other miscellaneous observations (NASSCO, 2001). A defect "family" is further divided into defect groups that are assigned a combination of capital letters to form a descriptive acronym and a grade number to indicate the severity of the defect. For example, "FL" signifies a longitudinal fracture. The code families are further described below:

- **Continuous defect coding:** Continuous defect coding consists of two sub-classifications. "Truly" continuous defects extend along the sewer for a minimum distance of 3 ft. These defects include longitudinal fractures and cracks. "Repeated" continuous defects occur at regular intervals along the pipe, usually at pipe joints, and include encrustation, open joints, and circumferential fractures. Continuous defect coding can be used in conjunction with other codes.

- **Structural defect coding:** Structural defect coding consists of a number of classifications related to structural degradation of the pipe: crack (C), fracture (F), broken (B), hole (H), deformed (D), collapse (X), joint (J), surface damage (S), lining failure (LF), weld failure (WF), point repair (PR) and brickwork (B). With each of these designations, additional letters further describe the defect. For example: HSV indicates a hole with soil visible.

- **Operational and maintenance defect coding:** This family codes defects that are related to lack of maintenance in the pipe system. The O&M defect code groups are deposits (D), roots (R), infiltration (I), obstacles (OB) and vermin (V). Additional letters further describe the defect. For example, VR indicates that there are vermin, specifically rats, in the pipe.

- **Construction features coding:** This family of codes describes defects related to construction features located in or around the pipe system. Code groups are tap (T), intruding seal material (IS), line (L) and access point (A). As with the other families, additional letters further define the defect. For example, AMH indicates that there is an access point in the line that is a manhole.

- **Other coding:** This coding family comprises miscellaneous observations about the pipe system that are of interest. It uses the code letter "M," plus additional letters to further define the observation. For example, MCU designates that the camera is under water.

The PACP code system is used to describe different characteristics of each observed defect including its classification, severity, size, proximity to joints, circumferential location (clock location), image/video reference number, and comments. Defect codes are recorded on a standardized form; an example is illustrated in Figure B-1. The PACP code system uses numerical grading on a scale of 1 to 5 to define the severity of each pipe defect, with 1 representing a minimal defect and 5 representing the most severe defect.

The PACP codes for individual defects are used to determine several overall scores for the pipe segment (manhole-to-manhole pipe run). Structural and O&M defects are graded separately based on the risk of further deterioration or failure. These terms for expressing pipe condition are outlined below:

- **Segment Grade Scores:** A scoring assigned to individual pipe segments based on the number and severity of the defects. Each segment receives five Segment Grade Scores, one for each of the five grades. The score equals the number of defects multiplied by the grade number. For example, a pipe segment with six Grade 5 defects has a Segment Grade 5 Score of 30 (6 defects multiplied by a grade of 5). If a pipe segment has no defects for a particular grade, the Segment Grade Score for that grade is 0.

- **Overall Pipe Rating:** The sum of five Segment Grade Scores.

- **Structural Pipe Rating:** The sum of five Segment Grade Scores considering only structural defects.

- **O&M Pipe Rating:** The sum of five Segment Grade Scores considering only O&M defects.

- **Quick Rating:** A rapid method for summarizing the number and severity of the two most severe defects in a pipe segment. The Quick Rating is a four-character score:

    1. The first character is the highest severity grade occurring along the pipe length.
    2. The second character is the total number of occurrences of the highest severity grade. If the total number exceeds 9, then alphabetic characters are used as follows: 10 to 14-A, 15-19-B, 20 to 24-C and so on.
    3. The third character is the next highest severity grade occurring along the pipe length.
    4. The fourth character is the total number of the second highest severity grade occurrences, which is formatted the same way as the second character.

    For example, a Quick Rating of "3224" is deciphered as follows: the highest severity defect on this pipe segment is a grade **3**; the pipe segment has **2** defects with a grade 3; the next highest severity defect is a grade **2**; there are **4** defects with a grade 2. This pipe segment has no grade 4 or 5 defects.

- **Overall Pipe Rating Index:** An expression of the average defect severity found in the pipe segment. The index is calculated by dividing the Overall Pipe Rating by the number of defects. PACP provides general guidelines for assessing the Pipe Rating Index score with the following stipulation: "The mechanisms and rates of pipeline deterioration are highly dependent on local conditions. However the following general guidelines are provided to estimate the amount of time before the defect causes complete line failure. These guidelines should be verified by actual research under prevailing local conditions." (NASSCO, 2001)

    - Pipe Rating Index = 5: Pipe segment has failed or will likely fail within the next 5 years. Pipe segment requires immediate attention.
    - Pipe Rating Index = 4: Pipe segment has severe defects with failure likely within the next 5 to 10 years.
    - Pipe Rating Index = 3: Pipe segment has moderate defects. Deterioration may continue, but failure is not likely for 10 to 20 years.
    - Pipe Rating Index = 2: Pipe segment has minor defects. Pipe is unlikely to fail for at least 20 years.
    - Pipe Rating Index = 1: Pipe segment has minor defects. Failure is unlikely in the foreseeable future.

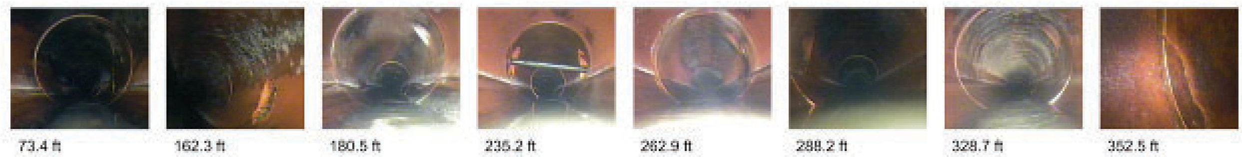
- **Structural Pipe Rating Index:** The average severity of structural defects in the pipe segment. The index is calculated by dividing the Structural Pipe Rating by the number of defects.

- **O&M Pipe Rating Index:** The average severity of O&M defects in the pipe segment. The index is calculated by dividing the O&M Pipe Rating by the number of defects.

The Quick Rating and Ratings Index scores are the methods most commonly used to assess the general condition of a pipe from CCTV inspection data.

Example of PACP Coding Methodology

This example uses CCTV inspection data from an 8-in. diameter VCP located in Huntsville, Ala., to demonstrate the use of the PACP coding methodology. Figure B-1 summarizes the information gathered for each defect using the PACP defect code system. The level of detail required depends on the particular defect code used and observations within the pipe. Distance measurements are provided for each defect and are measured from the starting manhole. Defect codes are then provided and may include group, descriptor, modifier, and severity codes. The start and end distances of any continuous defects are noted, and additional information related to each defect may be provided.



Distance	Code		Continuous Defect	Value				Joint	Circumferential Location		Remarks
	Group/Descriptor	Modifier/Severity		S/M/L	Inches		%		At/From	To	
					1st	2nd					
0.0	AMH										MH 4S1W06105
0.0	MWL						5				
73.4	TF	D			4			J	2		Fractured at connection. Roots in fracture.
73.4	RF	L							2		
162.3	TB	A			4				2		Roots growing in lateral.
180.5	TF	A			4			J	2		
235.2	OBI								3	10	
235.2	H							J	3		
235.2	H							J	10		
262.9	TF	D			4			J	2		Fractured at connection. Roots in fracture.
288.2	TF	A			4			J	10		Roots growing in lateral.
328.7	TF	A			4			J	2		
352.5	CC							J	9	11	
356.7	AMH										MH 4S1W06104

Figure B-1. Example of PACP coding methodology for 8 in. VCP, Huntsville, Ala.

Notes for Figure B-1
1. In Column 1, distance is measured in ft.
2. In column 2, defect codes are described using the following group/descriptors: AMH = access manhole, CC = circumferential crack, H = hole, MWL = miscellaneous water level, OBI = object intruding through wall, RF = roots fine, TB = tap break in and TF = tap factory.
3. In column 3, the following modifiers are used to indicate defect severity: D = defective, L = lateral and A = active.
4. Column 4 is used to provide information on continuous defects. For this example, no continuous defects were observed.
5. Columns 5, 6, 7 and 8 denote additional specific values for some defect codes. For example, a value of "4" in column 6 indicates that all lateral tap connections observed in this pipe have a diameter of 4 in.
6. Column 9 is used to classify defects located near a pipe joint. A "J" indicates that the observed defect is located within 8 in. of a pipe joint.
7. Columns 10 and 11 describe the circumferential location of certain defects as a clock position or a starting and ending clock position. For example, "2" refers to the 2:00 o'clock position.

The raw data shown in Figure B-1 and structural grades from PACP Reference Manual (NASSCO, 2001) are used to calculate the pipe rating scores. These scores are computed separately for Structural, O&M, and Overall categories, as described below.

Structural Rating: In Figure B-1, the following structural defects were included in the calculation of the Structural Rating: the H defects located at a distance of 235.2 ft and a circumferential location of 3:00 and 10:00; and the CC defect located at a distance of 352.5 ft and a circumferential location from 9:00 to 11:00. The defects were assigned a structural grade based on the designated PACP code and their clock position using a reference table in NASSCO's PACP Reference Manual (NASSCO, 2001): the two H defects were both assigned a structural grade 4, and the CC defect was assigned a structural grade 1. Therefore, the Structural Rating = (2 defects × grade 4) + (1 defect × grade 1) = **9**.

O&M Rating: In Figure B-1, the following defects were used to calculate the O&M Rating: the TFD defect located at a distance of 73.4 ft, and the RFL, OBI and TFD defects located at a distance of 262.9 ft. The two TFD defects were assigned an O&M Grade of 2, the RF defect was assigned an O&M Grade of 1 and the OBI defect was assigned an O&M Grade of 2. Therefore, the O&M Rating = (3 defects × grade 2) + (1 defect × grade 1) = **7**.

Overall Rating: The Overall Rating is calculated based on the structural and O&M Ratings. Therefore, the Overall Rating = 9 + 7 = **16**.

The Quick Ratings are based on the two most severe grades and the number of defects observed in a pipe. The three quick ratings are determined as follows:

Structural Quick Rating: In the example shown in Figure B-1, the most severe grade was a "4" and was assigned to two defects; the second most severe grade was a "1" and was assigned to 1 defect. Therefore, the Structural Quick Rating is "**4211**."

O&M Quick Rating: The most severe O&M grade was a "2" and was assigned to 3 defects; the second most severe O&M grade was a "1" and was assigned to 1 defect. Therefore, the O&M Quick Rating is "**2311.**"

Overall Quick Rating: Considering both structural and O&M categories, the most severe grade used in this pipe segment was a "4" and was assigned to 2 defects. The second most severe grade was a "2" and was assigned to 3 defects. Therefore, the Overall Quick Rating is "**4223.**"

The Structural, O&M and Overall Ratings Indices are calculated by dividing the Structural Rating, the O&M Rating and Overall Rating by the number of respective defects in each category. These indices represent the average pipe condition on a five-point scale. The indices are calculated as follows:

Structural Ratings Index = 9 ÷ 3 = **3.0**.
O&M Ratings Index = 7 ÷ 4 = **1.8**.
Overall Ratings Index = 16 ÷ 7 = **2.3**.

In summary, the PACP scores for the example in Figure B-1 are provided below:

Structural Rating	9
Structural Quick Rating	4211
Structural Ratings Index	3.0
O&M Rating	7
O&M Quick Rating	2311
O&M Ratings Index	1.8
Overall Rating	16
Overall Quick Rating	4223
Overall Ratings Index	2.3

SCREAM™ Defect Codes

The SCREAM™ defect code system has six defect categories: Access (A), Connecting Pipe (C), Fitting (F), Joint (J), Lateral Connection (L) and Pipe (P). Categories generally reflect a location relative to when and where along the pipe the CCTV operator is considering entering a code. The six categories are further described below:

- **Access:** These codes generally describe where the inspection was launched (e.g., a manhole, a cleanout, etc.). All access codes are in the Inventory Group and are not scored but provide information.

- **Connecting Pipe:** Defects within the connecting pipe defect category are located in the interface area of a connecting pipe with the sewer or storm sewer pipe that contains the CCTV camera and do not represent the connecting pipe itself. Connecting pipes are sewer pipes serving a much larger service area than laterals or pipes that service a high-flow industry and bring flow to the sewer or storm sewer pipe. Connecting pipes (also known as "blind connections") are typically ≥ 8 in. in diameter.

- **Fitting:** These codes are for factory-manufactured fittings such a 45- or 90-degree bend when the camera is in a lateral. Fittings do not include the lateral tees or wyes, which are included under Lateral Connection.

- **Joint:** These codes are for the sewer pipe, fitting or lateral junction points of two pipe segments; a fitting and pipe or a fitting and lateral.

- **Lateral Connection:** These codes are for the factory-manufactured tee or wye and include field installed cored, saddle and hammer-tap connections that connect a lateral to the pipe. A lateral connection includes the interface area of the service lateral with the sewer pipe. Laterals bring flow from a residence or commercial building to the pipe and are typically 4 to 6 in. in diameter.

- **Pipe:** These codes refer to the sewer or storm sewer pipe and the interior space within the confines of the pipe barrel. Pipe codes are also applicable to the pipeline system components when considering continuous type defects such as grease, sediment, lining and coating defects.

Within each of these categories, the SCREAM™ defect code system establishes four defect coding groups: Inventory, Structural, Maintenance and I/I. Inventory codes do not influence the score. SCREAM™ defect codes are also classified by type of defect (e.g., roots, pipe collapse, and turbulence) and defect severity (e.g., minimum, moderate, major).

SCREAM™ Defect Scoring Approach

The SCREAM™ rating analysis system includes assigning a score to individual defects, groups of defects (e.g., structural, maintenance, I/I) and the overall pipe condition.

For each defect type, SCREAM™ calculates a minimum or base defect score and a maximum defect score. The base defect score represents the score of a single defect of that defect type that has the minimum possible extent or the minimum length observed for defects of this type (e.g., ≤ 1 ft). The maximum defect score represents the score for defects of that defect type that have the maximum cumulative extent over the pipe segment (e.g., multiple occurrences of the same defect or defect that extends the entire length of the pipe). The actual score assigned to a specific occurrence of a defect is determined based on the defect's size or extent in the pipe segment (e.g., < 1 ft, occurs over 50% of pipe length) and has a value between the minimum and maximum defect scores. If the defect affects < 1 ft of the pipe segment (a point defect), the score would be equal to the minimum or base defect score; defects which affect the entire pipe segment would be assigned a value close to the maximum value for that defect type. Using this approach, the SCREAM™ scoring methodology considers the relative criticality of specific defect types and the extent of their occurrence in the pipe segment. As a result, the occurrence of a major defect in one limited area can be scored higher than multiple occurrences of minor defects.

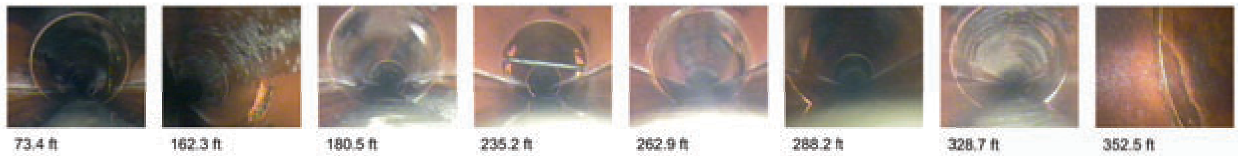
For both defect coding and pipe condition scoring, a scoring scale of 1 to 100 is applied with 1 representing a very minor defect and 100 representing the most severe defect (e.g., a collapsed pipe). For easier visual display of pipe condition, a simpler scoring scale of Grades 1 to 5 may also be used. For example, Grade 1 may represent pipe scores of 1 to 25; Grade 2 represents pipe scores of 26 to 40; and so forth. It is not necessary to use a linear relationship to define Grades 1 to 5 in terms of the pipe scores. For each pipe segment, the pipe score value using the 1-to-100 scale is retained for subsequent prioritization or corrective action decisions.

The SCREAM™ methodology includes computation of an Overall Pipe Score for the aggregated defects found in the pipe. It also computes a separate score for the structural, maintenance and I/I groups of defects. These scores are calculated using a multiple attribute method that involves advanced root-square-mean mathematical principles. One key principle is to identify and build upon the highest scored defect value found in the inspection (Kathula, 2004).

Each defect code is pre-assigned a minimum base score from 1 to 100, and the score for the defect is increased depending on its extent along the pipe. A score of 1 represents a nearly new pipe, and a score of 100 represents immediate urgency such as a pipe collapse. SCREAM™'s mathematical algorithm uses a scoring system that automatically selects the highest defect score value in the pipe segment. The worst defect score becomes the beginning point for aggregating all additional asset defect scores.

Example of SCREAM™ Coding Methodology

This example uses CCTV inspection data from an 8-in. diameter VCP located in Huntsville, Ala., to demonstrate use of the SCREAM™ coding methodology. Figure B-2 summarizes inspection distance (ft from manhole) and describes the type and severity of pipe defects observed. In contrast to PACP, SCREAM™ defect codes contain all relevant information within each defect code, and no additional supporting information is required to further describe the defect. Once the defect code is provided, the defect category, defect family, defect type, defect severity and defect group are all known by definition.



Distance	Code	Defect Category	Defect Family	Defect Type	Defect Severity	Defect Group
0.0	AMH	Access	None	Manhole		Inventory
0.0	PFLWLEV2	Pipe	Flow Level		Mod: <25%	Inventory
73.4	LLOC	Lateral Connection	None		Location	Inventory
73.4	LDIS3	Lateral Connection	Displaced	Displaced	Major. Dropped Outside Joint	Structural
73.4	LROJ1	Lateral Connection	Roots	Roots + Open Joint	Minor. <=20% of Pipe + Open Minor	Maintenance & Structural
73.4	LRF1	Lateral Connection	Roots	Roots From	Minor. <=20% of Pipe	Maintenance
162.3	LLOC	Lateral Connection	None		Location	Inventory
162.3	LROJ1	Lateral Connection	Roots	Roots + Open Joint	Minor. <=20% of Pipe + Open Minor	Maintenance & Structural
180.5	FSAD	Fitting	None	Saddle	Location	Inventory
235.2	POB1	Pipe	Obstacle	Obstacle	Minor. <=20% of Pipe	Maintenance
235.2	PBROPE3	Pipe	Broken Pipe	Broken Pieces	Major. Hole, Void	Structural
235.2	PBROPE3	Pipe	Broken Pipe	Broken Pieces	Major. Hole, Void	Structural
262.9	LLOC	Lateral Connection	None		Location	Inventory
262.9	LROJ1	Lateral Connection	Roots	Roots + Open Joint	Minor. <=20% of Pipe + Open Minor	Maintenance & Structural
262.9	LRU1	Lateral Connection	Roots	Roots Up	Minor. <=20%	Inventory
288.2	LLOC	Lateral Connection	None		Location	Inventory
288.2	LRU1	Lateral Connection	Roots	Roots Up	Minor. <=20%	Inventory
328.7	LLOC	Lateral Connection	None		Location	Inventory
352.5	JCRKMUL2	Joint	Crack	Crack: Multiple	Moderate. Tight	Structural
356.7	AMH	Access	None	Manhole		Inventory

Figure B-2. Example of SCREAM™ coding methodology for 8 in. VCP, Huntsville, Ala.

Notes for Figure B-2

1. In Column 1, distance is measured in ft.
2. Acronyms used in Column 2 are defined as follows: AMH = access manhole, FSAD = factory saddle, JCRKMUL2 = joint crack multiple moderate, LDIS3 = lateral connection displaced major, LLOC = lateral connection location, LRF1 = lateral connection roots minor, LROJ1 = lateral connection roots & open joint minor, LRU1 = lateral connection roots up lateral minor, PFLWLEV2 = pipe flow level moderate, POB1 = pipe obstacle minor and PBROPE3 = pipe broken pieces major. The numbers 1, 2 and 3 represent defect severity in terms of minor, moderate and major, respectively.
3. Column 6 provides additional details on defect severity using the same severity terms introduced in column 2 (minor, moderate, major). For example, in row 2, the defect code indicates a moderate severity for pipe flow level; column 6 indicates that the flow level is <25%.

The SCREAM™ scores for the example in Figure B-2 are provided below:

Structural Score	93.6	100-point scale
Maintenance Score	5.1	100-point scale
Total Score	93.9	100-point scale
Total Grade	5	5-point scale

SCREAM™ also has a feature that maps PACP defect codes to related SCREAM™ defect codes, to allow the use of the SCREAM™ scoring and grading system with PACP defect codes. The SCREAM™ scores for the example in Figure B-1 are provided below.

Structural Score	96.7	100-point scale
Maintenance Score	32.0	100-point scale
Total Score	96.9	100-point scale
Total Grade	5	5-point scale

Note that the structural and total scores are quite similar when the SCREAM™ scoring algorithm is used with SCREAM™ defect codes or with PACP defect codes. A more significant difference between the maintenance scores is observed. However, the total grade computed by the SCREAM™ algorithm using either SCREAM™ defect codes or PACP defect codes is the same in both cases.

Appendix C. Technology Vendors

Digital Scanning

Product(s)	Vendor/Address	Phone/Fax/E-mail/URL
DigiSewer	Envirosight, LLC 111 Canfield Ave. Randolph, NJ 07869	Tel: (866) 936-8476 Fax: (973) 252-1176 E-mail: through Web site URL: http://www.envirosight.com
Panoramo	Rapidview-IBAK USA 1828 West Olson Road Rochester, IN 46975	Tel: (800) 656-4225 Fax: (574) 224-5426 E-mail: info@rapidview.com URL: http://www.rapidview.com
Cleanflow/Fly Eye	CUES Inc. 3600 Rio Vista Ave. Orlando, FL 32805	Tel: (800) 327-7791 Fax: (407) 425-1569 E-mail: salesinfo@cuesinc.com URL: http://www.cuesinc.com

Zoom Cameras

Product	Vendor/Address	Phone/Fax/E-mail/URL
Aqua Zoom	AquaData, Inc.95 5th Avenue Pincourt, Quebec Canada J7V 5K8	Tel: (800) 567-9003 Fax: (514) 425-3506 E-mail: info@aquadata.com URL: http://www.aquadata.com
Aries HC3000 Zoom Pole Camera	Aries Industries 550 Elizabeth St. Waukesha, WI 53186	Tel: (800) 234-7205 Fax: (262) 896-7099 E-mail: through Web site URL: http://www.ariesind.com
QuickView	Envirosight, LLC 111 Canfield Ave. Randolph, NJ 07869	Tel: (866) 936-8476 Fax: (973) 252-1176 E-mail: through Web site URL: http://www.envirosight.com
Everest Ca-Zoom PTZ	GE Sensing & Inspection Technologies 721 Visions Drive Skaneateles, NY 13152	Tel: (888) 332-3848 Fax: (866) 899-4184 E-mail: through Web site URL: http://www.geinspectiontechnologies.com
CUES IMX Truck-Mounted Zoom Camera	CUES IMX Corporate Office 3600 Rio Vista Ave. Orlando, FL 32805	Tel: (800) 327-7791 Fax: (407) 425-1569 E-mail: salesinfo@cuesinc.com URL: http://www.cuesinc.com
PortaZoom	CTZoom Technologies 2500 Boul. Des Enteprises #104 Terrebonne, Quebec Canada J6X 4J8	Tel: (888) 965-8987 Fax: (450) 965-8987 E-mail: info@ctzoom.com URL: http://www.ctzoom.com

Push Cameras

Product(s)	Address	Phone/Fax/E-mail/URL
Insight Vision Push Camera	Insight Vision 600 Dekora Woods Boulevard	Tel: (800) 488-8177 Fax: (262) 268-9952

	Saukville, WI 53080	URL: http://insightvisioncameras.com
CrystalCam Push Camera	Inuktun Services Ltd. 2569 Kenworth Road, Ste. C Nanaimo, British Columbia Canada V9T 3M4	Tel: (877) 468-5886 Fax: (250) 729-8080 E-mail: sales@inuktun.com URL: http://www.inuktun.com/head-office.htm
Flexiprobe	Pearpoint/RADIODETECTION 154 Portland Road Bridgton, ME 04000	Tel: (877) 247-3797 Fax: (207) 647-9495 E-mail: rd.sales.us@spx.com URL: http://www.pearpoint.com
Hydrus, Orion, Orion L	Rapidview-IBAK USA 1828 West Olson Road Rochester, IN 46975	Tel: (800) 656-4225 Fax: (574) 224-5426 E-mail: info@rapidview.com URL: http://www.rapidview.com

Lateral Launchers

Product(s)	**Vendor/Address**	**Phone/Fax/E-mail/URL**
LAMP	CUES Inc. 3600 Rio Vista Ave. Orlando, FL 32805	Tel: (800) 327-7791 Fax: (407) 425-1569 E-mail: salesinfo@cuesinc.com URL: www.cuesinc.com
Lateral Evaluation Television System	Aries Industries 550 Elizabeth St. Waukesha, WI 53186	Tel: (800) 234-7205 Fax: (262) 896-7099 URL: http://www.ariesind.com
Lateral Inspection System	RS Technical Services 1327 Clegg St. Petaluma, CA 94954	Tel: (800) 767-1974 Fax: (707) 778-1974 URL: http://www.rstechserv.com
IBAK LISY 150-M	Rapidview-IBAK USA 1828 West Olson Road Rochester, IN 46975	Tel: (800) 656-4225 Fax: (574) 224-5426 E-mail: info@rapidview.com URL: http://www.rapidview.com

Small Diameter Tractors

Product(s)	**Address**	**Phone/Fax/E-mail/URL**
ELKT100 Mini	Pearpoint/RADIODETECTION 154 Portland Road Bridgton, ME 04000	Tel: (877) 247-3797 Fax: (207) 647-9495 E-mail: rd.sales.us@spx.com URL: http://www.pearpoint.com
KRA 65	Rapidview-IBAK USA 1828 West Olson Road Rochester, IN 46975	Tel: (800) 656-4225 Fax: (574) 224-5426 E-mail: info@rapidview.com URL: http://www.rapidview.com
Mighty Mini Transporter	RS Technical Services 1327 Clegg St. Petaluma, CA 94954	Tel: (800) 767-1974 Fax: (707) 778-1974 URL: http://www.rstechserv.com

Product(s)	Address	Phone/Fax/E-mail/URL
ROVVER 100	Envirosight 111 Canfield Ave. Randolph, NJ 07869	Tel: (866) 936-8476 Fax: (973) 252-1176 E-mail: through Web site URL: http://www.envirosight.com
Versatrax 100	Inuktun Services Ltd. 2569 Kenworth Road, Ste. C Nanaimo, British Columbia Canada, V9T 3M4	Tel: (877) 468-5886 Fax: (250) 729-8080 E-mail: sales@inuktun.com URL: http://www.inuktun.com/head-office.htm
Xpress Silver-Bullet Crawler	Insight Vision 600 Dekora Woods Boulevard Saukville, WI 53080	Tel: (800) 488-8177 Fax: (262) 268-9952 URL: http://insightvisioncameras.com

Long-Range Tractors

Product	Vendor/Address	Phone/Fax/E-mail/URL
Versatrax 300 VLR	Inuktun Services Ltd. 2569 Kenworth Road, Ste. C Nanaimo, British Columbia Canada V9T 3M4	Tel: (877) 468-5886 Fax: (250) 729-8080 E-mail: sales@inuktun.com URL: http://www.inuktun.com/head-office.htm
Responder	RedZone Robotics 91 43rd St., Ste.250 Pittsburgh, PA 15201	Fax: (412) 476-8981 E-mail: through Web site URL: http://www.redzone.com

Condition Assessment Software

Product	Vendor/Address	Phone/Fax/E-mail/URL
Canalis™ part of Aqua CAD® suite	Aqua Data Inc. 95 5th Avenue Pincourt, Quebec Canada, J7V 5K8	Tel: (514) 425-1010 Toll Free: 1-800-567-9003 Fax: (514) 425-3506 E-Mail: info@aquadata.com URL: http://www.aquadata.com
CapPlan Sewer	MWH Soft 618 Michillinda Avenue, Suite 200 Arcadia, CA 91007 USA	Tel: (626) 568-6868 Fax: (626) 568-6870 E-mail:sales@mwhsoft.com
CASS WORKS®	RJN Group Inc. 200 West Front Street Wheaton, IL 60187	Tel: (630) 682- 4700 Fax: (630) 682- 4754 E-mail: slaitas@rjn.com URL: http://www.rjn.com/
CityWorks	Azteca Systems, Inc. 11075 South State St., Ste. 24 Sandy, UT 84070 USA	Tel: (801) 523-2751 Fax: (801) 523-3734 URL: http://www.azteca.com/
CTSpec	CTZoom Technologies, Inc. 2500 Boul. des Entreprises #104 Terrebonne, Quebec Canada J6X 4J8	Tel: (450) 965-8987 Toll free: 1-888-965-8987 Fax: (450) 965-6622 E-mail: info@ctzoom.com URL: http://www.ctzoom.com

Product	Vendor/Address	Phone/Fax/E-mail/URL
Granite XP	CUES Corporate Office 3600 Rio Vista Avenue Orlando, Florida 32805	Tel: 800-327-7791 Fax: (407) 425-1569 E-mail: salesinfo@cuesinc.com URL: http://www.cuesinc.com/
GBA Master Series ® or gbaMS	GBA Master Series, Inc. 10561 Barkley, Suite 500 Overland Park, KS 66212	Tel: (800) 492-2468 or (913) 341-3105 Fax: (913) 341-3128 E-mail: info@gbams.com URL: http://www.gbams.com/contact.htm
Hansen Asset Management	INfOR 13560 Morris Road Suite 4100 Alpharetta, GA 30004	Tel: (866) 244-5479 Fax: (678) 319-8682 URL: www.infor365.com
InfoNet™	Wallingford Software Inc. 6015 Harris Parkway Suite 120 Fort Worth, TX 76132	Tel: (817) 370-2425 Toll Free: 1-888-520-2224 Fax: (817) 370-1981 Sales E-mail: sales@wallingfordsoftware.com Support E-mail: support@wallingfordsoftware.com URL: http://www.wallingfordsoftware.com
Maximo® Asset Management	IBM Corporation 1 New Orchard Road Armonk, New York 10504	Tel: (877) 426-6006 Fax: (800) 314-1092 URL: http://www-01.ibm.com/software/tivoli/solutions/asset-management/
SEWERview	CartêGraph 3600 Digital Drive Dubuque, IA 52003	Tel: (563) 556-8120 Fax: (563) 556-8149 E-mail: info@cartegraph.com

Appendix D. Example Inspection Report – Fort Worth, Texas

Example Inspection Report: Fort Worth, Texas[1]

Project Background

In fiscal year 2006-2007, SC03_05 Sub Drainage Basin Area was selected for cleaning and CCTV inspection. The cleaning activities were conducted from April 2007 through July 2007. CCTV inspection was also conducted between May 2007 and July 2007. The SC03_05 Sub Drainage Basin Area is part of the Sycamore Creek Major Drainage Basin located in the south portion of Fort Worth. The SC03_05 Sub Drainage Basin Area bounded on the north by MARION ST., the west by LOUSE ST., the east by MISSISSIPPI AVE. and the south by BERRY ST. The drainage basin is comprised of approximately 40,148 linear feet (LF) of sanitary sewer ranging in size from 6-inch to 12-inch in diameter.

Cleaning and CCTV Inspection

A total of 39,778 LF of the collection system was cleaned representing 99% of the SC03_05 Sub Drainage Basin Area. A total of 35,966 LF of the system was inspected representing 89.6% of the SC03_05 Sub Drainage Basin Area. The purpose of the TV inspection was to evaluate for quality control of the cleaning operations and pipe condition.

Analysis and Recommendation

Fifteen segments were selected for open cut and/or trenchless point repairs. Table D-1 contains four segments identified for open-cut method. Table D-2 contains eleven segments identified for trenchless method. Table D-3 represents a total of 6,805 LF of pipe (19 segments) identified for complete replacement. Table D-4 represents a total of 6,935 LF (17.3%) of pipe was added to Field Operations root control program.

A complete list of all lines within the SC03_05 Sub Drainage Basin Area along with a detailed summary of all related activities associated with this report is given in Table D-5 and shown on the subsequent project maps.

Should you have any questions concerning the information contained in this report, please do not hesitate to contact me.

Kirit Patel, Graduate Engineer
Field Operations, Water Department
City Of Fort Worth

[1] Note: This report is presented in its original form as provided by The City of Fort Worth.

Table D-1. Open cut point repairs

Object ID	Lateral/ Main	USID	DSID	Pipe Size	Pipe Material	Additional Review/ Comment	CCTV review Comments	O & M Recommendation	Structural Recommendation
1143251	L02057	008+65	003+07	6	Vitrified Clay	Roots removed.	Line is in fair condition w/ some minor cracking and root intrusion. Section of is broken badly around taps @ 151' US.	Root Program	Open Cut Point Repair
1143243	L03553	005+35	071+32	6	Concrete	CANT PUSH ROCK ANYMORE DO RSU.	Fair condition pipe until CCTV blocked (same as 2005 inspection) by offset, bend, grade & material change @ 114' DS (spot of previous repair). This time debris also involved. RSU doesn't make it out of the DSMH-Operator says he's blocked in MH but doesn't say by what.	None at this time	Open Cut Point Repair
1143218	L04167	011+00	004+27	6	Concrete	LINE VERY POOR BLOCKED BY GREASE 575 FT	Line is in fair/poor condition. Much cracking & broken pipe, especially in upper portion. Bad pipe @ 326' US" being repaired. Grease @ 575' US blocks Jeteye, survey abandoned. No RSU attempted."	None at this time	Open Cut Point Repair
483782	M00017	090+09	090+03	8	Concrete	NO U/S M/H; 4' DEEP M/H D/S	Line is in good condition. Cap on the EOL is missing w/ a void created from recent cleaning.	None at this time	Open Cut Point Repair

Table D-2. Trenchless point repairs

Object ID	Lateral/ Main	USID	DSID	Pipe Size	Pipe Material	Additional Review/ Comment	CCTV review Comments	O & M Recommendation	Structural Recommendation
569985	L01394	003+15	013+98	6	Concrete	LINE IS FAIR	Line is in fair condition aside from a large void in the pipe @ 8' US fro DSMH (same as in 2005).	None at this time	Trenchless Point Repair
1143247	L02914	004+63	088+30	6	Concrete	U/S M/H UNMAPPED	Line is in fair condition. Pipe coated w/ a layer of glue which is heavy in spots & threatens to clog main. Large hole w/ void in pipe @ 203' DS (across from tap).	None at this time	Trenchless Point Repair
596003	L03390	001+61	001+46	6	Concrete	None	Line is in fair condition w/ minor deterioration & encrustation @ joints noted. Holes in pipe @ 19' & 73' DS. 6" CO line slips into 8" line approx. 2' US from DSMH. "	None at this time	Trenchless Point Repair
567864	L04167	024+73	021+82	6	Concrete	LINE IS FAIR	Line appears to be in fair condition. Light to moderate encrustation @ joints (mostly in lower portion of segment). Infiltration (runner) @ 116' US. Previous repair w/ VCP/PVC @ 125' US noted.	None at this time	Trenchless Point Repair
569071	L04168	012+53	010+50	6	Concrete	LINE IS POOR	Line is in fair to poor condition. 40' section, from approx. 115' DS to 165' DS, is cracked & broken and in need of repair or fortification. Remainder of pipe is fair w/ only minor cracks noted.	None at this time	Trenchless Point Repair
1143229	L04168	006+00	003+11	6	Concrete	LINE IS FAIR	Line appears to be in fair condition w/ minor deterioration & root intrusion noted. Pipe more notably cracked/broken around 200' to 220' US.	Root Program	Trenchless Point Repair
584210	L04828	004+14	024+73	6	Concrete	LINE IS FAIR	Line appears to be in fair condition except for broken pipe @ approx. 60' US (fairly severe).	None at this time	Trenchless Point Repair

Object ID	Lateral/ Main	USID	DSID	Pipe Size	Pipe Material	Additional Review/ Comment	CCTV review Comments	O & M Recommendation	Structural Recommendation
1143228	L05012	006+50	001+27	6	Concrete	LINE IS FAIR	Line appears to be in fair/poor condition w/ some minor cracking noted (slightly more severe around 130' US).	None at this time	Trenchless Point Repair
1143160	L05248	005+83	050+80	6	Concrete	LINE IS FAIR	Line appears to be in fair condition except for a section of broken pipe @ around 45' US.	None at this time	Trenchless Point Repair
1143226	L05740	005+03	000+71	6	Concrete	Crew says collapse @ 137' DS, I disagree. See Jeteye footage	Line is in fair condition until CCTV encounters a heavily used tap (laundromat & cleaners) @ 137' DS and gets obstructed for unknown reason (can't see for the soap suds) but flow appears fine. RSU-Line appears to be in fair condition except for severely broken pipe somewhere around the 270' US mark. Footage and video skip around" make it hard to pinpoint."	None at this time	Trenchless Point Repair
483785	M00017	086+86	085+00	8	Vitrified Clay	None	Fair condition glue caked" line w/ broken pipe @ 14' DS."	None at this time	Trenchless Point Repair

Table D-3. Replacements

Object ID	Lateral/ Main	USID	DSID	Pipe Size	Pipe Material	Additional Review/ Comment	CCTV review Comments	O & M Recommendation	Structural Recommendation
1143157	L00385	018+00	013+50	6	Vitrified Clay	DSMH 6' DEEP; VERY POOR OLD CLAY PIPE	Limited quality video shows poor condition VCP w/ much cracked & broken pipe. Roots intrude @ many taps, joints, & defects. Video cuts out @ 386' US, although report says CCTV made it to the USMH.- See 2005 video also.	Root Program	Replace

Object ID	Lateral/ Main	USID	DSID	Pipe Size	Pipe Material	Additional Review/ Comment	CCTV review Comments	O & M Recommendation	Structural Recommendation
1143146	L00385	008+00	004+97	8	Vitrified Clay	poor line	Pipe is in fair up to 103' from U/S MH, after that it is in poor condition with multiple cracks, broken pipe throughout the lower 210' of this segment.	None at this time	Replace
1143252	L01113R	013+20	007+78	6	Vitrified Clay	DO RSU BLOCK BY ENCRUS-TATION CAN'T PASS	Poor condition line, CCTV blocked @ 50' US by what appears to be a large root mass growing in the flow line, survey abandoned. RSU-Poor condition pipe in surveyable portion. CCTV blocked @ 101' DS by broken & collapsing pipe. Only able to inspect 151' of this 542' segment.	Root Program	Replace
1143151	L01328	015+33	008+48	6	Concrete	DSMH is 5' deep.	Poor condition line w/ deterioration & broken pipe throughout surveyed portion. Line collapsing (as it was back in 2005 survey) @ 142' US, now collecting debris & clogging main line.	None at this time	Replace
1143221	L01381	013+98	008+00	6	Vitrified Clay	45 ' SHORT OF M/H COMPLETE-SEE RSU.	Line is in fair/poor condition. Multiple cracks & defective joints w/ root intrusion (minor/moderate) throughout. Pipe & taps from 400' DS on are in poor shape. Intruding tap @ 554' DS blocks camera. RSU- Line is fair to 31' US where a (12 o'clock) tap is intruding and blocks camera.	Root Program	Replace
1143211	L01381	008+00	003+60	6	Concrete	LINE VERY POOR	Line is in poor condition w/ cracked, eroded, brittle, & broken pipe & roots intruding throughout. Jeteye blocked by broken pipe somewhere around 465' DS. See next inspection for RSU. RSU-More poor condition broken up CO pipe.	Root Program	Replace
569980	L01381	003+60	002+80	6	Concrete	LINE VERY POOR	Line is in poor condition w/ cracked, eroded, brittle, & broken pipe & roots intruding throughout. Jeteye blocked by broken pipe somewhere around 465' DS. See next inspection for RSU.	Root Program	Replace

Object ID	Lateral/ Main	USID	DSID	Pipe Size	Pipe Material	Additional Review/ Comment	CCTV review Comments	O & M Recommendation	Structural Recommendation
							RSU-More poor condition broken up CO pipe.		
569981	L01381	002+80	046+50	6	Concrete	LINE IS POOR	Line is in poor condition. Cracked, broken, & deteriorated pipe w/ heavy roots intruding throughout. Additional cleaning or root cutting could be detrimental and cause premature collapse.	Root Program	Replace
1143223	L01389	007+38	003+15	6	Concrete	LINE IS POOR	Line is in fair to poor condition. CO pipe is cracked throughout w/ roots intruding, more severely broken in spots. 1 previous repair w/ PVC & 2 offset joints noted.	None at this time	Replace
1143129	L02506	005+05	008+00	6	Vitrified Clay	LINE IS VERY POOR	Line is fair to poor w/ moderate to heavy cracks/broken pipe in areas. Line is currently serviceable but could fail at any time, especially from 275' to 375' US. Pipe collapsing @ 450' US.	None at this time	Replace
1143242	L02612	003+04	073+00	6	Concrete	None	Line is in fair/poor condition. 2 recent repairs were done (92' and 126' US) in order to reach EOL. Pipe is currently serviceable, but it has many cracks and is especially poor around the taps.	None at this time	Replace
1143246	L02759	004+75	086+86	6	Concrete	None	Fair/poor condition CO line w/ several areas of broken/missing pipe. Pipe is totally collapsed @ 441' US (possibility of no services beyond this point). Video skips from 325' to 416' US.	None at this time	Replace
1143213	L03674	002+05	046+50	6	Concrete	Need to do temp open cut point repair to improve flow.	Line is in poor condition. Multiple cracks, voids, previous point repairs and collapsed pipe at 101' D/D. Replace this line - RSU done.	None at this time	Replace
567871	L04167	014+10	011+00	6	Concrete	VERY POOR; LIKE 12 FT TO DN ST STA	Line is fair from USMH to 235' DS w/ only minor encrustation & moderate roots inside taps. Pipe goes	Root Program	Replace

Object ID	Lateral/ Main	USID	DSID	Pipe Size	Pipe Material	Additional Review/ Comment	CCTV review Comments	O & M Recommendation	Structural Recommendation
						011+00	poor @ 235' DS w/ moderate/major cracking throughout remainder until blocked by debris @ 300' DS.		
603291	M00017	081+88	079+46	8	Vitrified Clay	None	Line is in fair/poor condition. Fine roots noted in spots. Section of pipe broken (69' to 79' DS). Pipe becomes poor & broken starting @ 193' DS. CCTV submerged & blocked by unknown @ 224' DS. No RSU.	Root Program	Replace
1143240	M00017	079+46	076+23	8	Vitrified Clay	THIS LINE SHOULD NOT BE RETVED	Poor condition VCP line w/ cracked & broken pipe throughout. Pipe is severely broken and threatening total collapse from 220' DS on to where it IS COLLAPSING @ 262' DS, survey abandoned.	None at this time	Replace
1143241	M00017	076+23	073+00	8	Vitrified Clay	None	Surveyed portion of line (60' of 322') is in poor condition. Pipe is severely cracked & broken throughout. Camera remains near total submergence for entire inspection until being obstructed @ 60' DS.	None at this time	Replace
1143244	M00017	073+00	071+32	8	Vitrified Clay	Videoed in reverse	Fair/poor condition line w/ some cracking & broken pipe detectable (video was shot while in reverse due to high amount of flow, yet camera still remains submerged for most of the inspection.	None at this time	Replace
572405	M00017	046+50	042+65	12	HDPE	RECORDING COMMING BACK...due to high flow	Fair condition HDPE from DSMH to 309' US then turns to POOR condition, replace VCP for the remaining 62' (from USMH to 62' DS).	None at this time	Replace

Table D-4. Root abatement

Object ID	Lateral/ Main	USID	DSID	Pipe Size	Pipe Material	Additional Review/ Comment	CCTV review Comments	O & M Recommendation	Structural Recommendation
603292	L00385	020+50E	018+00	6	Vitrified Clay	POOR OLD CLAY PIPE-see also 2005 inspection	Fair/poor condition VCP has much broken pipe (at least 12 separate spots) w/ minor/moderate roots intruding joints & cracks throughout. Previous repair from 75' to 95' sits lower than rest of line.	Root Program	None at this time
1143157	L00385	018+00	013+50	6	Vitrified Clay	DSMH 6' DEEP; VERY POOR OLD CLAY PIPE	Limited quality video shows poor condition VCP w/ much cracked & broken pipe. Roots intrude @ many taps, joints, & defects. Video cuts out @ 386' US, although report says CCTV made it to the USMH.- See 2005 video also.	Root Program	Replace
1143145	L00385	000+01	008+00	8	Vitrified Clay	POOR	Reviewable portion of segment (video skips from 7' US to 202' US) is in fair condition w/ only minor cracks noted.	Root Program	None at this time
1143252	L01113R	013+20	007+78	6	Vitrified Clay	DO RSU BLOCK BY ENCRUSTATION CAN'T PASS	Poor condition line, CCTV blocked @ 50' US by what appears to be a large root mass growing in the flow line, survey abandoned. RSU-Poor condition pipe in surveyable portion. CCTV blocked @ 101' DS by broken & collapsing pipe. Only able to inspect 151' of this 542' segment.	Root Program	Replace
1143148	L01113R	007+78	004+08	6	Vitrified Clay	None	Line appears to be in fair condition. Much footage is either submerged or blurry. A few cracks and some roots in taps were noted.	Root Program	None at this time
1143154	L01328	003+80	001+80	6	Concrete	DO RSU...when?	Fair/poor condition CO line w/ minor cracks & broken pipe throughout (structurally adequate). Roots (minor) intrude joints & defects throughout. CCTV blocked @ 368' US by debris in flowline.	Root Program	None at this time
1143220	L01381	021+30	013+98	6	Concrete	LINE IS FAIR	Line appears to be in fair condition	Root Program	None at this time

Object ID	Lateral/ Main	USID	DSID	Pipe Size	Pipe Material	Additional Review/ Comment	CCTV review Comments	O & M Recommendation	Structural Recommendation
							w/ minor to moderate roots intruding joints & taps and some minor cracks noted. Moderate (flow friendly) offset joint @ 14' US (previous repair w/ VCP).		
1143221	L01381	013+98	008+00	6	Vitrified Clay	45 ' SHORT OF M/H COMPLETE-SEE RSU.	Line is in fair/poor condition. Multiple cracks & defective joints w/ root intrusion (minor/moderate) throughout. Pipe & taps from 400' DS on are in poor shape. Intruding tap @ 554' DS blocks camera. RSU-Line is fair to 31' US where a (12 o'clock) tap is intruding and blocks camera.	Root Program	Replace
1143211	L01381	008+00	002+80	6	Concrete	LINE VERY POOR	Line is in poor condition w/ cracked, eroded, brittle, & broken pipe & roots intruding throughout. Jeteye blocked by broken pipe somewhere around 465' DS. See next inspection for RSU. RSU-More poor condition broken up CO pipe.	Root Program	Replace
569981	L01381	002+80	046+50	6	Concrete	LINE IS POOR	Line is in poor condition. Cracked, broken, & deteriorated pipe w/ heavy roots intruding throughout. Additonal cleaning or root cutting could be detrimental and cause premature collapse.	Root Program	Replace
569938	L01389	007+97	007+38	6	Concrete	LINE IS FAIR	Line appears to be in fair condition. Some moderate cracking w/ roots intruding in spots.	Root Program	None at this time
1143251	L02057	008+65	003+07	6	Vitrified Clay	Roots removed.	Line is in fair condition w/ some minor cracking and root intrusion. Section of is broken badly around taps @ 151' US.	Root Program	Open Cut Point Repair

Object ID	Lateral/ Main	USID	DSID	Pipe Size	Pipe Material	Additional Review/ Comment	CCTV review Comments	O & M Recommendation	Structural Recommendation
596059	L02057	003+07	007+78	6	Vitrified Clay	None	Surveyed portion of line (181' of 307') is fair/poor w/ defective joints, minor cracks, & roots throughout. CCTV blocked by root mass/ grease/ grade change @ 181' DS. RSU-CCTV blocked by same root mass @ 116' US.	Root Program	None at this time
567871	L04167	014+10	011+00	6	Concrete	VERY POOR; LIKE 12 FT TO DN ST STA 011+00	Line is fair from USMH to 235' DS w/ only minor encrustation & moderate roots inside taps. Pipe goes poor @ 235' DS w/ moderate/major cracking throughout remainder until blocked by debris @ 300' DS.	Root Program	Replace
569072	L04168	013+78	012+53	6	Concrete	LINE IS FAIR	Line appears to be in fair condition w/ minor encrustation @ joints. Root mass intrudes from 10 o'clock tap @ 104' US (945 E Berry).	Root Program	None at this time
1143229	L04168	006+00	003+11	6	Concrete	LINE IS FAIR	Line appears to be in fair condition w/ minor deterioration & root intrusion noted. Pipe more notably cracked/broken around 200' to 220' US.	Root Program	Trenchless Point Repair
594772	L04602	009+07	006+00	6	Concrete	BLOCKED AT 225	Line appears to be in fair condition until Jeteye gets blocked by a build-up of unknown origin (looks like grease) @ around 225' US. RSU-Surveyed portion of line (116' of 302') in fair condition w/ light/moderate roots intruding taps & joints. CCTV blocked @ 68' DS by encrustation (concrete swag build-up) near tap.	Root Program	None at this time
1143159	L04602	006+00	050+80	6	Concrete	LINE IS FAIR	Line appears to be in fair/poor condition w/ moderate cracks noted (mostly around taps in upper 1/2 of segment) and fine/moderate root intrusion (mostly through joints/taps in lower 1/2 of segment).	Root Program	None at this time

Object ID	Lateral/ Main	USID	DSID	Pipe Size	Pipe Material	Additional Review/ Comment	CCTV review Comments	O & M Recommendation	Structural Recommendation
603291	M00017	081+88	079+46	8	Vitrified Clay	None	Line is in fair/poor condition. Fine roots noted in spots. Section of pipe broken (69' to 79' DS). Pipe becomes poor & broken starting @ 193' DS. CCTV submerged & blocked by unknown @ 224' DS.	Root Program	Replace

Table D-5. Summary

Object ID	Lateral/ Main	USID	DSID	Pipe Size	Pipe Material	Additional Review/ Comment	CCTV review Comments	O & M Recommendation	Structural Recommendation
603292	L00385	020+50E	018+00	6	Vitrified Clay	POOR OLD CLAY PIPE-see also 2005 inspection	Fair/poor condition VCP has much broken pipe (at least 12 separate spots) w/ minor/moderate roots intruding joints & cracks throughout. Previous repair from 75' to 95' sits lower than rest of line.	Root Program	None at this time
1143157	L00385	018+00	013+50	6	Vitrified Clay	DSMH 6' DEEP; VERY POOR OLD CLAY PIPE	Limited quality video shows poor condition VCP w/ much cracked & broken pipe. Roots intrude @ many taps, joints, & defects. Video cuts out @ 386' US, although report says CCTV made it to the USMH.- See 2005 video also.	Root Program	Replace
1143144	L00385	013+50	000+01	6	Vitrified Clay	Videoed upper portion in reverse after cleaning lens @ DSMH.	Line is in fair condition w/ several minor/moderate cracks and 2 old point repairs noted.	None at this time	None at this time

Object ID	Lateral/ Main	USID	DSID	Pipe Size	Pipe Material	Additional Review/ Comment	CCTV review Comments	O & M Recommendation	Structural Recommendation
1143146	L00385	008+00	004+97	8	Vitrified Clay	poor line	Pipe is in fair up to 103' from U/S MH, after that it is in poor condition with multiple cracks, broken pipe throughout the lower 210' of this segment.	None at this time	Replace
1143155	L00385	004+85	001+80	8	Vitrified Clay	None	Fair condition VCP w/ only a few minor cracks noted. Offset joint @ 314' DS (just US from DSMH where VCP meets PVC inflow stub portion).	None at this time	None at this time
1143156	L00385	001+80	054+86	6	Vitrified Clay	None	Line appears to be in fair condition. Very high flow amount for a 6 pipe."	None at this time	None at this time
1143145	L00385	000+01	008+00	8	Vitrified Clay	POOR	Reviewable portion of segment (video skips from 7' US to 202' US) is in fair condition w/ only minor cracks noted.	Root Program	None at this time
587036	L00863	013+19	008+54	8	Polyvinyl Chloride	PIPE GOOD 8 PVC"	Line is in good condition.	None at this time	None at this time
1143158	L00863	008+54	004+35	8	Polyvinyl Chlorid	GOOD PIPE PCV&DIP	Line is in good condition. DIP for 1st 60' DS then PVC for the rest.	None at this time	None at this time
587039	L00863	004+35	002+50	8	Polyvinyl Chloride	GOOD PIPE 8' PVC	Line is in good condition. Video skips from 54' to 65' DS and then again from 150' to 154' DS near where taps are located (according to previous inspection).	None at this time	None at this time
587040	L00863	002+50	000+01	8	Polyvinyl Chloride	GOOD PIPE PVC 8";No"	Line is in good condition.	None at this time	None at this time
1143239	L00940	083+40	079+46	6	Concrete	8 ' DEEP M/H D/S; NO U/S FOUND-nor does it ping in GIS.	Condition unknown. Camera gets blocked by bend in line @ 2' US. No USMH for RSU.	None at this time	None at this time
478443	L00943	005+94	002+90	8	Polyvinyl Chloride	None	Line is in good condition. Do not rely on distances as crew forgot to reset counter at the DSMH.	None at this time	None at this time

Object ID	Lateral/ Main	USID	DSID	Pipe Size	Pipe Material	Additional Review/ Comment	CCTV review Comments	O & M Recommendation	Structural Recommendation
478444	L00943	002+90	085+00	8	Polyvinyl Chloride	None	Line is in good condition. Minor compression deformities noted, but none are severe.	None at this time	None at this time
1143248	L01113	022+00	005+35	6	Vitrified Clay	LINE IS FAIR	Line appears to be in fair condition w/ only minor cracks noted.	None at this time	None at this time
1143252	L01113R	013+20	007+78	6	Vitrified Clay	DO RSU BLOCK BY ENCRUSTATION CAN'T PASS	Poor condition line, CCTV blocked @ 50' US by what appears to be a large root mass growing in the flow line, survey abandoned. RSU-Poor condition pipe in surveyable portion. CCTV blocked @ 101' DS by broken & collapsing pipe. Only able to inspect 151' of this 542' segment.	Root Program	Replace
1143148	L01113R	007+78	004+08	6	Vitrified Clay	None	Line appears to be in fair condition. Much footage is either submerged or blurry. A few cracks and some roots in taps were noted.	Root Program	None at this time
1143147	L01113R	004+08	004+85	8	Vitrified Clay	See also 2005 inspection from USMH...it's clearer.	Fair condition VCP aside from 2 spots w/ broken pipe (146' US @ joint of a previous repair & 363' US). Heavy roots inside service line @ 196' US (10 o'clock tap serves 945 E Morningside Dr.).	None at this time	None at this time
1143151	L01328	015+33	008+48	6	Concrete	DSMH is 5' deep.	Poor condition line w/ deterioration & broken pipe throughout surveyed portion. Line collapsing (as it was back in 2005 survey) @ 142' US, now collecting debris & clogging main line.	None at this time	Replace
1143152	L01328	008+48	003+80	6	Vitrified Clay	1/2 VCP and 1/2 CO	Line is in fair/poor condition w/ several cracks (minor/moderate) noted throughout (especially in CO portions), however none are currently severe enough to warrant immediate repairs.	None at this time	None at this time
1143154	L01328	003+80	001+80	6	Concrete	DO RSU... when?	Fair/poor condition CO line w/ minor cracks & broken pipe	Root Program	None at this time

Object ID	Lateral/ Main	USID	DSID	Pipe Size	Pipe Material	Additional Review/ Comment	CCTV review Comments	O & M Recommendation	Structural Recommendation
							throughout (structurally adequate). Roots (minor) intrude joints & defects throughout. CCTV blocked @ 368' US by debris in flowline.		
601588	L01380	009+05	005+00	8	Polyvinyl Chloride	GOOD LINE... bad inspection!	Line is in good condition. Video missing from 338' to 400' US.	None at this time	None at this time
601590	L01380	005+00	001+80	8	Polyvinyl Chloride	GOOD	Line is in good condition. Video skips (115' to 122' US & 214' to 220' US).	None at this time	None at this time
1143220	L01381	021+30	013+98	6	Concrete	LINE IS FAIR	Line appears to be in fair condition w/ minor to moderate roots intruding joints & taps and some minor cracks noted. Moderate (flow friendly) offset joint @ 14' US (previous repair w/ VCP).	Root Program	None at this time
1143221	L01381	013+98	008+00	6	Vitrified Clay	45 ' SHORT OF M/H COMPLETE- SEE RSU.	Line is in fair/poor condition. Multiple cracks & defective joints w/ root intrusion (minor/moderate) throughout. Pipe & taps from 400' DS on are in poor shape. Intruding tap @ 554' DS blocks camera. RSU- Line is fair to 31' US where a (12 o'clock) tap is intruding and blocks camera.	Root Program	Replace

Object ID	Lateral/ Main	USID	DSID	Pipe Size	Pipe Material	Additional Review/ Comment	CCTV review Comments	O & M Recommendation	Structural Recommendation
1143211	L01381	008+00	002+80	6	Concrete	LINE VERY POOR	Line is in poor condition w/ cracked, eroded, brittle, & broken pipe & roots intruding throughout. Jeteye blocked by broken pipe somewhere around 465' DS. See next inspection for RSU. RSU- More poor condition broken up CO pipe.	Root Program	Replace
569981	L01381	002+80	046+50	6	Concrete	LINE IS POOR	Line is in poor condition. Cracked, broken, & deteriorated pipe w/ heavy roots intruding throughout. Additional cleaning or root cutting could be detrimental and cause premature collapse.	Root Program	Replace
569938	L01389	007+97	007+38	6	Concrete	LINE IS FAIR	Line appears to be in fair condition. Some moderate cracking w/ roots intruding in spots.	Root Program	None at this time
1143223	L01389	007+38	003+15	6	Concrete	LINE IS POOR	Line is in fair to poor condition. CO pipe is cracked throughout w/ roots intruding, more severely broken in spots. 1 previous repair w/ PVC & 2 offset joints noted.	None at this time	Replace
1143224	L01389	003+15	003+15	6	Concrete	FAIR	Line is in fair condition.	None at this time	None at this time
1143222	L01394	008+40	003+15	6	Concrete	BLOCK DEBIS DO RSU	Surveyed portion of line (185' of 525') is in fair to poor condition w/ deterioration, cracks, & broken pipe throughout. 2 previous repairs noted. CCTV blocked by debris (rocks) in flowline @ 185' DS. RSU w/ Jeteye-Line is in fair/poor condition. CO pipe is cracked & broken in many places, yet still structurally adequate. 2 previous PVC repairs noted. Blocked @ 264ish' US by rock, see RSU.	None at this time	None at this time

Object ID	Lateral/ Main	USID	DSID	Pipe Size	Pipe Material	Additional Review/ Comment	CCTV review Comments	O & M Recommendation	Structural Recommendation
569985	L01394	003+15	013+98	6	Concrete	LINE IS FAIR	Line is in fair condition aside from a large void in the pipe @ 8' US fro DSMH (same as in 2005).	None at this time	Trenchless Point Repair
1143135	L01701	009+02	005+34	6	Concrete	LINE IS FAIR	Line appears to be in fair condition, for its age.	None at this time	None at this time
1143128	L01701	005+34	004+85	6	Concrete	LINE IS FAIR	Line appears to be in fair condition w/ only a few minor cracks notable. Fine roots intrude joints in lower portion of segment (30' to 40' of VCP from DSMH).	None at this time	None at this time
586621	L01704R*	003+40	076+23	8	Polyvinyl Chloride	None	Line is in good condition w/some debris present (small rocks pushed by camera).	None at this time	None at this time
572466	L01705	008+20	002+27	8	Polyvinyl Chloride	STAT #'S DONT MATCH	Line is in good condition.	None at this time	None at this time
572467	L01705	002+27	073+00	8	Polyvinyl Chloride	None	Line is in good condition.	None at this time	None at this time
569986	L01707R	008+68	006+50	8	Polyvinyl Chloride	None	Line is in good condition.	None at this time	None at this time
569987	L01707R	006+50	002+50	8	Polyvinyl Chloride	None	Line is in good condition.	None at this time	None at this time
569929	L01707R	002+50	076+23	8	Polyvinyl Chloride	None	Line is in good condition.	None at this time	None at this time
596115	L01743	003+55	003+08	6	Vitrified Clay	None	Line is in fair condition. See Jeteye inspection from lower segment on this line. He shot thru to this EOL and it is fair.	None at this time	None at this time
1143130	L01743	003+08	000+01	6	Concrete	LINE IS FAIR	CO line is in fair condition w/ some minor/moderate deterioration & cracks noted. 2 old point repairs w/ PVC also noted.	None at this time	None at this time
596048	L02057	017+28E	014+50	6	Polyvinyl Chloride	None	Line is in good condition.	None at this time	None at this time
596049	L02057	014+50	008+47	8	Polyvinyl Chloride	None	Line is in good condition.	None at this time	None at this time

Object ID	Lateral/ Main	USID	DSID	Pipe Size	Pipe Material	Additional Review/ Comment	CCTV review Comments	O & M Recommendation	Structural Recommendation
1143251	L02057	008+65	003+07	6	Vitrified Clay	Roots removed.	Line is in fair condition w/ some minor cracking and root intrusion. Section of is broken badly around taps @ 151' US.	Root Program	Open Cut Point Repair
596059	L02057	003+07	007+78	6	Vitrified Clay	None	Surveyed portion of line (181' of 307') is fair/poor w/ defective joints, minor cracks, & roots throughout. CCTV blocked by root mass/grease/grade change @ 181' DS. RSU-CCTV blocked by same root mass @ 116' US.	Root Program	None at this time
1143245	L02235	005+78	081+88	6	Concrete	LINE IS FAIR	Line appears to be in fair condition. 1 previous repair noted @ 240' US.	None at this time	None at this time
478892	L02303	012+35	010+82	8	Polyvinyl Chloride	None	Line is in good condition. Other lateral, entering same DSMH from the west suffers infiltration.	None at this time	None at this time
478891	L02303	010+82	006+71	8	Polyvinyl Chloride	None	Line is in fair condition. Tap @ 344' DS has exposed gasket. Minor offset joint @ 352' DS.	None at this time	None at this time
478889	L02303	006+71	003+36	8	Polyvinyl Chloride	None	Line is in good condition. Flatness causes slight debris build-up in flowline, not severe.	None at this time	None at this time
478890	L02303	003+36	085+00	8	Polyvinyl Chloride	None	Line is in good condition.	None at this time	None at this time
479319	L02303A	001+76	010+82	6	Vitrified Clay	Line runs under building (2933 Bryan). No MH @ EOL.	Line is in good condition.	None at this time	None at this time
1143129	L02506	005+05	008+00	6	Vitrified Clay	LINE IS VERY POOR	Line is fair to poor w/ moderate to heavy cracks/broken pipe in areas. Line is currently serviceable but could fail at any time, especially from 275' to 375' US. Pipe collapsing @ 450' US.	None at this time	Replace

Object ID	Lateral/ Main	USID	DSID	Pipe Size	Pipe Material	Additional Review/ Comment	CCTV review Comments	O & M Recommendation	Structural Recommendation
1143242	L02612	003+04	073+00	6	Concrete	None	Line is in fair/poor condition. 2 recent repairs were done (92' and 126' US) in order to reach EOL. Pipe is currently serviceable, but it has many cracks and is especially poor around the taps.	None at this time	Replace
1143246	L02759	004+75	086+86	6	Concrete	None	Fair/poor condition CO line w/ several areas of broken/missing pipe. Pipe is totally collapsed @ 441' US (possibility of no services beyond this point). Video skips from 325' to 416' US.	None at this time	Replace
479302	L02914	005+03	004+77	6	Concrete	NO U/S M/H @ EOL.	Line in fair condition w/minor deterioration noted. Moderate encrustation in top of 2nd US joint.	None at this time	None at this time
1155541	L02914	004+77	004+64	6	Concrete	None	Line in fair condition. Large chunk of debris pushed to DSMH.	None at this time	None at this time
1143247	L02914	004+63	088+30	6	Concrete	U/S M/H UNMAPPED	Line is in fair condition. Pipe coated w/ a layer of glue which is heavy in spots & threatens to clog main. Large hole w/ void in pipe @ 203' DS (across from tap).	None at this time	Trenchless Point Repair
479303	L02914A	000+34	004+77	6	Concrete	NO U/S M/H	Condition unknown. Camera never enters the line (just a manhole inspect). Report claims only encrustation.	None at this time	None at this time
596013	L02981	006+16	001+46	8	Polyvinyl Chloride	None	Line is in good condition.	None at this time	None at this time
596012	L02981	001+46	063+19	8	Polyvinyl Chloride	GOOD	Line is in good condition. Video skips from USMH to 35' DS.	None at this time	None at this time
596003	L03390	001+61	001+46	6	Concrete	None	Line is in fair condition w/ minor deterioration & encrustation @ joints noted. Holes in pipe @ 19' & 73' DS. 6" CO line slips into 8" line approx. 2' US from DSMH. "	None at this time	Trenchless Point Repair

Object ID	Lateral/ Main	USID	DSID	Pipe Size	Pipe Material	Additional Review/ Comment	CCTV review Comments	O & M Recommendation	Structural Recommendation
1143250	L03553	007+19	005+35	6	Concrete	None	Line is in fair condition. Section of VCP (old spot repair) from 155' to 160' US is slightly displaced, nothing severe.	None at this time	None at this time
1143243	L03553	005+35	071+32	6	Concrete	CANT PUSH ROCK ANYMORE DO RSU	Fair condition pipe until CCTV blocked (same as 2005 inspection) by offset, bend, grade & material change @ 114' DS (spot of previous repair). This time debris also involved. RSU doesn't make it out of the DSMH-Operator says he's blocked in MH but doesn't say by what.	None at this time	Open Cut Point Repair
596002	L03553R	008+47	007+19	8	Polyvinyl Chloride	BIG BEND INTO M/H D/S COMPLETE	Line is in fair condition, flat in spots. Severe bend in line leading into DSMH causes restriction of flow, submerging camera for the final 10' to 15'.	None at this time	None at this time
1155542	L03674	002+60	002+05	6	Concrete	CHANGED STA. NUMBERS & W/O #	Line is in fair condition. Some deterioration but overall OK	None at this time	None at this time
1143213	L03674	002+05	046+50	6	Concrete	Need to do temp open cut point repair to improve flow.	Line is in poor condition. Multiple cracks, voids, previous point repairs and collapsed pipe at 101' D/D. Replace this line - RSU done.	None at this time	Replace
1143227	L04167	030+47	024+73	6	Concrete	LINE IS FAIR	Line appears to be in fair condition. 2 previous repairs w/ PVC noted @ 140' & 210' US.	None at this time	None at this time
567864	L04167	024+73	021+82	6	Concrete	LINE IS FAIR	Line appears to be in fair condition. Light to moderate encrustation @ joints (mostly in lower portion of segment). Infiltration (runner) @ 116' US. Previous repair w/ VCP/PVC @ 125' US noted.	None at this time	Trenchless Point Repair

Object ID	Lateral/ Main	USID	DSID	Pipe Size	Pipe Material	Additional Review/ Comment	CCTV review Comments	O & M Recommendation	Structural Recommendation
567865	L04167	021+82	017+00	6	Concrete	LINE IS FAIR	Line appears to be in fair condition. Reported infiltration is only dripper when Jeteye isn't on.	None at this time	None at this time
1143219	L04167	017+00	014+10	6	Concrete	LINE IS GOOD	Line appears to be in fair condition.	None at this time	None at this time
567871	L04167	014+10	011+00	6	Concrete	VERY POOR; LIKE 12 FT TO DN ST STA 011+00	Line is fair from USMH to 235' DS w/ only minor encrustation & moderate roots inside taps. Pipe goes poor @ 235' DS w/ moderate/major cracking throughout remainder until blocked by debris @ 300' DS.	Root Program	Replace
1143218	L04167	011+00	004+27	6	Concrete	LINE VERY POOR BLOCKED BY GREASE 575 FT	Line is in fair/poor condition. Much cracking & broken pipe, especially in upper portion. Bad pipe @ 326' US" being repaired. Grease @ 575' US blocks Jeteye, survey abandoned. No RSU attempted."	None at this time	Open Cut Point Repair
567877	L04167*	004+27	001+27	8	Polyvinyl Chloride	LINE IS GOOD	Line is in good condition.	None at this time	None at this time
567878	L04167*	001+27	038+58	8	Polyvinyl Chloride	LINE IS GOOD	Line is in good condition.	None at this time	None at this time
569072	L04168	013+78	012+53	6	Concrete	LINE IS FAIR	Line appears to be in fair condition w/ minor encrustation @ joints. Root mass intrudes from 10 o'clock tap @ 104' US (945 E Berry).	Root Program	None at this time
569071	L04168	012+53	010+50	6	Concrete	LINE IS POOR	Line is in fair to poor condition. 40' section, from approx. 115' DS to 165' DS, is cracked & broken and in need of repair or fortification. Remainder of pipe is fair w/ only minor cracks noted.	None at this time	Trenchless Point Repair
569070	L04168	010+50	006+00	6	Concrete	LINE IS FAIR	Line appears to be in fair condition w/ only a few minor cracks noted.	None at this time	None at this time
1143229	L04168	006+00	003+11	6	Concrete	LINE IS FAIR	Line appears to be in fair condition w/ minor deterioration & rooty	Root Program	Trenchless Point Repair

Object ID	Lateral/ Main	USID	DSID	Pipe Size	Pipe Material	Additional Review/ Comment	CCTV review Comments	O & M Recommendation	Structural Recommendation
							intrusion noted. Pipe more notably cracked/broken around 200' to 220' US.		
584201	L04168*	003+11	004+27	8	Polyvinyl Chloride	LINE IS GOOD	Line appears to be in good condition.	None at this time	None at this time
594772	L04602	009+07	006+00	6	Concrete	BLOCKED AT 225	Line appears to be in fair condition until Jeteye gets blocked by a build-up of unknown origin (looks like grease) @ around 225' US. RSU-Surveyed portion of line (116' of 302') in fair condition w/ light/moderate roots intruding taps & joints. CCTV blocked @ 68' DS by encrustation (concrete swag build-up) near tap.	Root Program	None at this time
1143159	L04602	006+00	050+80	6	Concrete	LINE IS FAIR	Line appears to be in fair/poor condition w/ moderate cracks noted (mostly around taps in upper 1/2 of segment) and fine/moderate root intrusion (mostly through joints/taps in lower 1/2 of segment).	Root Program	None at this time
584193	L04828	004+50	004+14	6	Concrete	LINE IS GOOD	Line appears to be in good condition.	None at this time	None at this time
584210	L04828	004+14	024+73	6	Concrete	LINE IS FAIR	Line appears to be in fair condition except for broken pipe @ approx. 60' US (fairly severe).	None at this time	Trenchless Point Repair
1143217	L05012	010+10	006+50	6	Concrete	LINE IS FAIR	Line appears to be in fair condition.	None at this time	None at this time
1143228	L05012	006+50	001+27	6	Concrete	LINE IS FAIR	Line appears to be in fair/poor condition w/ some minor cracking noted (slightly more severe around 130' US).	None at this time	Trenchless Point Repair
1143160	L05248	005+83	050+80	6	Concrete	LINE IS FAIR	Line appears to be in fair condition except for a section of broken pipe @ around 45' US.	None at this time	Trenchless Point Repair
567827	L05469	015+31	014+27	6	Concrete	LINE IS FAIR	Line appears to be in fair	None at this time	None at this time

Object ID	Lateral/ Main	USID	DSID	Pipe Size	Pipe Material	Additional Review/ Comment	CCTV review Comments	O & M Recommendation	Structural Recommendation
							condition.		
567826	L05469	014+27	012+26	6	Concrete	LINE IS FAIR...........is it?	Line reported to be fair by Jeteye crew. Overall condition is uncertain due to video being blurred by full-on Jeteye spray for nearly the whole segment & no reverse footage.	None at this time	None at this time
1143214	L05469	012+26	006+50	6	Concrete	LINE IS FAIR	Line appears to be in fair condition.	None at this time	None at this time
1143215	L05469	006+50	045+28	6	Concrete	None	Line appears to be in fair condition w/ some minor cracks noted (mostly near break-in taps and around a few joints).	None at this time	None at this time
1143225	L05740	008+09	005+03	6	Concrete	LINE IS GOOD	Line appears to be in fair condition.	None at this time	None at this time
1143226	L05740	005+03	000+71	6	Concrete	Crew says collapse @ 137' DS, I disagree. See Jeteye footage	Line is in fair condition until CCTV encounters a heavily used tap (Laundromat & cleaners) @ 137' DS and gets obstructed for unknown reason (can't see for the soap suds) but flow appears fine. RSU-Line appears to be in fair condition except for severely broken pipe somewhere around the 270' US mark. Footage and video skip around" make it hard to pinpoint."	None at this time	Trenchless Point Repair
567814	L05740	000+71	021+82	6	Concrete	LINE IS FAIR	Line appears to be in fair condition. Encrustation @ joints and 1 previous repair w/ VCP noted.	None at this time	None at this time
567790	L06409	016+57	012+50	6	Concrete	LINE IS FAIR	Line appears to be in fair condition.	None at this time	None at this time
1143216	L06409	012+50	006+00	6	Concrete	LINE IS FAIR	Line appears to be in fair condition w/ only a few minor cracks and 1 previous repair noted.	None at this time	None at this time
1143230	L06409	006+00	040+48	6	Concrete	LINE IS FAIR	Line appears to be in fair	None at this time	None at this time

Object ID	Lateral/ Main	USID	DSID	Pipe Size	Pipe Material	Additional Review/ Comment	CCTV review Comments	O & M Recommendation	Structural Recommendation
							condition. Video is too blurry to accurately review but Jeteye travels MH to MH and crew reports line in fair condition.		
584216	L08450*	000+58	003+11	8	Polyvinyl Chloride	LINE IS GOOD	Line is in good condition.	None at this time	None at this time
584221	L09113*	000+74	004+14	6	Vitrified Clay	LINE IS GOOD	Line is in good condition.	None at this time	None at this time
483782	M00017	090+09	090+03	8	Concrete	NO U/S M/H; 4 ' DEEP M/H D/S	Line is in good condition. Cap on the EOL is missing w/ a void created from recent cleaning.	None at this time	Open Cut Point Repair
483783	M00017	090+03	088+30	8	Concrete	None	Line is in fair condition w/ slight wear & minor crack @ 6' DS noted.	None at this time	None at this time
483784	M00017	088+30	086+86	8	Vitrified Clay	BLKED BY GLUE FROM U/S PLANT; see next inspection for RSU	Surveyed portion of line (34' of 139') in fair condition except for the fact that glue from the factory US is collecting on the walls of the main line. CCTV blocked by glue build up @ 34' DS. RSU-Video skips from 2.7' to 90.3' US then videos in reverse thru fair condition glue caked" pipe."	None at this time	None at this time
483785	M00017	086+86	085+00	8	Vitrified Clay	None	Fair condition glue caked" line w/ broken pipe @ 14' DS."	None at this time	Trenchless Point Repair

Object ID	Lateral/ Main	USID	DSID	Pipe Size	Pipe Material	Additional Review/ Comment	CCTV review Comments	O & M Recommendation	Structural Recommendation
603291	M00017	081+88	079+46	8	Vitrified Clay	None	Line is in fair/poor condition. Fine roots noted in spots. Section of pipe broken (69' to 79' DS). Pipe becomes poor & broken starting @ 193' DS. CCTV submerged & blocked by unknown @ 224' DS. No RSU.	Root Program	Replace
1143240	M00017	079+46	076+23	8	Vitrified Clay	THIS LINE SHOULD NOT BE RETVED	Poor condition VCP line w/ cracked & broken pipe throughout. Pipe is severely broken and threatening total collapse from 220' DS on to where it IS COLLAPSING @ 262' DS, survey abandoned.	None at this time	Replace
1143241	M00017	076+23	073+00	8	Vitrified Clay	None	Surveyed portion of line (60' of 322') is in poor condition. Pipe is severely cracked & broken throughout. Camera remains near total submergence for entire inspection until being obstructed @ 60' DS	None at this time	Replace
1143244	M00017	073+00	071+32	8	Vitrified Clay	Videoed in reverse	Fair/poor condition line w/ some cracking & broken pipe detectable (video was shot while in reverse due to high amount of flow, yet camera still remains submerged for most of the inspection.	None at this time	Replace
603280	M00017	068+82	068+29	10	Concrete	CAM . UNDER WATER ALL THE WAY / REC COMMING BACK , NO USE	Line is fair. Camera, although submerged all the way, travels MH to MH.	None at this time	None at this time
589069	M00017	068+29	068+10	10	Concrete	None	Line is in fair condition w/ a capped hole @ 9' DS. Hole does not threaten failure to pipe anytime soon.	None at this time	None at this time

Object ID	Lateral/ Main	USID	DSID	Pipe Size	Pipe Material	Additional Review/ Comment	CCTV review Comments	O & M Recommendation	Structural Recommendation
1143161	M00017	052+83	050+80	12	HDPE	None	Line is in fair condition w/ slightly intruding tap @ 168' DS, no cause for concern.	None at this time	None at this time
1143212	M00017	050+80	046+50	12	HDPE	None	Line is in good condition w/ the exception of a minor offset joint @ 218' DS from USMH. See RSU.	None at this time	None at this time
572405	M00017	046+50	042+65	12	HDPE	RECORDING COMING BACK...due to high flow	Fair condition HDPE from DSMH to 309' US then turns to POOR condition, replace VCP for the remaining 62' (from USMH to 62' DS).	None at this time	Replace
572403	M00017	045+28	043+64	10	Vitrified Clay	2005 inspection	Line is in good condition.	None at this time	None at this time
572402	M00017	043+64	041+99	10	Vitrified Clay	None	Line is in fair condition. High flow.	None at this time	None at this time
572404	M00017	042+65	045+28	10	Vitrified Clay	None	Line is in fair condition. High flow.	None at this time	None at this time
569066	M00017	041+99	040+48	12	Polyvinyl Chloride	None	Line is in good condition.	None at this time	None at this time
569065	M00017	040+48	038+58	12	Polyvinyl Chloride	None	Line is in fair condition.	None at this time	None at this time
572401	M00017	038+58	033+74	12	Vitrified Clay	D/S M/H IN CREEK BED	Camera totally submerged & obscured by flow & suds. Appears to be flowing well.	None at this time	None at this time
483786	M00017R	085+00	081+88	10	Polyvinyl Chloride	None	Line is in good but somewhat glue caked" condition. Video is almost totally from submerged viewpoint."	None at this time	None at this time
591073	M00017R	073+75	071+06	10	Ductile Iron	UNDER I -35	Line is in fair condition w/ a moderate deterioration zone from 32' to 38' DS. Pipe here has some wear & small holes w/ sharp edges, none threaten the pipes current structural capabilities.	None at this time	None at this time

Object ID	Lateral/ Main	USID	DSID	Pipe Size	Pipe Material	Additional Review/ Comment	CCTV review Comments	O & M Recommendation	Structural Recommendation
603281	M00017R	071+32	073+75	10	Ductile Iron	M/H 071+32 =075+97 BK	Line is in fair condition, making a couple of fairly dramatic bends in the 1st 40' DS from USMH.	None at this time	None at this time
603282	M00017R	071+06	068+82	10	Ductile Iron	None	Line is in fair condition. High flow.	None at this time	None at this time
589070	M00017R	068+10	065+70	10	Polyvinyl Chloride	None	Line is in good condition.	None at this time	None at this time
589071	M00017R	065+70	063+19	10	Polyvinyl Chloride	None	Line is in good condition.	None at this time	None at this time
589072	M00017R	063+19	058+95	10	Polyvinyl Chloride	None	Line is in good condition.	None at this time	None at this time
589073	M00017R	058+95	054+86	10	Polyvinyl Chloride	None	Line is in good condition. Final 50' of video is obstructed by soap suds, line flowing well.	None at this time	None at this time
589074	M00017R	054+86	052+83	10	Polyvinyl Chloride	RECORDED COMMING BACK	Line appears to be in fair condition. High flow results in mostly submerged video.	None at this time	None at this time


FORT WORTH
WATER
SEWER SYSTEM'S STRUCTURAL AND O & M RECOMMENDATION
Legend :
Manhole
Root Program
Open Cut Point Repair
Trenchless Point Repair
Replace
Sewer Lines
SC03_05 Location Map :
NOTES :
4. Four (4) segments identified for open cut method.
5. Eleven (11) segments identified for trenchless method.
Sub Drainage Basin Area
SC03_05