If You Are Using CCTV to Find Defects in Sewers, You Might Be Fixing the Wrong Pipe

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Abstract. Sewer authorities are coming under increasing pressure to correctly assess, rank, and prioritize sewer rehabilitation projects. While many agencies are moving towards the 'smarter use of utility survey data,' leading authorities are embracing a 'smarter use of utility data gathering' to prioritize needed upgrades and improvements. While recent studies have documented a number of shortcomings in the use of legacy Closed Circuit Television (CCTV) surveying, a new technology, known as Electro Scan, has emerged as a new standard to rapidly quantify sewer defects.

Called "the most significant development since the introduction of the UK Sewer Rehabilitation Manual (SRM)," Electro Scan automatically assesses pipe integrity by measuring the variation of electricity that can pass through the wall of a pipe, in accordance with ASTM Standard 2550-06. While CCTV manufacturers have introduced a number of advancements, including the ability to generate continuously draped side-scanning imagery, provide higher resolution lenses, and improved luminosity controls, reliance on visual observations have often led to incomplete or inaccurate pipeline diagnostics, especially in identifying and quantifying sources of infiltration and defects in sewers.

This paper describes the development, introduction, and benchmark testing of the Electro Scan technology, including product description, field operation, and estimation of peak infiltration rates in Gallons or Litres per Minute. A key aspect of this paper will be discussion of two recently completed US EPA studies, separately covering the assessment of sewer mains and private sewer laterals, respectively. Independent comparison of CCTV and Electro Scan, for the same sewer pipes, will be reviewed for sewers at the City of Kansas City, Missouri (USA) and for laterals at the City of Wauwatosa, Wisconsin (USA). Similar competitive survey results from Christchurch, New Zealand is also discussed, particularly in accurately certifying relined, repaired, and newly installed projects as "leak-free."

Keywords CCTV, Sewer Leaks, Electro Scan, Pipe Lining, Infiltration, Exfiltration

1 Introduction

Sewer authorities are coming under increasing pressure to correctly assess, rank, and prioritize sewer rehabilitation projects. While many agencies are moving towards the 'smarter use of utility survey data,' leading authorities are embracing a 'smarter use of utility data gathering' to prioritize needed upgrades and improvements. While recent studies have documented a number of shortcomings in the use of legacy Closed Circuit Television (CCTV) surveying, a new technology, known as Electro Scan, has emerged as a new standard to rapidly quantify sewer defects and certify pipe repairs, relining, and new construction projects as "leak free."

2 Drawbacks In Using Closed-Circuit Television (CCTV) to Inspect Sewage Assets

CCTV equipment manufacturers and suppliers have introduced a number of advancements during the past sixty years.

Today, sewerage authorities, independent contractors, and consulting engineers, can generate continuously draped side-scanning imagery, provide high-resolution optics, and advanced luminosity controls. Tied to Geographic Information Systems (GIS) and Global Positioning Systems (GPS), owners and managers can upload and stream high-definition video able to start and stop images from remote locations. With over fifty

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(50) international standards used to catalogue sewerage pipeline defects, the technology has remained deeply rooted in subjective visual identification and interpretation that oftentimes has led to incorrect, incomplete, or conflicting condition assessments.

Unable to conduct CCTV inspections when pipes are full or partially full of water, television inspection activities have been largely conducted during dry weather conditions – i.e. when operators will be least likely to observe active leaks from infiltration. Often referred to as a 'Catch-22' industry participants acknowledge that CCTV inspections would be best performed during wet weather conditions, but given the limitation of camera technologies to operate underwater or eliminate the reflection caused by high intensity lighting on the surface of water inside the pipe, CCTV is limited to the identification of only the most obvious structural defects, such as alignment problems, sags, broken or collapsed joints, protruding laterals, roots, and grease. While many of these conditions may be contributing factors to possible sources of sewer infiltration and exfiltration, CCTV inspection is being increasingly found to be inappropriate in identifying and measuring leaks.

In fact, leading sewer authorities are embracing 'smarter use of utility data gathering and assessment tools' as opposed to a 'smarter use of utility survey data.'

2.1 CCTV Inspection as a Baseline to Assess Sewer Mains and Laterals

Two recently completed USEPA-funded studies have provided clear evidence of the shortcomings of CCTV inspection for identifying, locating, and measuring pipeline defects, particularly as it relates to infiltration.

2.2.1 Sewer Mains – USEPA-Sponsored Benchmark in Kansas City, Missouri, USA

Traditionally, CCTV inspection has allowed sewerage utilities to identify defects manifested on the inner surface of sewer pipes. Used to locate specific defects (i.e. structural deficiencies, maintenance needs, and/or construction/installation deficiencies), CCTV has been used to locate sources of infiltration of groundwater into the sewer system, exfiltration, defects that may affect a pipe's hydraulic capacity, and/or structural failures. Because sewer pipes need to be relatively free of debris for CCTV cameras to freely move, pre-cleaning is often required.

CCTV cannot be used to inspect pipe conditions below the water line or to quantitatively characterize structural defects; nor can CCTV identify defects through joints or identify voids, often associated with pavement collapses. Yet, CCTV has been the mainstay for sewer pipe evaluations.

CCTV is a subjective assessment tool that is dependent on a technician's expertise and judgment. With the frequency and size of reported defects, routinely dependent on the experience of the operator, common defects and maintenance issues that the industry has most often claimed to be able to identify using CCTV have included the identification of active leaks, cracks, offset joints, sags, pipe deflections, sediment, debris, and roots.

In November 2007, USEPA-ORD's National Risk Management Research Laboratory funded a three-year research project entitled Condition Assessment of Wastewater Collection Systems. The primary goal of this project was to help wastewater utilities identify viable alternatives to legacy condition assessment programs. The overall project objectives included the evaluation of state of condition assessment technology, using camera-based CCTV technologies as a performance baseline to assess other emerging technologies.

As part of the project, a field demonstration program was conducted in Kansas City, Missouri in August 2010, with CCTV providing a visual representation of the interior condition of the pipe, above the water line, used as a "baseline" for comparison of pipe conditions. To avoid any potential bias in demonstration testing, CCTV inspection results were not shared with other vendors during the course of the field demonstration and all CCTV inspection results were reviewed by a third-party technician, certified by the National Association of Sewer Service Companies (NASSCO) Pipeline Assessment and Certification Program (PACP), as a quality assurance measure.

While not provided as part of the original study, subsequent analysis[1], compared the CCTV Overall Pipe Rating Index (OPRI) for each pipe segment, compiled in accordance with the NASSCO PACP standards. It should be noted that the OPRI is used by PACP to characterize the overall condition of

[1] Harris, R., Moy T., Wilmut, C., USEPA Sewer Electro Scan Field Demonstration Revisited, Water Environment Federation, 2012.

individual pipe segments and is calculated by adding the severity grade of each defect in a pipe segment and dividing this total by the number of individual defects in the pipe segment. The OPRI index uses a Scale of 1 to 5 to characterize defect grades, where an OPRI index of zero (0) indicates that no defects were observed in the pipe segment.

Defects were identified on the CCTV images and coded using PACP standards (NASSCO 2001), with Grades as follows:

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

2.2.2 Sewer Lateral - USEPA & WERF-Sponsored Benchmark in Wauwatosa, Wisconsin, USA

In contrast to assessing sewer mains, a separate study was completed with funding provided by the USEPA and Water Environment Research Foundation, entitled INFR4R12, Sewer Lateral Electro Scan Field Verification Pilot. WERF had selected a proposed research project to specifically field test Electro Scan to find defects in laterals that allow the infiltration of groundwater into the lateral. As part of the study, over 100 laterals were tested at the City of Wauwatosa, Wisconsin, as a pilot project partially funded by the Milwaukee Metropolitan Sewerage District (MMSD).

Tests were compared to baseline CCTV inspections, infiltration rates produced in a rainfall simulation tests, and water exfiltration tests. The objectives of this research effort included:

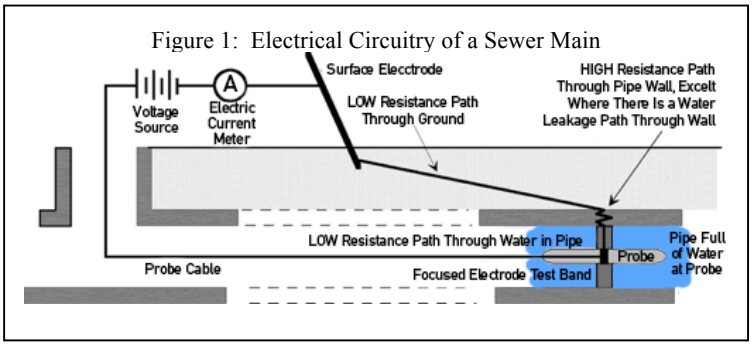
- Testing Electro Scan in the two pilot lateral rehabilitation project areas;
- Compare Electro Scan results to pre-rehabilitation condition dye water/rainfall simulation tests;
- Compare Electro Scan results to CCTV inspection results;
- Perform water exfiltration tests and compare results to Electro Scan results;
- Evaluate the feasibility of performing Electro Scan tests from basement cleanouts; and
- Establish pros and cons of Electro Scan lateral condition evaluations, including estimated costs.

2.2.3 Using Electro Scan to Assess Overall Pipe Condition

Electro scan measures the electric current that flows through the pipe wall. It therefore identifies pipe defects that water can flow into or out of the pipe. CCTV inspections observe structural defects (cracks, fractures, defective joints, and faulty taps) and the ingress of roots at joints that are inferred to show potential leaks. CCTV also shows other pipe defects such as pipe sag, grease and sediment deposits that do not indicate potential pipe leaks. One of the objectives of the demonstration was to determine whether electro scan results are comparable to the pipe defects that are potential leaks shown by CCTV and to what extent electro scan can distinguish between defect types.

Electro scanning was carried out according to the protocol described by the American Society for Testing and Materials (ASTM) standard F2550-06 (ASTM, 2006). Electro Scan measures the variation of electric current flow through a sewer pipe wall where the electrical flow is used to locate and measure defects that are potential paths of water leakage either into or out of the pipe.

Figure 1: Electrical Circuitry of a Sewer Main



Most sewer pipe materials such as clay, plastic, concrete, reinforced concrete and brick (i.e. non-conductive materials) have a high resistance to electrical current. A defect in such a pipe that leaks water will also leak electricity, whether or not water infiltration is occurring at the time of the Electro Scan.

The Electro Scan process is carried out by applying an electric voltage between an electrode in the pipe, called a probe, and an electrode on the surface, which is usually a metal stake pushed into the ground. The high electrical resistance of the pipe wall inhibits electrical current from flowing between the

two electrodes unless there is a defect in the pipe, such as a crack, defective joint or faulty tap. The probe is pulled through the pipe at a speed of 10m/minute (30 ft/min). Other than monitoring the water level in the pipe at the probe location no other action is required by the field operator while carrying out an electro scan.

The current flow between the surface electrode and the probe is recorded at approximately 10mm (0.5 in) intervals along the pipe. For sewer pipe materials that have high resistance to electrical current there is only a small current flow except where there is a pipe defect. As the center of the probe approaches within about 20mm (1in) of a pipe defect, the current from the defect electrode increases, reaching a maximum when the center of the probe is radially aligned with a defect.

As the probe is pulled through the pipe the electrical current flow through the pipe wall at the center of the probe and the position of the probe in the pipe are recorded and displayed in real time as a "current trace" on a smartphone or laptop computer.

To detect defects around the complete circumference of the pipe wall, the pipe needs to be completely full of water surrounding the probe, i.e. not requiring the entire sewer main or lateral to be filled. If the pipe is only partially full in the region of the probe then only that part of the pipe that is covered with water is electro scanned. For large diameter pipes it may not be practical to surcharge the pipe. In such cases electro scanning can provide information about the condition of the pipe below the water line.

2.2 Sample Comparisons of CCTV and Electro Scan Assessment Technologies

Using independently established CCTV inspections as baselines, side-by-side evaluations were conducted for both Kansas City (Sewer Main) and Milwaukee (Sewer Lateral) investigations to compare and contrast resulting pipe assessment data with Electro Scan. Side-by-side evaluations in both studies provided unambiguous analysis of the condition of both sewer mains and laterals relative to CCTV, indicating both location and severity of all defects. While Electro Scan does not rely on the visual interpretation by an operator, as is the case with CCTV inspections, Electro Scan automatically detected all defects, including those that may not currently be providing infiltration, but that may become infiltration sources over time, as sewer mains and laterals deteriorate.

Sample comparison reports for sewer main assessments, used in the EPA Report in the Kansas City Field Demonstration, are shown below, Figures 2 & 3:

Figure 2: Sample EPA Comparison Report

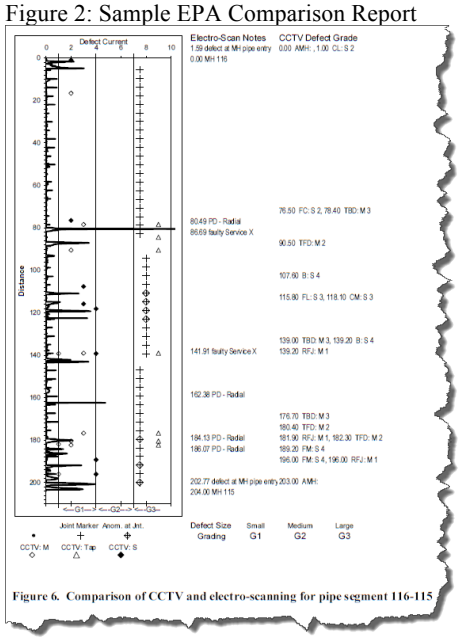


Figure 6. Comparison of CCTV and electro-scanning for pipe segment 116-115

Figure 3: Sample EPA Comparison Report

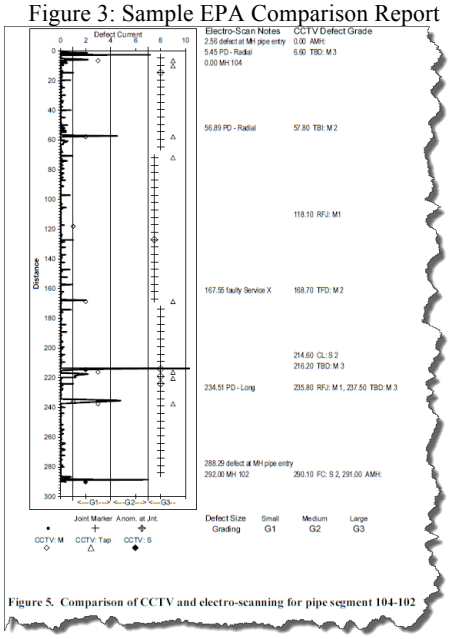


Figure 5. Comparison of CCTV and electro-scanning for pipe segment 104-102

Sample comparison reports for sewer lateral assessments, used in the EPA and WERF Field Demonstration conducted in Metro Milwaukee, are shown below in Figures 4, 5, 6, and 7:

Figure 4: Sample Lateral Comparison

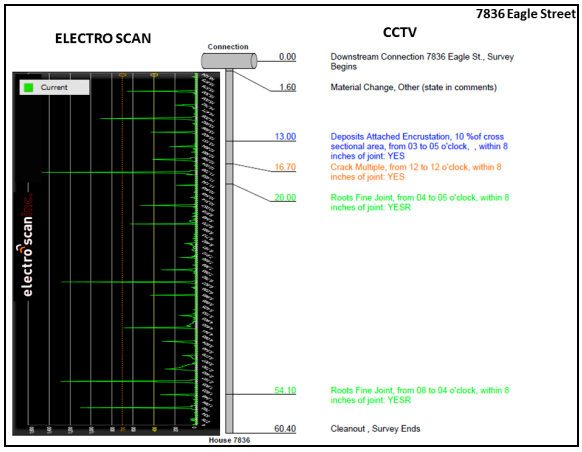


Figure 5: Sample Lateral Comparison

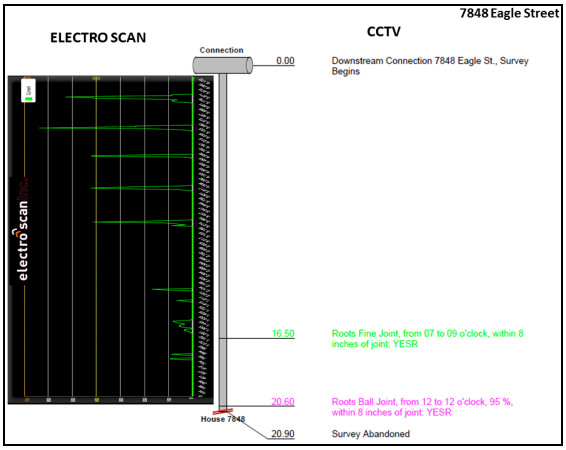


Figure 6: Sample Lateral Comparison

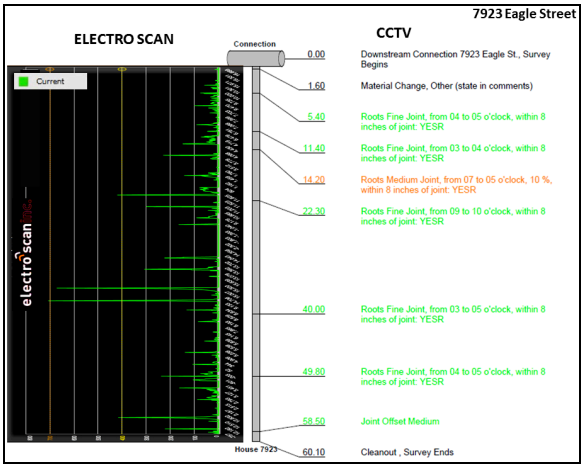
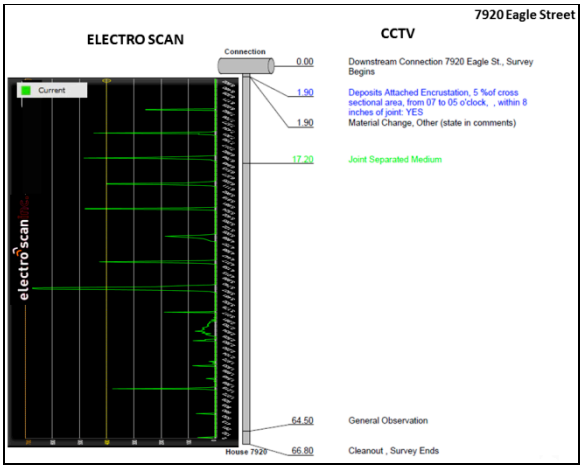


Figure 7: Sample Lateral Comparison

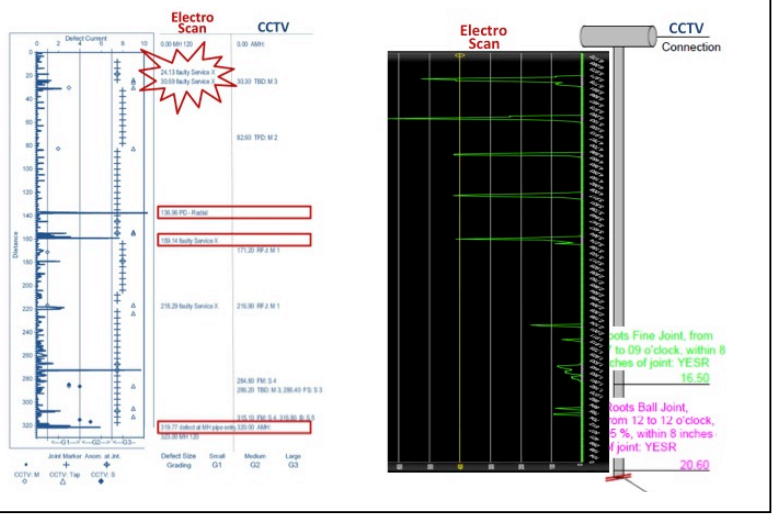


2.3 Defects Missed by CCTV Inspection

Several types of reporting gaps were identified in both EPA-sponsored projects that indicated significant drawbacks in the use of CCTV to assess sewers. The most frequent reporting gaps were defects identified by Electro Scan, but not identified by CCTV.

As shown in Figure 8, several significant defects found by Electro Scan, were not identified by CCTV. In fact, so many significant defects were not identified by CCTV, that CCTV reports were further reviewed to ensure that the CCTV reports matched the related video captured during the original investigation.

Figure 8: Defects Missed by CCTV in Sewer Mains and Sewer Laterals

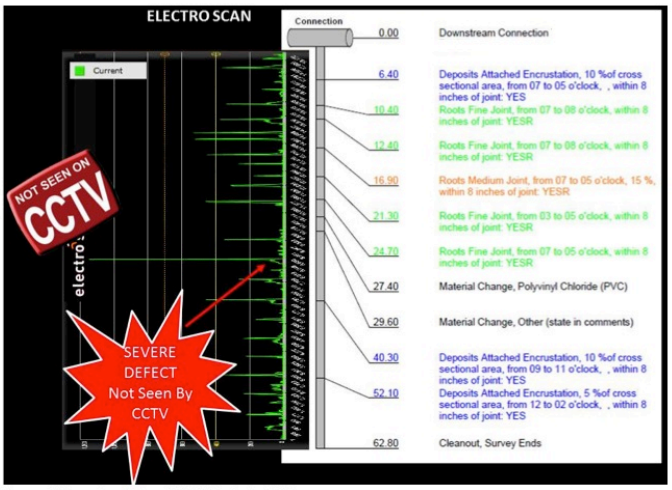


2.4 'Small' Defect Identified by CCTV is 'Large' Defect Identified by Electro Scan

Another common failure of CCTV inspections was the frequent cataloguing of *small* defects v. *large* defects identified by Electro Scan. As shown in Figure 9, CCTV operators appeared to have trouble quantifying differences between small and large defects, which were automatically recognized by Electro Scan.

Based on a detailed review of individual defects identified by CCTV as having small defects compared to large defects found by Electro Scan, it appears that Electro Scan's ability to trace & measure a defect current through joints or cracks allows the technology to identify unseen gaps where water may travel. As a result, CCTV reports often understated a pipe's integrity.

Figure 9: Large Defect by Electro Scan, Catalogued as Small by CCTV



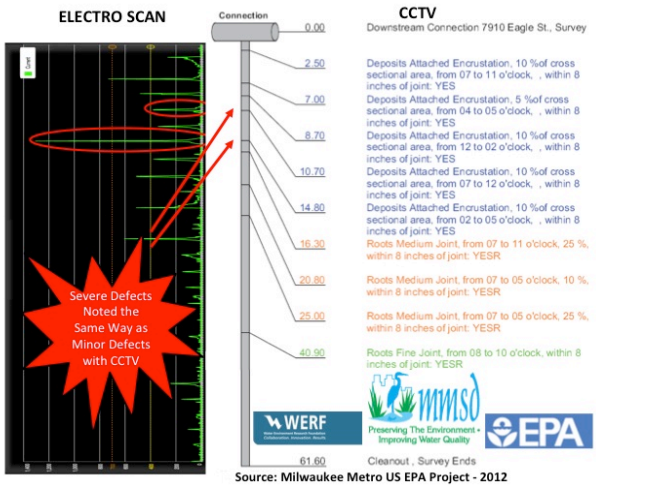
Source: Milwaukee Metro US EPA Project - 2012

2.5 Same Defect Coding Used for Multiple Defects by CCTV, Quantified by Different Defect Severity by Electro Scan

Another recurring problem with CCTV inspections, identified during both sewer main and sewer lateral investigations, was the inappropriate use of the same defect category for different defects. As shown in Figure 10, the CCTV operator used the same defect code to record several different sized defects as reported by Electro Scan.

A key requirement for any sewerage survey is the need to develop a comprehensive pipeline assessment that ranks and prioritizes pipe defects for systematic repair and renewal. Yet, if defects are not uniformly identified, located, measured, or graded, sewer authorities risk not fixing pipes that exhibit the greatest potential for inflow.

Figure 10: Same Observation by CCTV, Different for Electro Scan

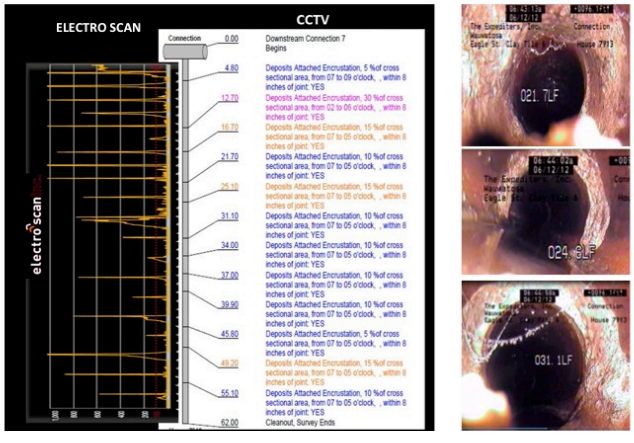


Source: Milwaukee Metro US EPA Project - 2012

2.6 Defects Identified by CCTV as Maintenance Issues; Electro Scan Identified As Needed Repair

Visual inspection using CCTV can lead to false interpretations, as shown in Figure 11. As indicated, the pipe segment had visible 'encrustations' throughout the pipe, and even successfully passed a water pressure test, which many industry observers might refer to as a self-healing occurrence; however, as build-up in a pipe is non-conductive, i.e. allowing electrical current to pass through to assess potential flow patterns, Electro Scan is able to diagram the location and peak potential for leaks. As encrustation is not an approved method of pipe rehabilitation, Electro Scan correctly recommends repair.

Figure 11: CCTV v. Electro Scan in Indicating Needed Repair



2.7 Worldwide CCTV and Electro Scan Benchmark Comparisons

Similar competitive survey results from Christchurch, New Zealand also confirms the consistent inability of CCTV cameras to identify, locate, and measure defects, particularly in accurately certifying relined, repaired, and newly installed projects as "leak-free."

Figure 12: CCTV v. Electro Scan

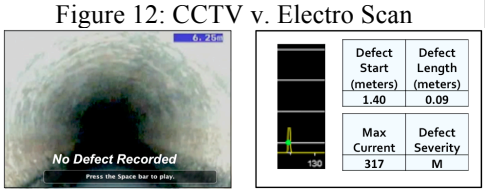


Figure 13: New Zealand CCTV v. Electro Scan Benchmark

Pipe Section	Project	Length (m)	CCTV # of Defects	ELECTRO SCAN # of Defects	ELECTRO SCAN Estimated LPM (Peak Infiltration)
SW 9 to SW 8	Ministry of Education	18.75	5	10	14.3
SW 7 to SW 8	Ministry of Education	37.51	0	10	9.6
Heaton 5 to Heaton 6	Ministry of Education	19.98	2	17	22.2
Heaton 6 to Heaton 7	Ministry of Education	51.01	4	12	10.7
MHA to MHB	Selwyn	56.72	0	8	6.3
MHB to MHC	Selwyn	22.2	1	32	18.2
MHC to MHD	Selwyn	48.64	0	25	8.1
MHF to MHD	Selwyn	83.82	2	7	40.7
MHE to MHF	Selwyn	82.41	3	82	50
35080	Akaroa	79.64	1	13	53.1
35081	Akaroa	45.45	0	6	11.3
36014	Akaroa	14.39	0	1	1.2
19763	SCIRT	30.7	7	15	10.7
19760	SCIRT	40.3	3	4	2.4
35550	Ashburton	57.6	12	42	42.5
	TOTAL	690	40	284	301

As shown in Figures 12 and 13, individual comparisons of CCTV and Electro Scan defects in New Zealand, routinely showed 'No Defect' for CCTV, with a measured estimated litre per minute of leak infiltration. In association with City Care (Christchurch, NZ), CCTV identified a total number of 40 defects, compared to 284 identified by Electro Scan.

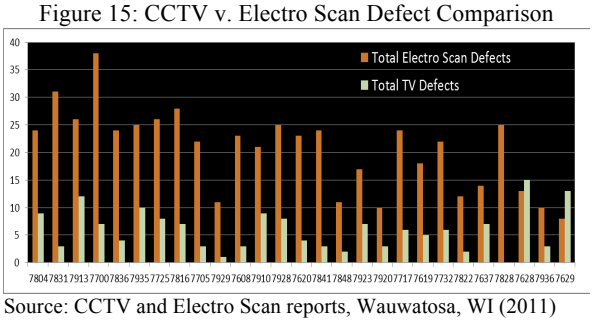
3 Key Findings

The difference between the total number of pipe defects shown by both CCTV and Electro Scan for each pipe segment varied considerably in both EPA-sponsored studies for sewer mains and sewer laterals.

As shown in Figure 14, defective sewer main segments are aligned to show their severity for CCTV Surveys, Electro Scanning, and an overlay comparison of both, indicating completing different conclusion in the identification of the *worst* pipe segment.

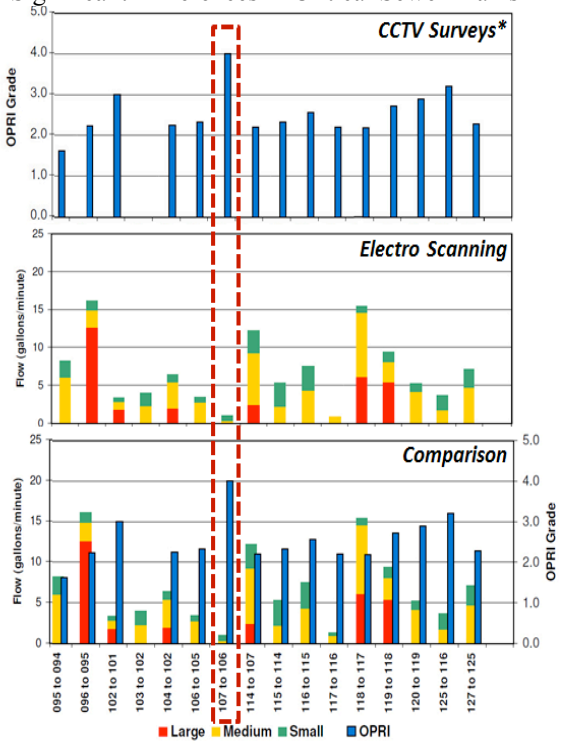
In the case of the Sewer Lateral Field Demonstration, shown in Figure 15, Electro Scan identified a significant number of defects as compared to CCTV. In a single survey area, Electro Scan found 555 defects compared to 160 defects found with CCTV.

Figure 15: CCTV v. Electro Scan Defect Comparison



Source: CCTV and Electro Scan reports, Wauwatosa, WI (2011)

Figure 14: CCTV OPRI & Electro Scan Rate Show Significant Differences in Critical Sewer Mains



Source: EPA/600/R-11/078 | July 2011, USEPA Revisited.

4 Conclusion

CCTV of sewerage assets has been a mainstay in evaluating the condition of sewer and stormwater pipe; however, while CCTV inspection is expected to have a continuing role in the visual inspection of structural defects, it is no longer an appropriate tool to accurately assess sources of infiltration and exfiltration, as compared to automated technologies, such as Electro Scan.

Since Electro Scan is able to identify, locate, and measure many more defects that can leak, if not all defects in a sewer pipe, it is reasonable to assume that Electro Scan represents a more reliable diagnostic tool to identify potential infiltration, compared to CCTV.

In keeping with the need to pursue a 'smarter use of utility survey data' leading sewer authorities must embrace a 'smarter use of utility data gathering' tools to more accurately and effectively rank and prioritize critical sewers requiring repair and renewal.

Because of its more effective identification of defects that can leak, Electro Scan should also replace the use of CCTV as an effective tool for quality assurance of repair, relining, and new pipeline construction projects, to ensure that contractors and consulting engineers deliver "leak free" pipeline networks.

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