Sydney Water Trial Project Using Low Voltage Conductivity to Assess Sewer Pipe Water Tightness

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EXECUTIVE SUMMARY

Worldwide water utilities and smart cities are adopting new technologies to replace legacy technologies that have been the mainstay to assess existing pipe conditions and accept new installations as water-tight.

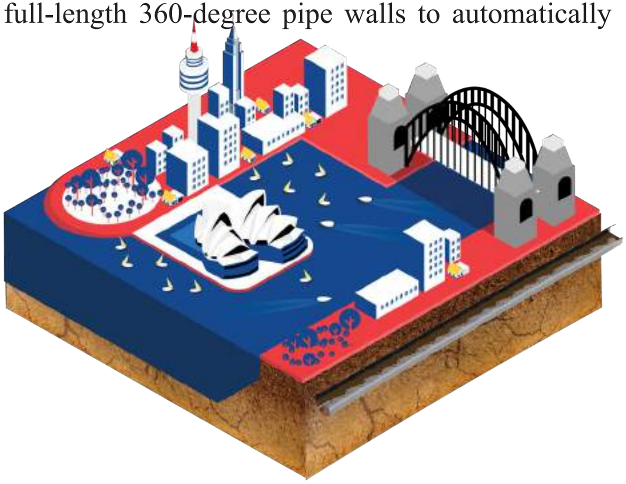
The importance of correctly assessing the water tightness of sanitary sewer pipes cannot be understated. Capital expenditure decisions rely on correct assessments to identify repair, rehabilitation, and replacement decisions; new installations rely on a minimum amount of water leakage to achieve design flows and useful life assumptions; and rehabilitation effectiveness is measured and reported to regulatory bodies for environmental compliance, stewardship, resiliency, and sustainability of water quality.

Yet, changes from longstanding practices often requires new methods, techniques, and standards, including higher performing pipe materials.

The purpose of this trial project was to facilitate a field trial of technology introduced nearly ten years ago that has been gaining momentum & acceptance.

Representing a potential disruptive technology, six (6) project locations were selected throughout the Sydney Water service area, representing different pipe materials, pipe diameters, and new & existing pipe installations. Once limited to visual inspection using high resolution digital closed-circuit television (CCTV) cameras, sonar, laser, and acoustic sensors to listen for leaks, this project trial tested the field application of electric current, capable of assessing full-length 360-degree pipe walls to automatically locate and estimate leaks in liters per second (l/s).

Figure 1. Selected field investigation locations for Electro Scan trial.



Referred to by the U.S. Environmental Protection Agency (USEPA) as focused electrode leak location (FELL)[1] the method demonstrated significant competitive advantages compared to legacy CCTV, especially in the assessment of trenchless pipe materials, including Cured-in-Place Pipe (CIPP) and Spiral Wound Pipe (SRP) with Rib-Loc fittings.

This white paper includes a detail review of existing assessment techniques, project findings, technology overview, and field results fom each project area included as part of Sydney Water's trial project evaluation of FELL technology.

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[1] USEPA, Field Demonstration of Condition Assessment Technologies, July 2011

SYDNEY WATER BUSINESS CASE

A Business Case was developed in October 2019 by Sydney Water's Urban Design and Engineering team to justify the evaluation Electro Scan's patented protected low voltage conductivity technology.

The Sydney Water Business Case established that the purpose of its evaluation was to test and document the practical application, field operation, ease of reporting, and data production, utilising ASTM F2550-13 (2018), compared to traditional Closed-Circuit Television (CCTV) inspection utilising WSA 05—2008 2.2 Conduit Inspection Reporting Code of Australia standards.

Key questions, included the following:

1. Does FELL technology deliver repeatable leak location and severity measurements not provided by traditional CCTV visual inspection?
2. Can FELL technology be used to more accurately locate infiltration and exfiltration?
3. What are FELL advantages & disadvantages?
4. How should new (possible) quality standards be introduced during start-up & operation of Sydney Water's Regional Delivery Consortium (RDC)? ***NOTE: This issue is outside the scope of this white paper.***

Key Findings from Electro Scan Trial Project

The Electro Scan pilot project demonstrated significant drawbacks to Sydney Water's present standards for testing existing sewer mains for water tightness, and more importantly, acceptance of repairs, rehabilitation, and replacements.

Six (6) locations were selected to provide a targeted mix of new and existing pipe materials.

1. **Potts Hill**. A test pipe observed that FELL technology successfully detected both pre-arranged defects, as did CCTV inspection; however, FELL technology additionally identified & measured numerous other defects at material changes transitioning from clay pipe-to-plastic pipe, and defects at each joint.

2. **Abbotsford**. Target of a recent sanitary sewer overflow into a customer's home, Electro Scan found several defects, not found by CCTV, in addition to defects in a recently lined sewer, that was abandoned by CCTV after successfully tested by FELL.

3. **Balgowlah Heights**. FELL found numerous defects not found by CCTV representing significant sources for infiltration and exfiltration, including defective junctions that CCTV observed in good workmanship.

4. **Birchgrove**. Prone to persistent tidal and wet weather infiltration (despite recent and significant rehabilitation), FELL found severe defects in recently lined cast iron pipes. One pipe where CCTV was attempted, but abandoned due to a significant bulge in Cured-In-Place Pipe (CIPP) liner, was successfully surveyed by FELL.

5. **Chatswood**. Numerous sources of potential exfiltration were identified in close proximity to a local stormwater channel, not seen by CCTV, including defects in a Spiral Wrap Pipe.

6. **Spring Farm**. A new Unplastised Plastic Pipe (uPVC) was evaluated by FELL. Already having undergone vacuum air testing by its prime contractor, Electro Scan noted several leak locations that may be a possible change of materials.

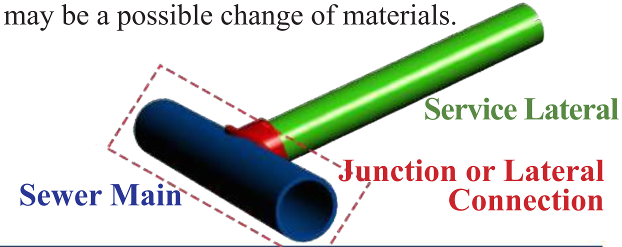
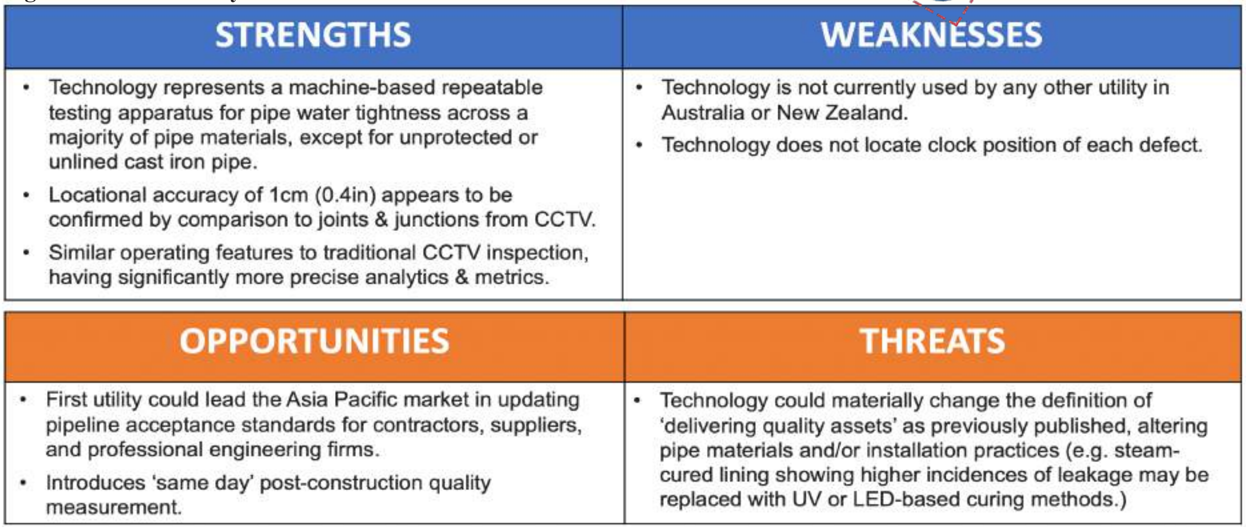


Figure 2. SWOT Analysis



STRENGTHS	WEAKNESSES
• Technology represents a machine-based repeatable testing apparatus for pipe water tightness across a majority of pipe materials, except for unprotected or unlined cast iron pipe. • Locational accuracy of 1cm (0.4in) appears to be confirmed by comparison to joints & junctions from CCTV. • Similar operating features to traditional CCTV inspection, having significantly more precise analytics & metrics.	• Technology is not currently used by any other utility in Australia or New Zealand. • Technology does not locate clock position of each defect.
OPPORTUNITIES	**THREATS**
• First utility could lead the Asia Pacific market in updating pipeline acceptance standards for contractors, suppliers, and professional engineering firms. • Introduces 'same day' post-construction quality measurement.	• Technology could materially change the definition of 'delivering quality assets' as previously published, altering pipe materials and/or installation practices (e.g. steam-cured lining showing higher incidences of leakage may be replaced with UV or LED-based curing methods.)

LEGACY METHODS & ADVANCED PIPE MATERIALS PROVE DIFFICULT TO TEST

The selection and proritisation of existing infrastructure to repair, rehabilitate, and replace, is a complicated, time consulting, and expensive task. Despite advancements being made in the use of desktop computer models using *age-based* algorithms, including pipe material, soil types, diameter, and flow dynamics, *condition-based* models using actual physical inspection techniques have often driven capital expenditure programs.

Given the importance of water to the Australian economy, combined with market-efficient behavior, it stands to reason that repairs and renewal of water infrastructure would be straightforward. Yet, basic technologies for seeing defects (e.g. CCTV cameras, smoke & dye testing, etc.) and listening devices to hear leaks (e.g. acoustic sensors, data correlators, hydraphones, etc.) have been inconsistent and incomplete in their total assessment of pipe segments.

The absence of significant industry technical innovations has prevented improvement in pipeline condition assessments. Slow adoption of new technologies by water utilities, aversion to technical innovations, and entrenched supplier networks have contributed to the slow introduction of unbiased and unambiguous leak detection technologies, risking poor allocation of capital for finding & fixing water & sewer infrastructure and inadvertently accepting sub-standard rehabilitated and newly installed pipes.

For pressurised water distribution networks and sewer force mains, acoustic sensors have historically dominated the leak detection market. Almost universally accepted, experts agree that listening for leaks has long been hampered by a variety of environmental, scientific, operational, and other external influences, as shown in Table 1, that often prevents dependable, repeatable, and quantifiable readings.

While acoustic leak detection equipment was considered to be satisfactory by most professionals, adoption of more sophisticated composite pipe materials offering lower installation costs, anti-corrosion, and durability features, rendered traditional acoustic sensors, data loggers, and correlators obsolete or lacking in their ability to detect leaks or anomalies. Unable to detect leaks in certain pipe materials using acoustic sensors, secondary technologies were attempted to anticipate catastrophic failures.

Table 1. Drawbacks of Using Traditional Acoustic Sensors, Data Loggers, and Correlators.

- Ambient noise interference.
- Variable water table heights affect results.
- Unable to assess innovative pipe materials, especially PE, PVC, & HDPE pipes.
- Different results for different pipe diameters.
- Leak size is difficult or unable to be determined.
- Multiple false-positive readings.
- Repair clamps on previous leaks will be bypassed by acoustic waves.
- Inability to quantify defect flow rates in GPM.
- Customer's continuous water use similar as a leak.
- Affected by changes in backfill materials.
- Lengthy data processing & reporting times.
- Lack of repeatability, by crew, by equipment.
- Special training required for field crews.
- Need for third-party data interpretation.
- Misses silent or undetected leaks.

Leaks that were normally detected using acoustic equipment became more challenged in plastic, lined, coated, and specialty-composite piping materials.

Continuing its growth and adoption by the world's leading water utilities, the challenges of bringing a new technology to market actually created a major strategic advantage by re-doubling its efforts to assess the widest range of pipe diameters, materials, field conditions, flow velocities, and more.

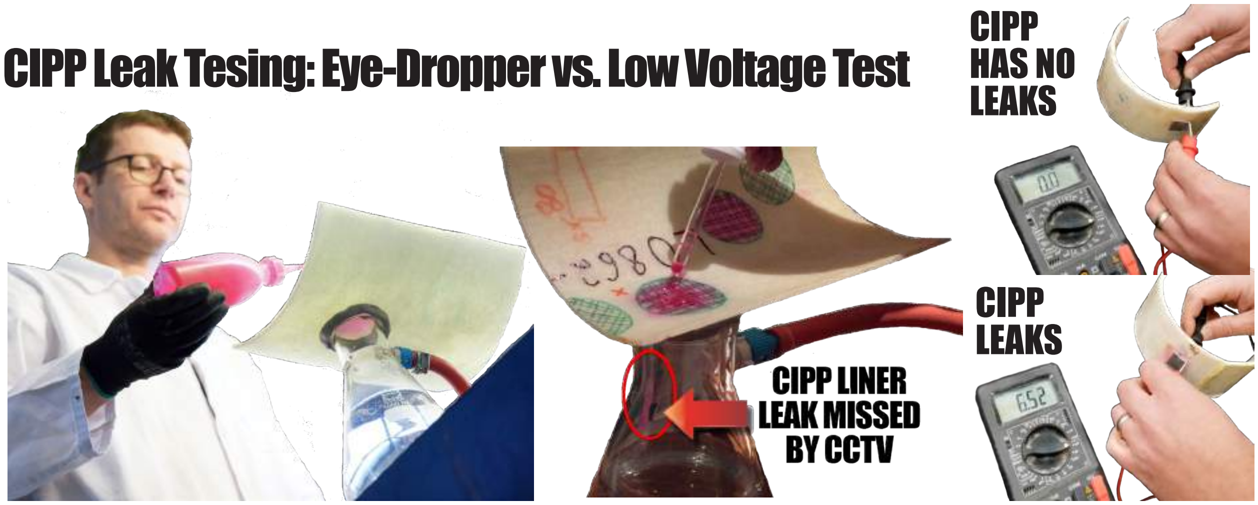


Figure36. Testing of a Cured-In-Place Pipe (CIPP) sample finds defects missed by visual inspection.

PIPE FAILURES QUESTION LEGACY ASSESSMENT TECHNIQUES

Lessons learned are essential to promote overall improved problem solving to support critical infrastructure management considerations. But, while water utilities frequently share success stories at conferences and seminars, problems that may reflect poorly on organizations, consultin engineeer, or suppliers, typically are shared less often.

In 2010, the renowned civil engineer & educator, Ken Kerri, Ph.D., P.E., with the Office of Water at California State University sought ways to improve pipeline water tightness evaluations after working with real-world challenges faced by his former students. Surprisingly, newly renovated pipe that used long-accepted trenchless construction practices begun in the 1970s were already showing deficiencies. Using traditional eye-droppers with coloured dye to test sample CIPP coupons for leaks, as shown in Figure 6 below, more accurate testing using low voltage electrical current was favored, if able to be deployed in the field for testing full-length 360-degree liners.

Now exceeding $5 billion in annual sales in the United States, Cured-In-Place Pipe (CIPP) lining has gained widespread acceptance as an alternative to traditional dig & replace methods of pipe replacement. First developed in 1971 in England, the CIPP process relines the interior of an existing pipe using heated water, steam, ultra-violet, or light-emitting diodes, to create or cure a new pipe wall inside the original host pipe, within hours.

Principally guided by the ASTM standard number F1216-16, *Standard Practice for Rehabilitation of Existing Pipelines and Conduits by the Inversion and Curing of a Resin-Impregnated Tube*, installation is recommended to be inspected *visually* if appropriate, or by CCTV if direct visual inspection cannot be accomplished.

Table 2. CIPP Liner Defects Commonly Found After Installation

- Accelerant Burns
- Accidental Cuts
- Bad Service Reconnections
- Bad Lateral Liners
- Blisters
- Delamination
- Defective Epoxy
- Equipment Damage
- Foreign Objects
- Lateral Connection Rehabilitation (LCR)
- Lowered Resin to Felt Ratios
- Mainline to House Lateral Connection (MTH)
- Pinholes
- Poor, Incomplete, or Uneven Curing
- Overcooking
- Stretching
- Top-Hat Defects
- Wet-Out Failures
- Wrinkles, including Buckling, Fins, Folds, Lifts, & Ridges

Specifically, ASTM F1216-16 states the following:

> **8.7 Inspection and Acceptance**. *The installation may be inspected visually if appropriate, or by closed-circuit television if visual inspection cannot be accomplished. Variations from true line and grade may be inherent because of the conditions of the original piping. No infiltration of groundwater should be observed. All service entrances should be accounted for and be unobstructed.*

Unfortunately, without mention of leak detection or water tightness, popular CIPP linings products merely have to show that no visible signs of "infiltration" are evident in the post-CCTV inspection and show that "all service entrances [should] be accounted for and be unobstructed."

Since most of the CCTV inspection is done by the same contractor completing the CIPP installation, reliable defect coding to protect the Owners' interest can often be problematic, especailly given the variety of post-CIPP installation defects that can occur, and as listed in Figure 6, belows.

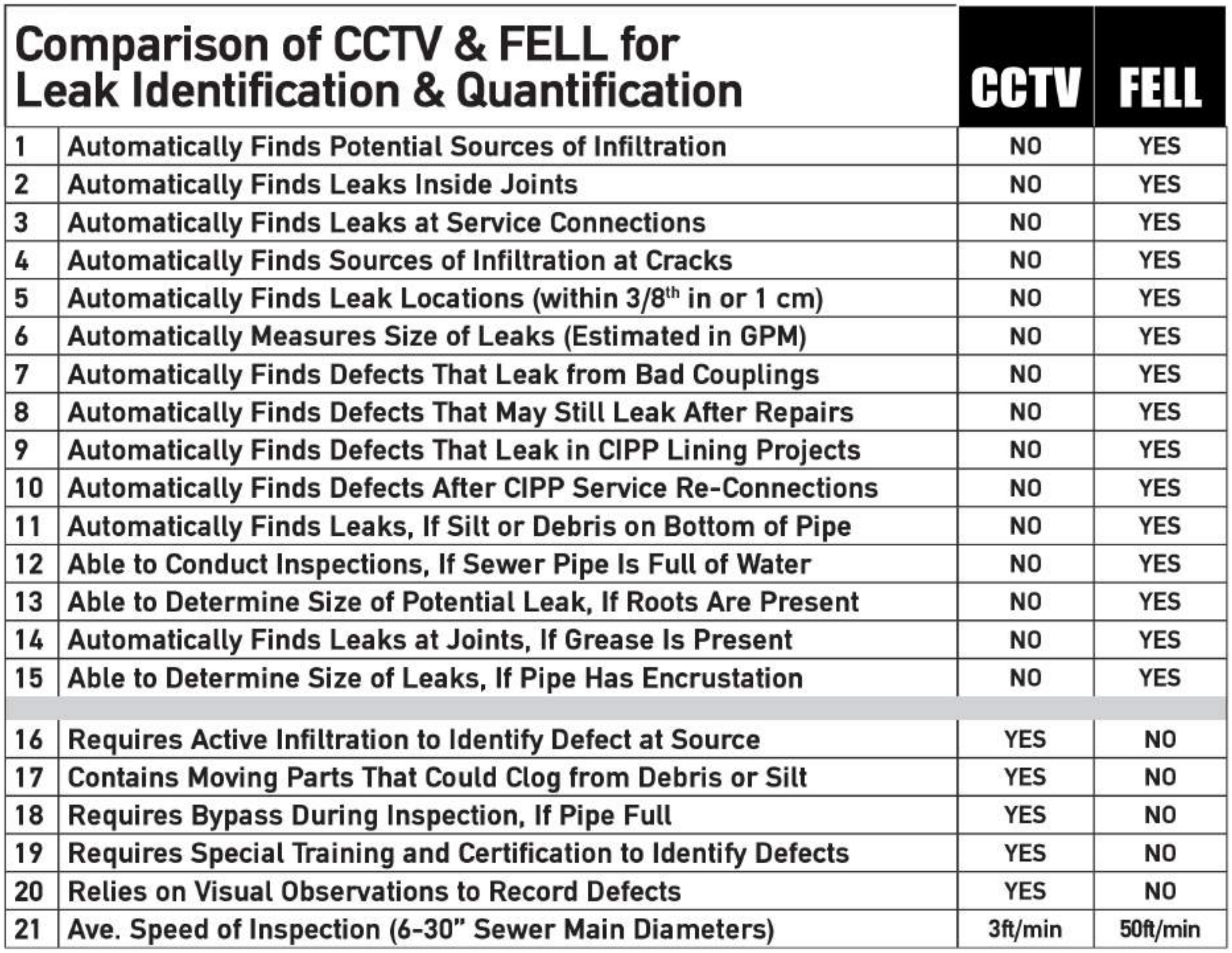
RISK OF INCORRECTLY ALLOCATING CAPEX & APPROVING PIPES WITH MAJOR LEAKS

According to ASTM Subcommittee F36.20 on *Inspection and Renewal of Water and Wastewater Infrastructure*, every dollar misallocated for pipeline capital expenditures requires five dollars to correct the mistake. The opportunity cost of lost benefits from correctly designating the right pipes to fix includes the original cost of repairs, inconvenience to residential and business customers, and financing cost of capital, and the potential damage to collateral underground utilities.

As shown in Figure 7, a recent U.S. customers found different rehabilitation selections from two different inspection techniques. Additional testing was required after rehabilitation in the originally proposed area, showed no meaningful reduction in infiltration, after the relining of both sewer mains and service laterals.

Figure 4. U.S. Infiltration Assessment Project Comparing Manual CCTV Inspection vs. Machine FELL Inspection

Table 2. Comparison of CCTV and FELL Features and Capabilties



	Comparison of CCTV & FELL for Leak Identification & Quantification	CCTV	FELL
1	Automatically Finds Potential Sources of Infiltration	NO	YES
2	Automatically Finds Leaks Inside Joints	NO	YES
3	Automatically Finds Leaks at Service Connections	NO	YES
4	Automatically Finds Sources of Infiltration at Cracks	NO	YES
5	Automatically Finds Leak Locations (within 3/8th in or 1 cm)	NO	YES
6	Automatically Measures Size of Leaks (Estimated in GPM)	NO	YES
7	Automatically Finds Defects That Leak from Bad Couplings	NO	YES
8	Automatically Finds Defects That May Still Leak After Repairs	NO	YES
9	Automatically Finds Defects That Leak in CIPP Lining Projects	NO	YES
10	Automatically Finds Defects After CIPP Service Re-Connections	NO	YES
11	Automatically Finds Leaks, If Silt or Debris on Bottom of Pipe	NO	YES
12	Able to Conduct Inspections, If Sewer Pipe Is Full of Water	NO	YES
13	Able to Determine Size of Potential Leak, If Roots Are Present	NO	YES
14	Automatically Finds Leaks at Joints, If Grease Is Present	NO	YES
15	Able to Determine Size of Leaks, If Pipe Has Encrustation	NO	YES
16	Requires Active Infiltration to Identify Defect at Source	YES	NO
17	Contains Moving Parts That Could Clog from Debris or Silt	YES	NO
18	Requires Bypass During Inspection, If Pipe Full	YES	NO
19	Requires Special Training and Certification to Identify Defects	YES	NO
20	Relies on Visual Observations to Record Defects	YES	NO
21	Ave. Speed of Inspection (6-30" Sewer Main Diameters)	3ft/min	50ft/min

Figure 5. Avoidance/Adoption Matrix

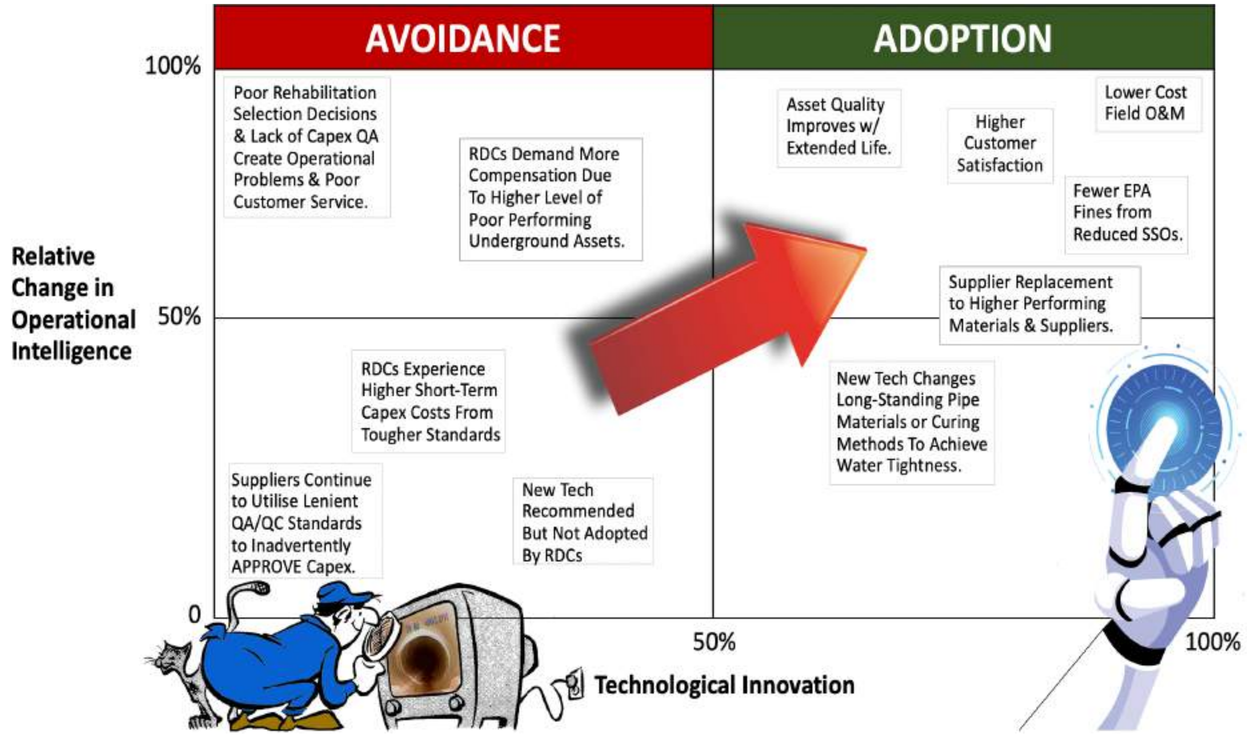


Figure 6. Chronology of Condition Assessment Coding Standards for Pipe Leaks

1850s	1880s	1920s	1930s	1950s	1965	1978	1980s	1990s	2001	2002	2003	2006	2017
Manual Sounding	Deacon Meter (Waste Measuring)	Helical Vane Meters	Step Testing	Closed-Circuit Television Cameras	Ground Microphones	Leak Noice Correlator	Electronic Step Tester DMAs	Acoustic Loggers Ground Penetrating Radar	Combined Acoustic Logger & Correlator	Digital Correlator	Advanced Ground Microphones	Focsued Electrode Leak Location	Satellite

Source: American Water Works Association, 2019

BACKGROUND

Infiltration into new and recently repaired gravity sewers continues to be a major challenge. While air and hydrostatic testing has been a traditional acceptance test for newly installed pipes, high groundwater conditions and the presence of service connections and junctions make testing problematic.

While alternative visual inspection using high resolution Closed-Circuit Television (CCTV) cameras are unable to 'see' inside of cracks or joints to determine watertightness, a new approach has emerged to test gravity sewers that promises to accurately locate and quantify defects. Referred to as Electro Scanning has been adopted by UK-based WRc plc and German-based IKT, warrants further review and benchmark review by Sydney Water, comparing new technology to existing test methodologies.

Ground water infiltration, and in some cases tidal infiltration, of hydraulically-challenged gravity sewers is recognised as a considerable problem for Sydney Water and its customers.

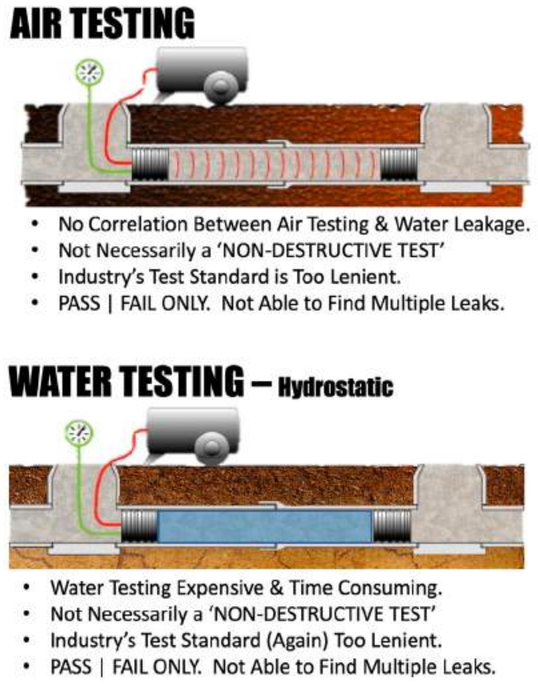
The need for infiltration (and exfiltration) reduction in new & existing sewers are numerous, including:

- Reduced Combined Sewer Overflows (CSO) and spills;
- Improved quality control of contractor work and possible warranty claims;
- Improved diagnostics of customer complaints and sources of sewage backups and floodin;
- Reduced treatment costs at the sewage works;
- Reduced power consumption when pumping forward to treatment;
- Improved environmental compliance standards and mandated reporting;
- Avoidance of fines or actions by New South Wales EPA;

Traditional pipe inspection and techniques for condition assessment have been problematic, often falling short of accurately certifying new and existing pipes as watertight and correctly prioritising pipes for repair, rehabilitaion, replacement.

Given the growing adoption of *low voltage conductivity*, also referred to as Focused Electrode Leak Location (FELL), as a new way to accurately and consistently test full-length non-conductive (i.e. non-metallic) pipes, for water tightness, a business case was pursued to conduct a field trial of the technology in partnership with U.S.-based Electro Scan Inc. and its Australian subsidiary Electro Scan Australia Pty Ltd.

Figure 7. Air and Water Testing for Leak



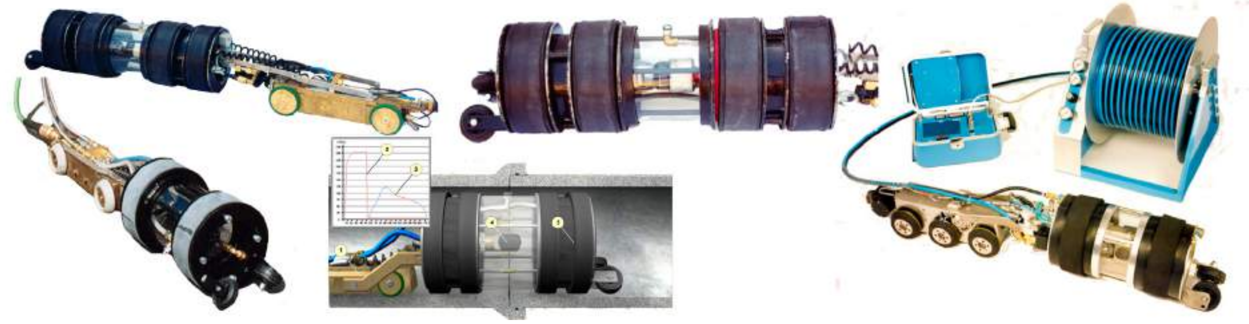
- No Correlation Between Air Testing & Water Leakage.
- Not Necessarily a 'NON-DESTRUCTIVE TEST'
- Industry's Test Standard is Too Lenient.
- PASS | FAIL ONLY. Not Able to Find Multiple Leaks.

- Water Testing Expensive & Time Consuming.
- Not Necessarily a 'NON-DESTRUCTIVE TEST'
- Industry's Test Standard (Again) Too Lenient.
- PASS | FAIL ONLY. Not Able to Find Multiple Leaks.

Working as a subcontractor to a Sydney Water approved contractor, Aqua Assets Pty Ltd., six (6) locations were selected, as shown in Figure 1, to conduct detail field investigations, including comparison with Sydney Water approved Closed-Circuit Television (CCTV) inspection, in accordance with current WSAA standards.

Subsequent to required Sydney Water induction and White Card certification, field work was undertaken from 6 December to 13 December 2019, with findings discussed in this report.

Figure 8. Example Air Testing Devices Used for Leak Testing of Joints and Junctions.



CCTV CAN'T RECORD WHAT CAN'T BE SEEN

Visual inspection has been a longstanding way to examine the internal condition of sewer and stormwater pipes. Original CCTV defect classification standards, first developed by British-based Water Research Centre (WRc) and Transport and Road Research Laboratory (TRRL), underwent successive revisions and refinements, with independent tranches emerging for different countries, and in some cases, utility-specific versions and equipment as shown in Figure 4.

Figure 8. Air and Water Testing for Leak

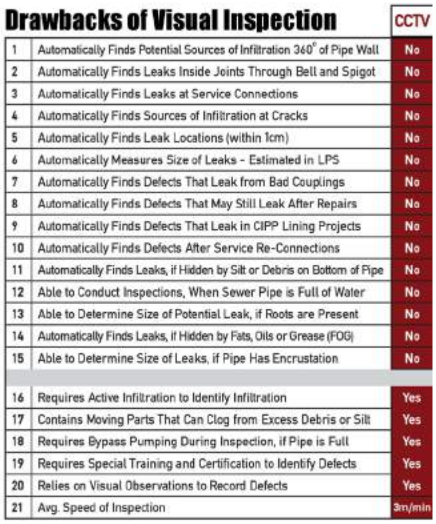
Yet, even as new defect classifications and grading methods were developed, basic drawbacks and deficiencies of visual detection remained, as shown in Figure 5 below. Since CCTV cameras are unable to tell the difference between superficial cracks and cracks that leak, or see inside a joint's bell & spigot to spot leaks, CCTV has often led to incorrect prioritization of rehabilitation.

More importantly, as seen through benchmarking studies by EPA, CCTV has fallen short as a dependable tool to test or certify CIPP for water tightness, unable to locate or quantify the severity of pinholes or confirm permeable surfaces, prior to acceptance.

Traditionally, CCTV operators have inspected underground pipes before and after rehabilitation, with installation contractors being allowed to check their work utilizing a self-administered visual coding system developed and adopted by CCTV manufacturers and contractors.

As traditional visual and listening devices have proven limited in certifying pipes as watertight, coupled with changes in advanced pipe materials and rising utility rates to finance needed repairs and capital plans, utilities have been open to new technologies that promise the ability to more accurately and dependably support complex infrastructure decision support.

Figure 9. Drawbacks of Closed-Circuit Television (CCTV) Inspection



Drawbacks of Visual Inspection

		CCTV
1	Automatically Finds Potential Sources of Infiltration 360° of Pipe Wall	No
2	Automatically Finds Leaks Inside Joints Through Bell and Spigot	No
3	Automatically Finds Leaks at Service Connections	No
4	Automatically Finds Sources of Infiltration at Cracks	No
5	Automatically Finds Leak Locations (within 1cm)	No
6	Automatically Measures Size of Leaks - Estimated in LPS	No
7	Automatically Finds Defects That Leak from Bad Couplings	No
8	Automatically Finds Defects That May Still Leak After Repairs	No
9	Automatically Finds Defects That Leak in CIPP Lining Projects	No
10	Automatically Finds Defects After Service Re-Connections	No
11	Automatically Finds Leaks, if Hidden by Silt or Debris on Bottom of Pipe	No
12	Able to Conduct Inspections, When Sewer Pipe is Full of Water	No
13	Able to Determine Size of Potential Leak, if Roots are Present	No
14	Automatically Finds Leaks, if Hidden by Fats, Oils or Grease (FOG)	No
15	Able to Determine Size of Leaks, if Pipe Has Encrustation	No
16	Requires Active Infiltration to Identify Infiltration	Yes
17	Contains Moving Parts That Can Clog from Excess Debris or Silt	Yes
18	Requires Bypass Pumping During Inspection, if Pipe is Full	Yes
19	Requires Special Training and Certification to Identify Defects	Yes
20	Relies on Visual Observations to Record Defects	Yes
21	Avg. Speed of Inspection	3m/min

Source: WRc Electro Scan MasterClass, Peterborough, England, 2017

THE SCIENCE OF LOW VOLTAGE CONDUCTIVITY TESTING

After a number of CIPP liner failures, during and directly after its warranty period, technical solutions were sought to create an accurate, cost-effective, and repeatable way to reliably certify the water tightness of pipelines. Complicating matters were the seemingly endless combinations of pipe materials, diameters, shapes, depths, lengths, gradients, soil types, and age profiles.

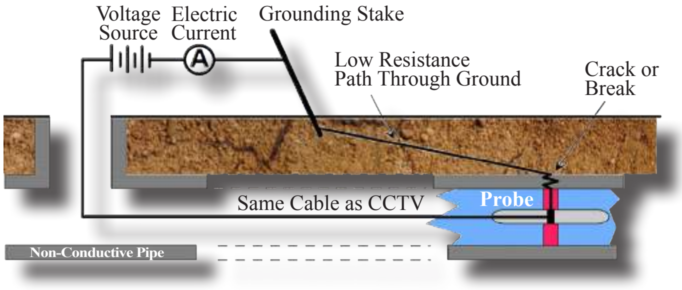
The science of using low voltage conductivity is straightforward. A similar application known as holiday testing, was already in use to evaluate protective coatings for exposed pipes, rooftops, and reservoir linings. The technology need was for a low voltage equivalent to internally assess full-length, 360-degree pipe wall integrity while allowing existing flow conditions during inspection.

Most sewer pipe materials such as brick, clay, plastic, concrete, and resin-based liners, are poor conductors of electrical current. As a result, if a defect exists in the wall of a pipe, then leakage of electrical current will indicate the location and size of the defect. The measured intensity and duration of the electrical signal emanating from the pipe can be correlated to a flow rate in Gallons per Minute (GPM), whether or not water infiltration or exfiltration actually occurs during the survey, without bypass required.

An approach was developed by establishing a low, 12-volt electrical circuit with a 40 milliamp (mA) signal, using water as a conductor, which allowed two ends of the circuit to connect and close the loop, as depicted in Figure 3. Applied to an underground pipe, one side of the circuit would remain inside a non-conductive pipe (e.g., asbestos cement, brick, epoxy-coated ductile iron, high density polyethylene, plastic, resin-based liner, vitrified clay pipe, etc.). Connected to a grounding stake, any defect current would need to travel to the surface to confirm a corresponding pipe wall defect, or leak.

If the loop is never closed, whereby an electrical circuit is closed, the pipe would be shown to have no defects. Conversely, if the loop is closed, whereby an electrical connection is made, then an opening or defect exists in the pipe wall, allowing a pathway from inside of the pipe to ground. Since water leakage and electric current are highly correlated, the intensity and duration of measured current can provide a specific defect size and corresponding flow rate in gallons per minute.

Figure 10. Low Voltage Conductivity Scientific Principle



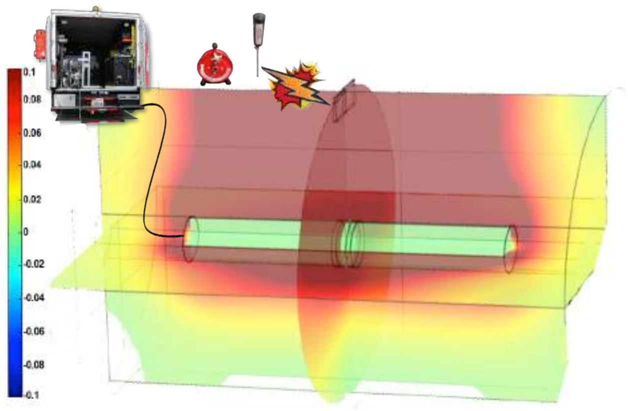
Source: ASTM F2550 (2006, 2013, and 2018).

Utilizing desktop pipe simulation tools that could reliably model variable impedance of the electric circuit would be the first step. Confirming probe dimensions, power settings, grounding sources, data capture, repeatability of results, and precision of leak location would offer precise locational accuracy. Important also to defect location is quantifying a leakage rate. Basic assumptions related to hydraulic head conditions on a defect and surrounding pipe burial soil conditions were made to develop a calculation for a relative leakage rate that is not made by other existing leak location products.

Following the principle operation of AC circuits, a grounding source was needed to simulate a conductive rod driven into the earth near the operation of the device to complete its circuit. The frequency of signal sources provided direction with regards to the system physics. In other words, modelling and thinking of electric fields, current and charge sources were done under the assumption of steady state or "static" conditions. Analyzing electric fields and current densities were performed under several static conditions including, but not limited to, pipe size, pipe material, defect size, voltage levels, and defect location along the pipe, relative to the probe.

As illustrated in Figure 9 (Below) electrostatic operational properties and parameters were modeled, analyzed, and plotted using COMSOL® Multiphysics® and MATLAB, a multi-paradigm numerical

Figure 11. COMSOL® Multiphysics® depiction of Electro Scan's narrowly focused electric beam able to assess 360^o of pipe wall traveling at a speed of 15-20m per minute.



computing environment and proprietary programming language developed by MathWorks. Summing static condition values over different parameter sweeps enabled accurate generation of results.

While COMSOL® has multiple choices on meshing approaches, it was found that more coarse mesh reduced simulation time and memory resources, while a user-defined mesh could affect data accuracy. To verify results, different meshed geometries were needed during testing, noting that a normal mesh created a more accurate response, as shown in Figure 4.

FELL technology developed by Electro Scan Inc. was evaluated using COMSOL® tools. As shown in Figure 5, COMSOL® simulation results and data, along with the 3D image processing of Electro Scan data and verification plots, confirmed consistently repeatable leak location results to within three-eighths (3/8th) of an inch, or one (1) centimeter (cm), accuracy across all non-conductive (i.e., non-metallic) pipes. These results are an industry breakthrough for leak location.

MEASURING LEAKS IN LITERS PER SECOND

When generating a high frequency electrode signal, one important aspect of the AC signal is that current levels of the defect electrode can be measured, demonstrating the breakthrough use of low voltage conductivity to locate leaks.

When the probe approaches a pipe defect as illustrated in Figure 10 (Below), AC current levels on the electrodes increase with spatial dependence inside a pipe, comprising the most important conduction characteristics that make the device perform, as shown in Figure 6. In other words, pipe defects are identified by the probe measured current levels. The measured area beneath the current spike curve can be used to compute the flow rate of the defect. Flow rates can be provided in any customary unit of measure, such as liters per second.

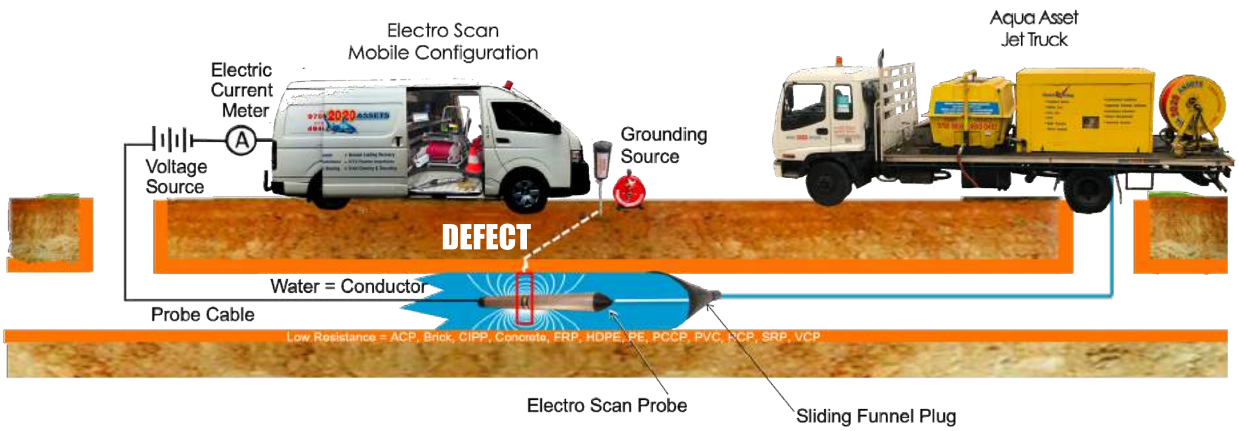
Figure 12. Low Voltage Conductivity Scientific Principle

Metrics for each defect, including:

- Starting Point, Ending Point, and Maximum Defect Current.
- Defect Classification as Large, Medium, or Small.
- Flow Classification as Sever, Moderate, or Minor Defect Readings.
- Total Estimated Defect Flow in units of volume over time.
- Total Pipe Segment Defect Flow in units of volume over time, by pipe diameter & length.

One of the benefits of utilizing COMSOL® Multiphysics® was the ability to model, test, and confirm single and multiple pipe defects, in minutes across multiple pipe materials. While COMSOL® easily accommodates multiple pipe materials, internal pipe pressures, gradients, and water conductivity, desktop results needed to be field validated to account for environmental constraints and demands of working in residential, commercial, and open areas as set-up in Figure 11 above.

Figure 13. Sydney Water Field Equipment Set-Up



ELECTRO SCAN FIELD OPERTIONS

FELL technology involves passing a tethered probe through a customer's pipe network, connected to a deployment support vehicle by a cable around 1000m in length. The probe emits a 40-milliamp current into the water, producing a one kilohertz signal distinct from that emitted by anything else in the ground, eliminating false positives.

To summarize the use of low voltage conductivity and its application to field testing of pipes, key elements include:

(a) If a crack or break occurs in a pipe wall, a tethered probe emitting electric current will complete the circuit above ground to map the precise location and severity of each leak in both gravity & pressurized pipes,

(b) That the technology could be easily retrofit to a standard TV truck or van,

(c) That FELL had the capability of measuring leaking joints missed by CCTV cameras that cannot see into bell & spigots, and

(d) That FELL was able to test full-length 360-degree surfaces for plastic pipes, including high density polyethylene, plastic, cured-in-place pipe, and spiral wound pipe for water permeability, leaks, and pinholes. Pipe materials are listed in Table 3 with set-up illustrated in Figures 12 and 13.

Table 3. Selected FELL Tested Materials, Shapes, Sizes

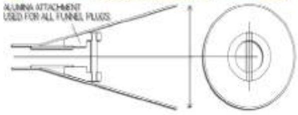
Pre-Rehabilitation Pipe Materials		**Pipe Types**
ABS	Acrylonitrile-Butadiene-Styrene Pipe	Gravity Sewers
ACP	Asbestos Cement Pipe	Rising (Force) Mains
BRK	Brick Pipe	Pressurised Water Mains
CON	Concrete Pipe	Private Sewer Laterals
DIP	Ductile Iron, with coating	Service Laterals
ORP	Orangeburg Pipe	Stormwater
PCCP	Pre-stressed Concrete Cylinder Pipe	Open Channels
PFP	Pitch Fiber Pipe	Home Plumbing Pipes
PVC	Polyvinyl Chloride Pipe	Large Diameter
RCP	Reinforced Concrete Pipe	Sewer Interceptros
VCP	Vitrified Clay Pipe	Manhole Chambers
Post-Rehabilitation Pipe Materials		**Pipe Shape**
CMLSP	Cement Mortar Lined Steel Pipe	Box
CIPP	Cured-In-Place Pipe	Circular
FF	Fold & Form	Oval
FRP	Fiberglass Reinforced Pipe	Trapezoidal
FRPM	Fiberglass Reinforced Polymer Mortar	**Pipe Diameter & Length**
GRP	Glass Reinforced Pipe	Smallest 76mm (3 inches)
GROUT	Grouted Joints and Laterals	
HDPE	High Density Polyethylene Pipe	
PE	Polyethylene Pipe	
RTR	Reinforced Thermosetting Resin Pipe	Largest 2000mm (70 inches)
SIPP	Spray-in-Place Pipe	
SPR	Spiral Wound Pipe	Up to 300m (1,000 feet)
Cost	Similar to CCTV Cost, but production rate up to 1km /day.	

Figure 15. Field Set-Up By Pipe Dynamic

Figure 14. Field Set-Up By Pipe Dynamic

1. Retrieving jet hose, typically at upstream manhole. Not needed for cleaning, but let's us know the pipe is somewhat unobstructed and will pull our probe.

2. Removing the jet hose nozzle from and screw on a right-sized funnel cone. Attached to the jet hose, this funnel cone will temporarily hold back water to surround the Electro Scan probe during survey.



NOTE
Sydney Water Field Photos of Holly Tonner, Aqua Assets & Matt Campos, Electro Scan at work.

3. Ready to deploy.

4. Easing the funnel cone into position.

5. Ease in the torpedo-style probe.

6. Laying down the probe at the bottom of the manhole, and filling water to temporarily surround probe that allows electric current to test full-length, 360-degree of pipe wall during pull back by jet truck, mechanical pulley, or manually completed.

What Equipment Was Used in Sydney Water Electro Scan Trial?

The Electro Scan system's adaptive design allows for quick, simple transitions between CCTV and Electro Scan configurations. The Electro Scan probe connects to the reel with the same type of plug the CCTV camera uses. A switchover box allows for data switching to either the CCTV Terminal or the Electro Scan Controller, and then to the Computer for viewing and storage.

Figure 16. Field Set-Up Configuration for Sydney Water Electro Scan Trial

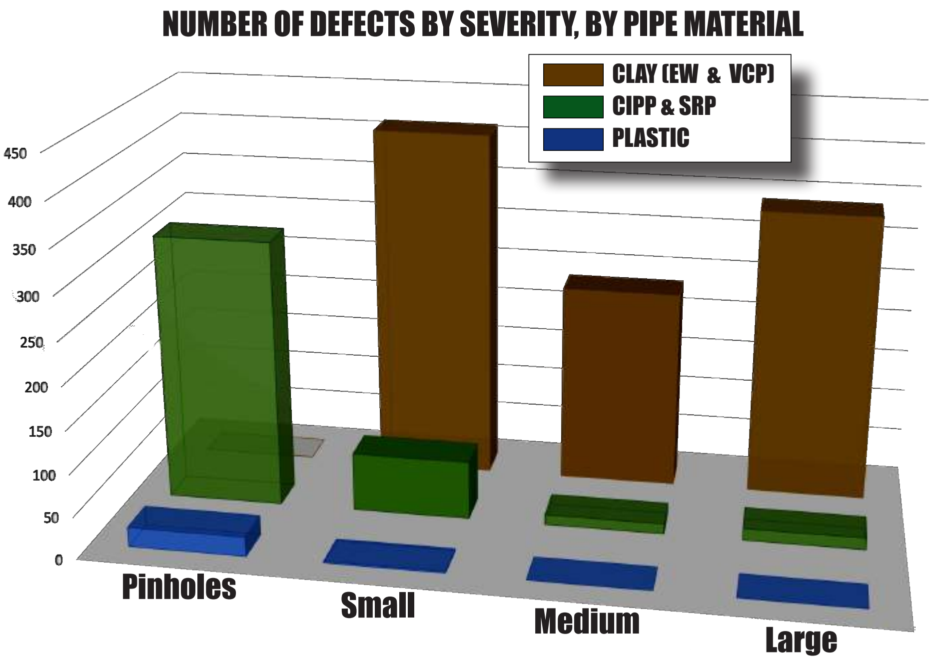
Sydney Water Electro Scan Trial Results

Electro Scan surveyed a total of 1,304 meters (4,278 feet) including 691m or 54% of Vitrified Clay Pipe, 431m or 33% of Cured-In-Place Pipe (CIPP), and 169m or 13% of Plastic pipe.

While clay pipe materials had a disproportionate number of Large, Medium, and Small Defects, CIPP showed an excessive number of total defects, primarily due to pinhole leaks, with only 2 of 22 pipes plastic.

While leakage in CIPP liners was large relative to all pipe materials tested, Sydney Water's CIPP performance is similar to line results worldwide.

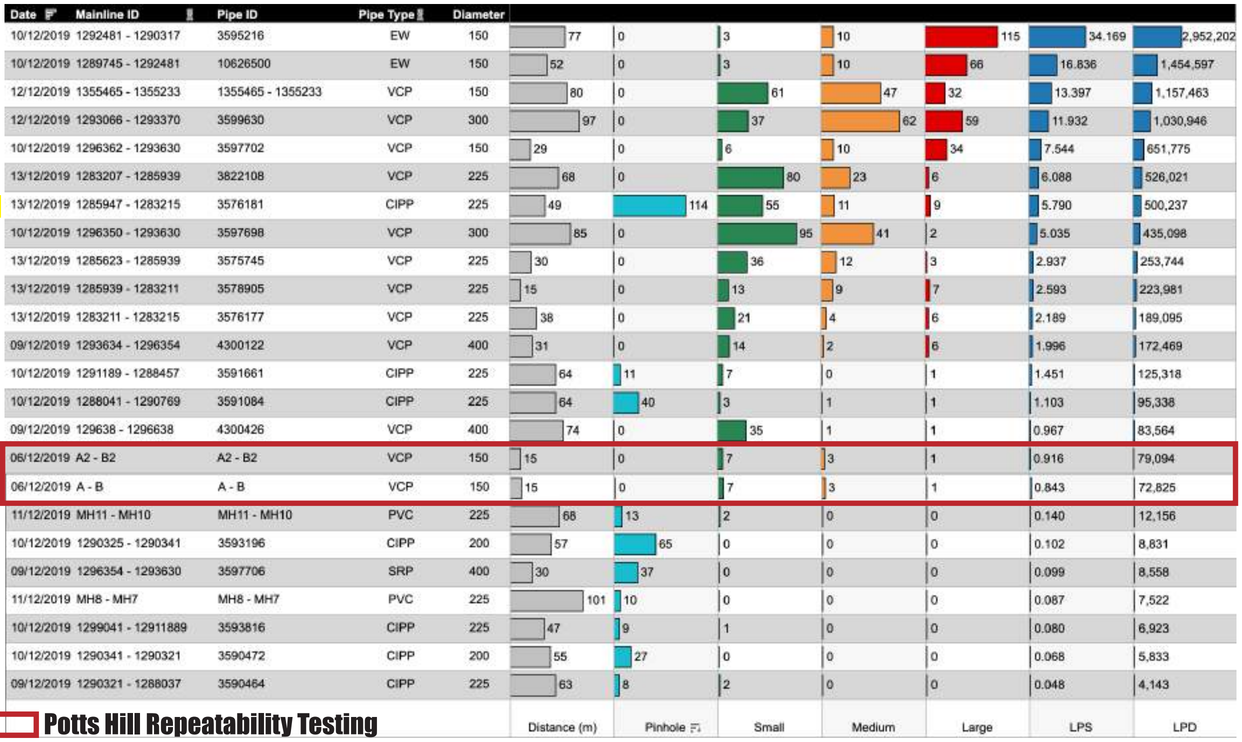
Figure 17. Number of Defects By Severity



Electro Scan found 1,421 Total Defects in 24 sewer mains, representing 116,409 liters per second of defect flow, with one sewer main repeated twice at Potts Hill for testing purposes.

Figure 18. Sydney Water Trial Project Survey Results, Ranked By Liters Per Second

Scans	Distance	Pinhole	Small	Medium	Large	Total Defects	LPS	LPD
24	1,304	334	488	249	350	1,421	116.409	10,057,731



	Date	Mainline ID	Pipe ID	Pipe Type	Diameter	Distance (m)	Pinhole	Small	Medium	Large	LPS	LPD
1	10/12/2019	1292481 - 1290317	3595216	EW	150	77	0	3	10	115	34.169	2,952,202
2	10/12/2019	1289745 - 1292481	10626500	EW	150	52	0	3	10	66	16.836	1,454,597
3	12/12/2019	1355465 - 1355233	1355465 - 1355233	VCP	150	80	0	61	47	32	13.397	1,157,463
4	12/12/2019	1293066 - 1293370	3599630	VCP	300	97	0	37	62	59	11.932	1,030,946
5	10/12/2019	1296362 - 1293630	3597702	VCP	150	29	0	6	10	34	7.544	651,775
6	13/12/2019	1283207 - 1285939	3822108	VCP	225	68	0	80	23	6	6.088	526,021
7	13/12/2019	1285947 - 1283215	3576181	CIPP	225	49	114	55	11	9	5.790	500,237
8	10/12/2019	1296350 - 1293630	3597698	VCP	300	85	0	95	41	2	5.035	435,098
9	13/12/2019	1285623 - 1285939	3575745	VCP	225	30	0	36	12	3	2.937	253,744
10	13/12/2019	1285939 - 1283211	3578905	VCP	225	15	0	13	9	7	2.593	223,981
11	13/12/2019	1283211 - 1283215	3576177	VCP	225	38	0	21	4	6	2.189	189,095
12	09/12/2019	1293634 - 1296354	4300122	VCP	400	31	0	14	2	6	1.996	172,469
13	10/12/2019	1291189 - 1288457	3591661	CIPP	225	64	11	7	0	1	1.451	125,318
14	10/12/2019	1288041 - 1290769	3591084	CIPP	225	64	40	3	1	1	1.103	95,338
15	09/12/2019	129638 - 1296638	4300426	VCP	400	74	0	35	1	1	0.967	83,564
16	06/12/2019	A2 - B2	A2 - B2	VCP	150	15	0	7	3	1	0.916	79,094
17	06/12/2019	A - B	A - B	VCP	150	15	0	7	3	1	0.843	72,825
18	11/12/2019	MH11 - MH10	MH11 - MH10	PVC	225	68	13	2	0	0	0.140	12,156
19	10/12/2019	1290325 - 1290341	3593196	CIPP	200	57	65	0	0	0	0.102	8,831
20	09/12/2019	1296354 - 1293630	3597706	SRP	400	30	37	0	0	0	0.099	8,558
21	11/12/2019	MH8 - MH7	MH8 - MH7	PVC	225	101	10	0	0	0	0.087	7,522
22	10/12/2019	1299041 - 12911889	3593816	CIPP	225	47	9	1	0	0	0.080	6,923
23	10/12/2019	1290341 - 1290321	3590472	CIPP	200	55	27	0	0	0	0.068	5,833
24	09/12/2019	1290321 - 1288037	3590464	CIPP	225	63	8	2	0	0	0.048	4,143

☐ **Potts Hill Repeatability Testing**
🟨 **Cured-In-Place Pipe (CIPP) Testing**

The FELL Electro Scan trail project was limited in its scope and, therefore may not be representative of Sydney Water's total network, leak profile, age, pipe condition, or thoroughness of current inspection techniques or contractor performance; however, even the limited scope of work indicates several drawbacks with current condition assessment practices.

Sydney Water condition assessment, inspection, and certification standards are similar to other water utilities survey by Electro Scan Inc.

Electro Scan Inc., and its wholly-owned British, German, and Canadian subsidiaries have cumulative assessment of over 1,200 km (4 million feet) of pipes using its patented low voltage conductivity technology, with all results stored on its proprietary Amazon Web Services cloud-based CriticalSewers® cloud application developed and supported by California-based Hansen Analytics LLC.

While additional field testing is warranted to understand scope and significance of its finding, especially before any across-the-board implementation, immediate need appears necessary in support of Sydney Water's CIPP acceptance program and dry weather & wet weather infiltration assessment program.

As shown on the following page, twenty-four (24) sewer mains surveyed as part of its trial project included Clay, CIPP, and Plastic pipes, as follows:

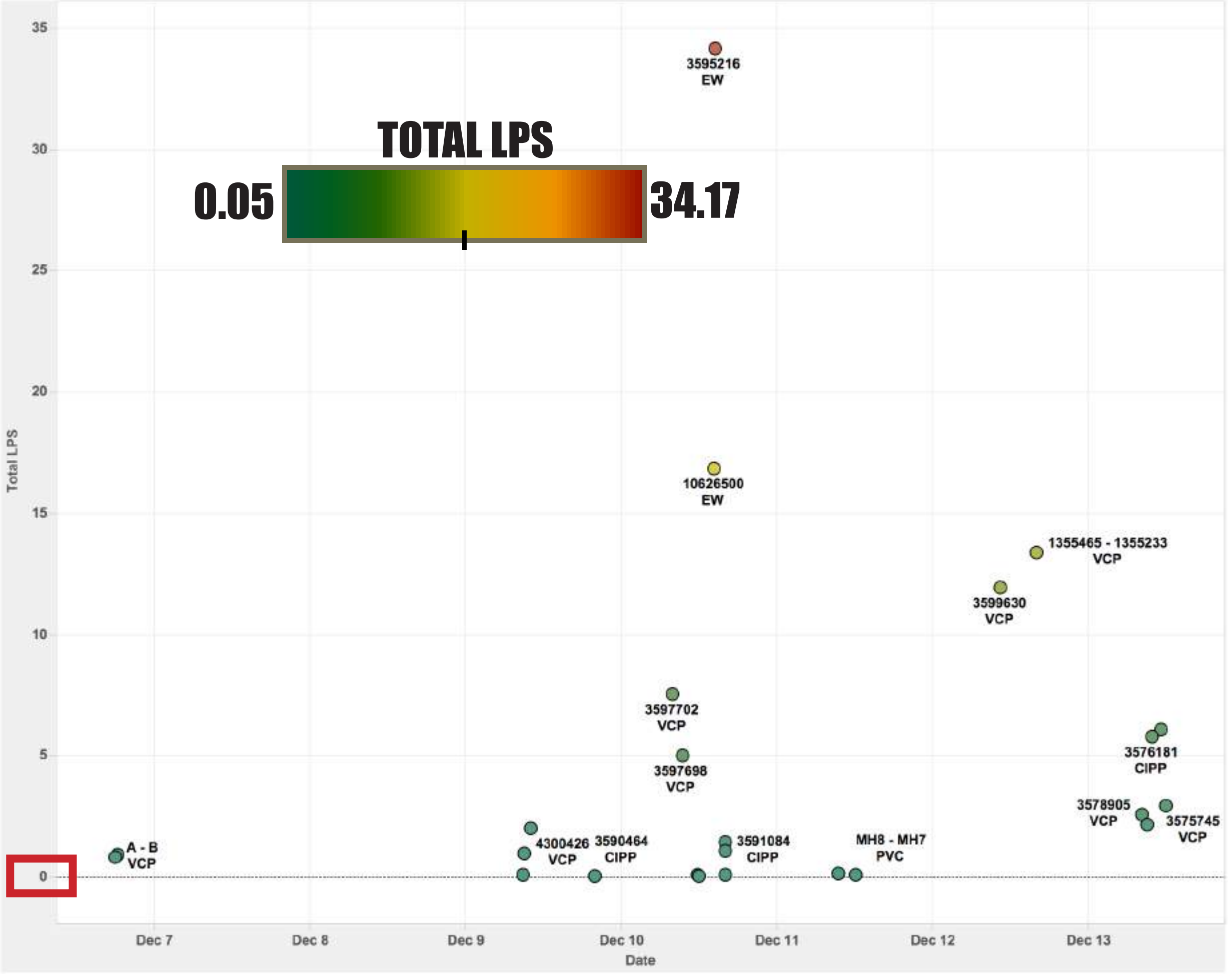
Table 4. Number of Meters, Defects and Defect Flow in l/s

	Meters	Defects	l/s
Clay[1]	706	994	107.44
CIPP	429	402	8.74
PVC	169	25	0.23
Total	1,304	1,421	116.41

[1] Clay pipe includes earthenware and vitrified clay pipe.

It should be noted that while defects counts and l/s defect flows for clay pipe appears consistent with older pipes, but defects found in newly installed CIPP appears excessive.

Figure 20. Sydney Water Trial Project Survey Matrix



Sydney Water Electro Scan Trial Results – By Pipe Material

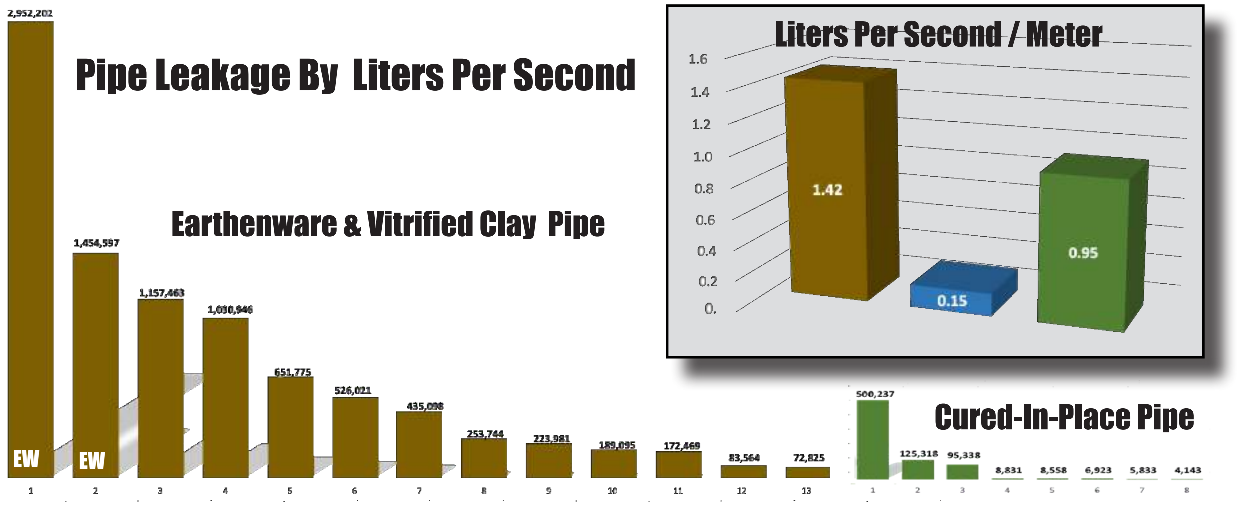
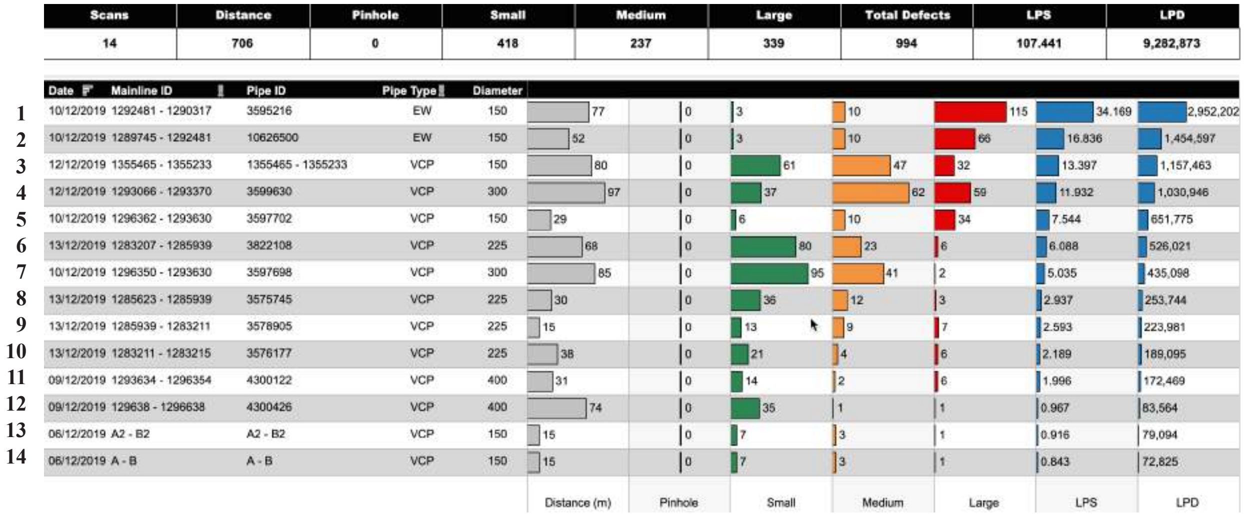


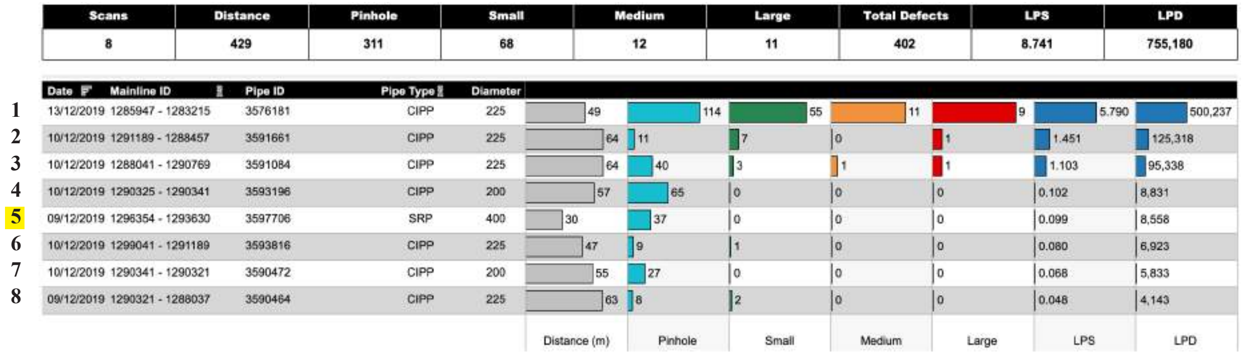
Figure 19. Clay Pipe, Ranked By Liters Per Second



Scans	Distance	Pinhole	Small	Medium	Large	Total Defects	LPS	LPD
14	706	0	418	237	339	994	107.441	9,282,873

	Date	Mainline ID	Pipe ID	Pipe Type	Diameter	Distance (m)	Pinhole	Small	Medium	Large	LPS	LPD
1	10/12/2019	1292481 - 1290317	3595216	EW	150	77	0	3	10	115	34.169	2,952,202
2	10/12/2019	1289745 - 1292481	10626500	EW	150	52	0	3	10	66	16.836	1,454,597
3	12/12/2019	1355465 - 1355233	1355465 - 1355233	VCP	150	80	0	61	47	32	13.397	1,157,463
4	12/12/2019	1293066 - 1293370	3599630	VCP	300	97	0	37	62	59	11.932	1,030,946
5	10/12/2019	1296362 - 1293630	3597702	VCP	150	29	0	6	10	34	7.544	651,775
6	13/12/2019	1283207 - 1285939	3822108	VCP	225	68	0	80	23	6	6.088	526,021
7	10/12/2019	1296350 - 1293630	3597698	VCP	300	85	0	95	41	2	5.035	435,098
8	13/12/2019	1285623 - 1285939	3575745	VCP	225	30	0	36	12	3	2.937	253,744
9	13/12/2019	1285939 - 1283211	3578905	VCP	225	15	0	13	9	7	2.593	223,981
10	13/12/2019	1283211 - 1283215	3576177	VCP	225	38	0	21	4	6	2.189	189,095
11	09/12/2019	1293634 - 1296354	4300122	VCP	400	31	0	14	2	6	1.996	172,469
12	09/12/2019	129638 - 1296638	4300426	VCP	400	74	0	35	1	1	0.967	83,564
13	06/12/2019	A2 - B2	A2 - B2	VCP	150	15	0	7	3	1	0.916	79,094
14	06/12/2019	A - B	A - B	VCP	150	15	0	7	3	1	0.843	72,825

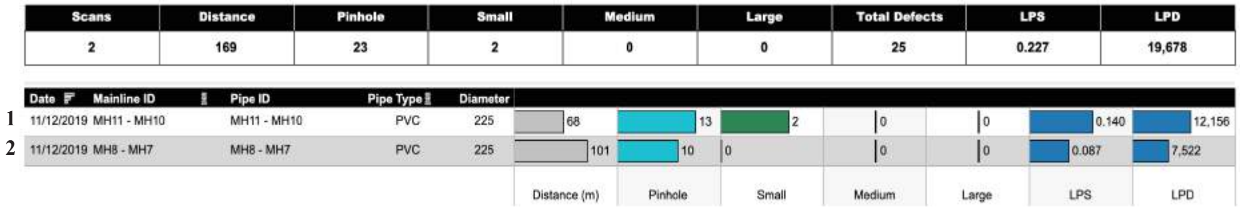
Figure 20. Cured-In-Place Pipe (CIPP), including 1 Spiral Wound Pipe, Ranked By Liters Per Second



Scans	Distance	Pinhole	Small	Medium	Large	Total Defects	LPS	LPD
8	429	311	68	12	11	402	8.741	755,180

	Date	Mainline ID	Pipe ID	Pipe Type	Diameter	Distance (m)	Pinhole	Small	Medium	Large	LPS	LPD
1	13/12/2019	1285947 - 1283215	3576181	CIPP	225	49	114	55	11	9	5.790	500,237
2	10/12/2019	1291189 - 1288457	3591661	CIPP	225	64	11	7	0	1	1.451	125,318
3	10/12/2019	1288041 - 1290769	3591084	CIPP	225	64	40	3	1	1	1.103	95,338
4	10/12/2019	1290325 - 1290341	3593196	CIPP	200	57	65	0	0	0	0.102	8,831
5	09/12/2019	1296354 - 1293630	3597706	SRP	400	30	37	0	0	0	0.099	8,558
6	10/12/2019	1299041 - 1291189	3593816	CIPP	225	47	9	1	0	0	0.080	6,923
7	10/12/2019	1290341 - 1290321	3590472	CIPP	200	55	27	0	0	0	0.068	5,833
8	09/12/2019	1290321 - 1288037	3590464	CIPP	225	63	8	2	0	0	0.048	4,143

Figure 21. Plastic Pipe, Ranked By Liters Per Second



Scans	Distance	Pinhole	Small	Medium	Large	Total Defects	LPS	LPD
2	169	23	2	0	0	25	0.227	19,678

	Date	Mainline ID	Pipe ID	Pipe Type	Diameter	Distance (m)	Pinhole	Small	Medium	Large	LPS	LPD
1	11/12/2019	MH11 - MH10	MH11 - MH10	PVC	225	68	13	2	0	0	0.140	12,156
2	11/12/2019	MH8 - MH7	MH8 - MH7	PVC	225	101	10	0	0	0	0.087	7,522

Clay Pipe Assessment
While Sydney Water recommends other pipe materials that may be better suited for specific locations, clay pipe, including earthenware (EW), salt glazed ware (SGW), and vitrified clay (VC) pipe, which represents the most significant percentage of sewer pipe material in the utility's service area, and not capable of adequately assessing leak profiles at cracks or joints.

Figure 22. FELL Inspection of Bell & Spigot Joints

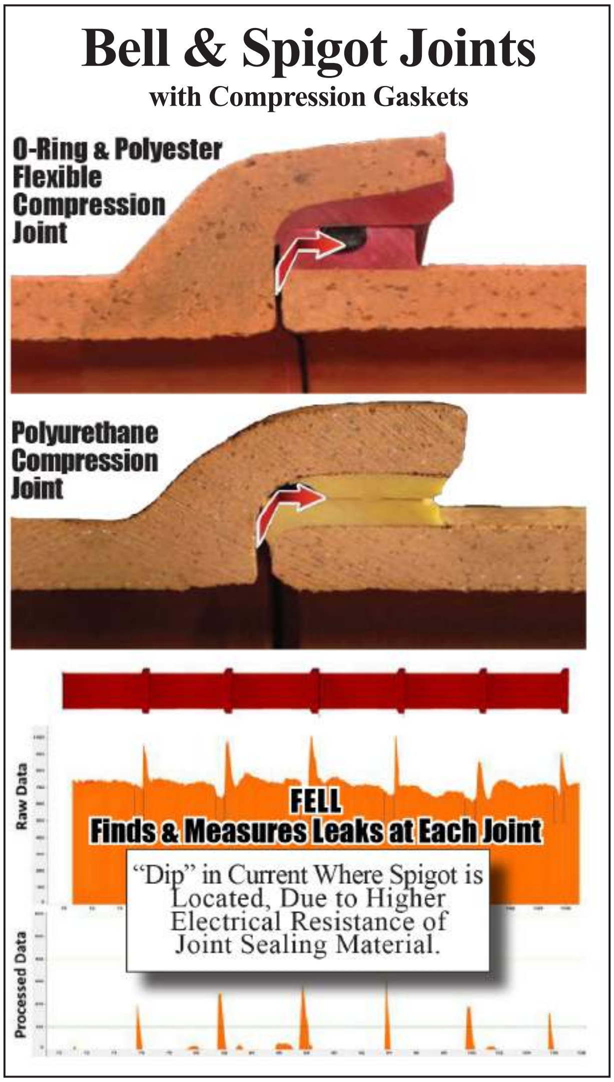


Figure 23. FELL Inspection of Open Ended Joints

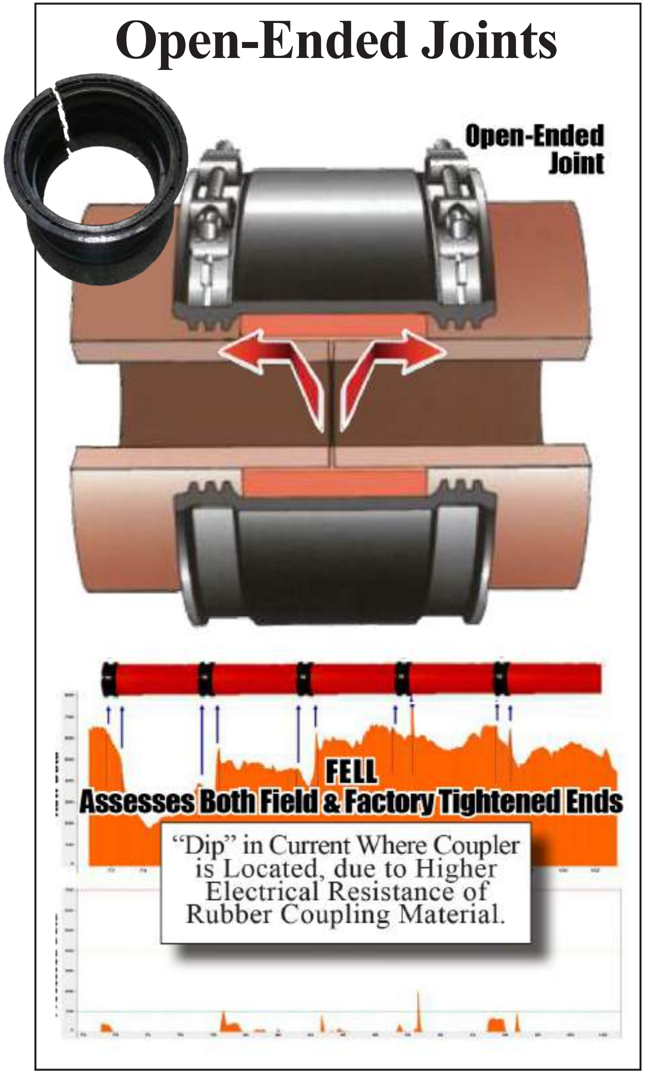
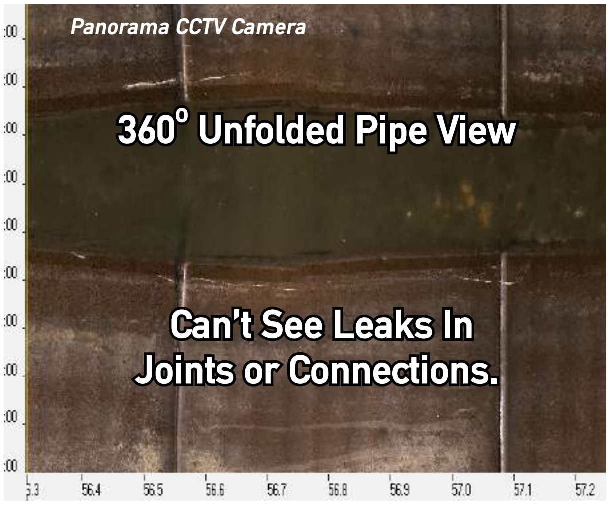


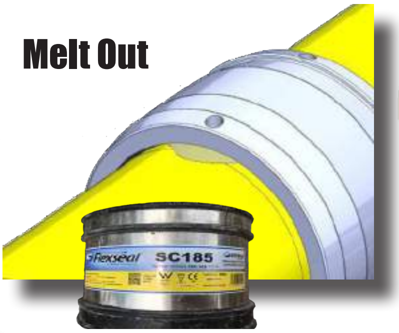
Figure 24. Example CCTV Inspection of Cracks

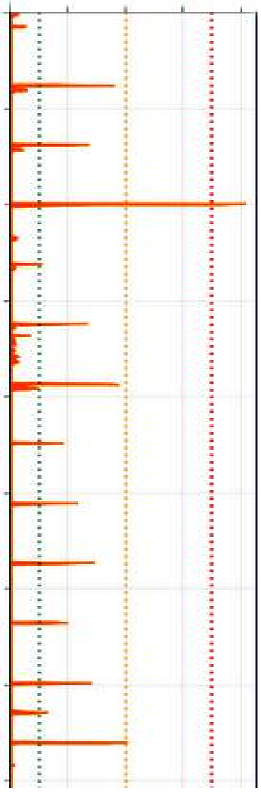
Figure 25. Example IBAK Panorama CCTV of Sewer

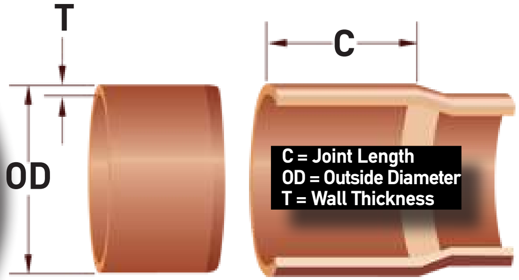


Plastic Pipe Assessment

The use of plastic pipes like High Density Polyethene Pipe (HDPE), Polyvinylchloride (Modified, Oriented, or Unplasticised), Polyethylene, and Polypropylene, are becoming the predominant pipe material installed at Sydney Water, but difficult to leak test as installed and after lateral connections. While pressure testing not recommended in high groundwater areas and CCTV is inconsistent and challenges in finding defects at joints, Electro Scan appears a superior techniques to find and measure leaks in plastic pipes.



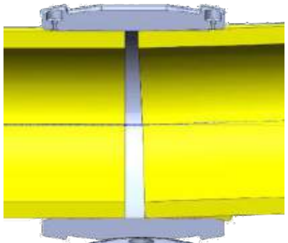




C = Joint Length
OD = Outside Diameter
T = Wall Thickness

Inconsistent results and the inability to pressure test pipes with lateral connections has led agencies to substitute F2550 to test and certify plastic pipes as watertight.

Inadequate Clamping or Restraint During Fusion



COMMON PLASTIC PIPE DEFECTS

- **Accidental Tears**
- **Bad Fusions**
- **Bad Joints**
- **Flat Spots**
- **Internal Damage**
- **Loose Clamps**
- **Melt Outs**
- **Out of Rounds**
- **Stress Fractures**

CURED-IN-PLACE PIPE (CIPP) TESTING BY IKT, WRc plc, & ELECTRO SCAN

Much work on the testing and inspection of CIPP liners has been spearheaded by the Institut für Unterirdische Infrastruktur (IKT), Gelsenkirchen, Germany. In 2016, IKT invited British-based Water Research Centre (WRc Plc) and American-based Electro Scan Inc. to participate on IKT's short-liner CIPP study. Conducting field and laboratory testing, including hydrostatic pressure testing and FELL testing utilising Electro Scan certified equipment, initial results were published in October 2019, with final results to be published upon approval by the German government.

A key finding of IKT's work was the consistent, repeatable test results of Electro Scan, which it had assessed as part of earlier version in 2001. While key readings demonstrated remarkable repeatability, IKT further recommended that additional software developments be undertaken to quantify pinholes leakage (less than 0.1 gallon per minute), as shown in Figures 26 & 27.


IKT - Institut für Unterirdische Infrastruktur,
Gelsenkirchen
www.ikt.de

IKT-Warentest
„Kurzliner für Hausanschlüsse“
- Auszug aus dem Forschungsbericht -

Gelsenkirchen, Oktober 2018

Figure 26. Repeatability Testing

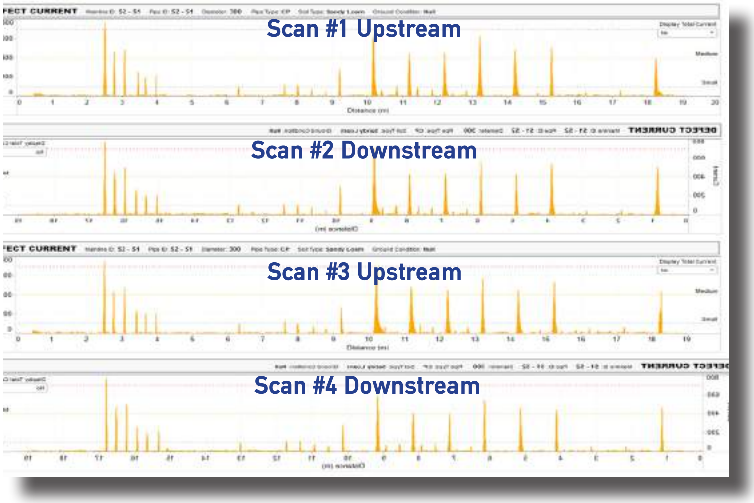
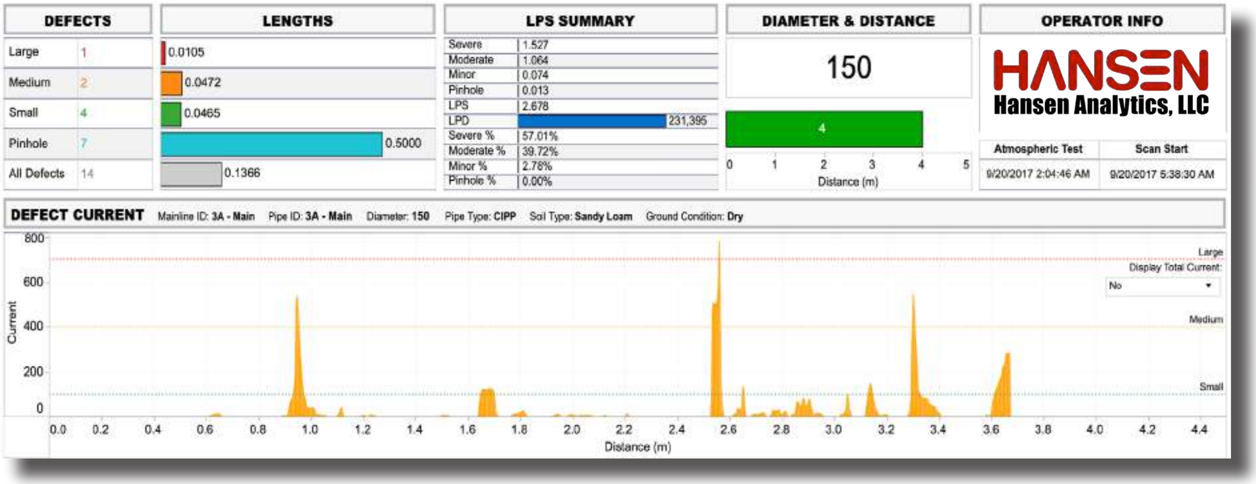


Figure 27. New Release of Cloud-Based CIPP Leak Assessment Application



DEFECTS		LENGTHS
Large	1	0.0105
Medium	2	0.0472
Small	4	0.0465
Pinhole	7	0.5000
All Defects	14	0.1366

LPS SUMMARY	
Severe	1.527
Moderate	1.064
Minor	0.074
Pinhole	0.013
LPS	2.678
LPD	231,395
Severe %	57.01%
Moderate %	39.72%
Minor %	2.78%
Pinhole %	0.00%

DIAMETER & DISTANCE

150

OPERATOR INFO

Hansen Analytics, LLC

Atmospheric Test	Scan Start
9/20/2017 2:04:46 AM	9/20/2017 5:38:30 AM

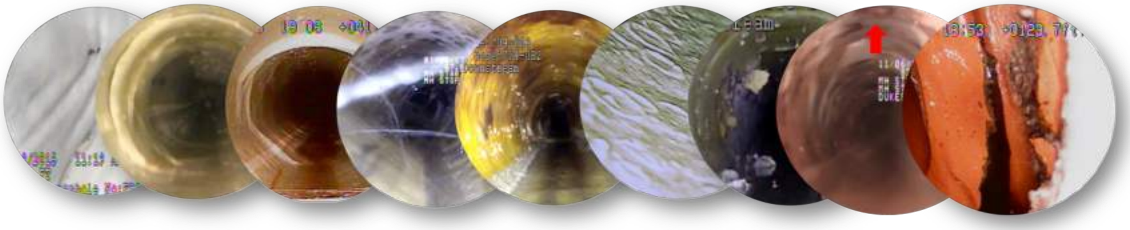
DEFECT CURRENT Mainline ID: 3A - Main Pipe ID: 3A - Main Diameter: 150 Pipe Type: CIPP Soil Type: Sandy Loam Ground Condition: Dry

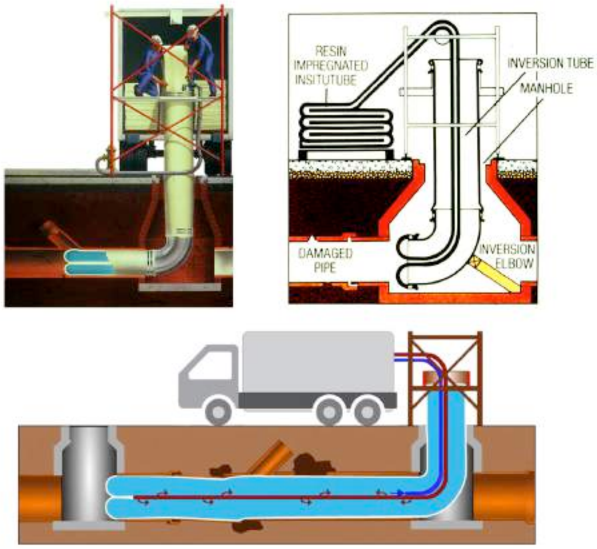
Display Total Current: No

Figure 28. Results of 4th Annual International CIPP Survey

2019 – Electro Scan's 4th Annual International Survey of Cured-In-Place Pipe (CIPP)

Published in January 2020, Electro Scan Inc. publishhed results from CIPP testing for the 12-months ending 31 December, showing 86% of all CIPP lined pipes, including pipes as evaluated in Sydney Water, had deffects, with 44% of all surveyed pipes with an estimated 20 gallon per minute (1.2618 liters per second) leakage rate, representing 14,450 leaks, including 6,775 pinhole leaks for first time in its annual survey.





Year Ending December 31st	2019	2018
CIPP Liners With Defect Flows	84%	78%
CIPP Liners w/ZERO Defect Flows	16%	22%

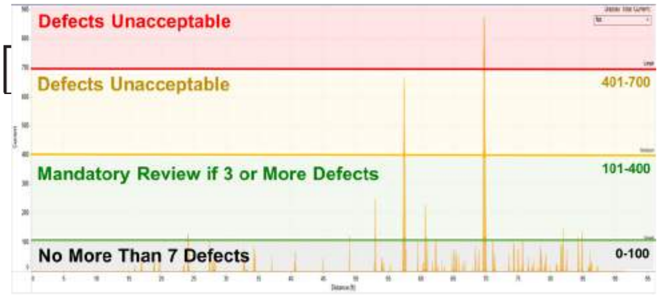
CIPP FELL INSPECTION In Linear Feet

Total Assessment Footage	111,607	98,255

CIPP DEFECT FLOWS BY SEVERITY

More than 1 gal/min	71%	68%
More than 2 gal/min	65%	62%
More than 3 gal/min	63%	60%
More than 4 gal/min	61%	56%
More than 5 gal/min	60%	54%
More than 10 gal/min	54%	46%
More than 20 gal/min	44%	32%

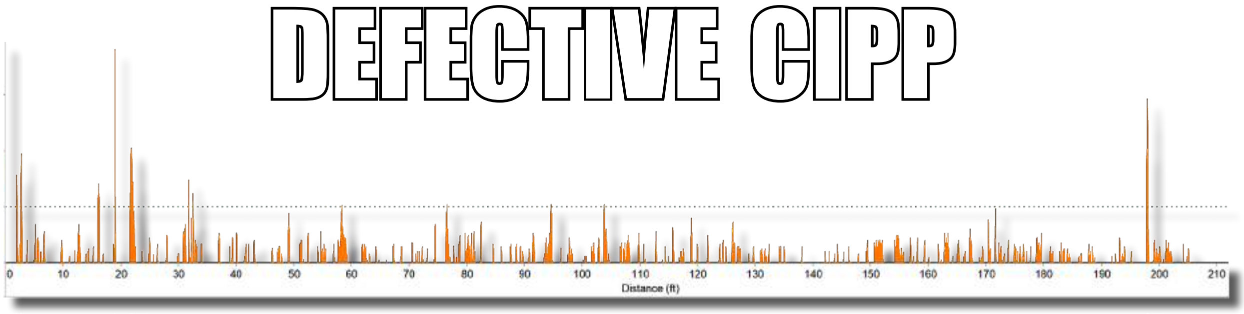
RECOMMENDED ACCEPTANCE GUIDELINES



NUMBER OF CIPP LEAKS

TOTAL COMBINED LEAKS	14,450	3,964
Large Leaks	1,379	744
Medium Leaks	1,209	516
Small Leaks	5,087	2,704
Pinhole Leaks	6,775	

Source: Hansen Analytics, LLC, Critical Sewers® January 1, 2020



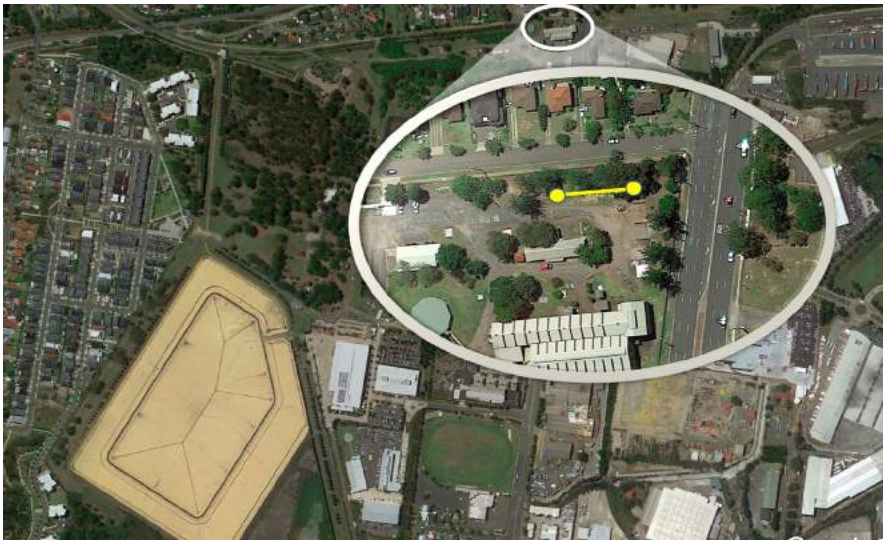
1. POTTS HILL

Sydney Water's outdoor test facility on Lewis Street was the location for the first trial of Electro Scan's FELL technology. Working with authorised contractor NWS-based Aqua Assets Pty Ltd., Sydney Water training was completed with Induction Cards duly certified, prior to conducting work on Sydney Water premises.

A 16m length 150mm diameter test bed was installed to allow vendors to test their unpackaged equipment and allow other field personnel to receive 'hands-on' familiarity with equipment configurations.

Sydney Water's test bed represented a 10m Vitrified Clay Pipe (VCP) segment, followed by a 2m Polyvinyl Chloride (PVC) section, followed by a 4m VCP sectional.

Standard plastic joints were used to connect each VCP Open Ended Joint, while Ferncos fittings were used to secure each end of the PVC sectional pipe.



Potts Hill, Lewis Street training facility.

Sydney Water trial test bed for pipe evaluations.

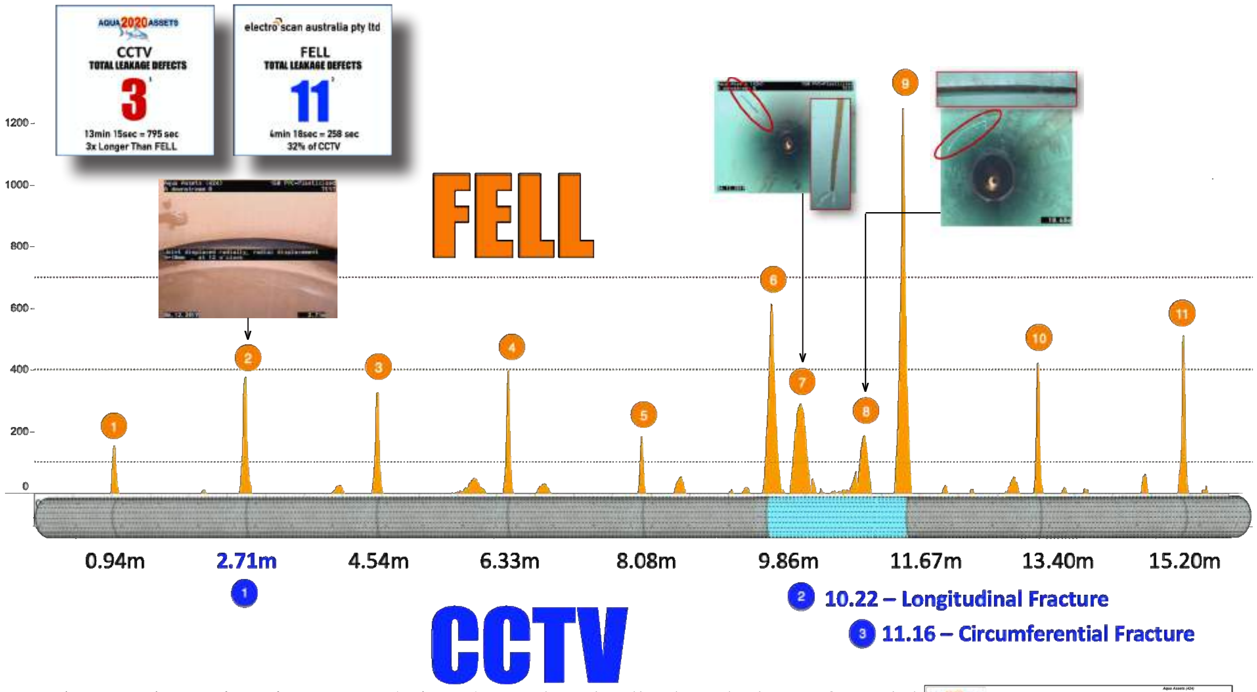
CCTV vs. FELL Results Comparison

A key question of Sydney Water's Business Case was whether significant difference existed between visual identification of defects from the operation of a high resolution CCTV camera versus machine identification of defects from the operation of FELL equipment.

Other obvious comparisons include ease of use, survey time & speed, data generation & storage, and repeatability. The Electro Scan FELL survey was completed first, including a second scan to demonstrate its data repeatability.

CCTV was conducted after FELL, with the seasoned, certified CCTV operator aware of the comparison and need to callout each defect.

Temporary Filling of Water from Jet Hose (Below).

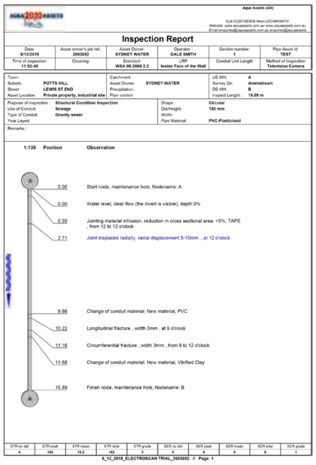


As shown above in Figure 16 (Above), CCTV recorded three (3) defect locations, including (a) displaced joint at 2,71m, (b) longitudinal fracture @10.22m, and (c) circumferential fracture @ 11.16m, with both defects at (b) and (c) placed by Sydney Water staff. Once fully set-up with the camera positioned in the pipe CCTV inspection took 13 minutes, 15 seconds to complete its inspection.

In contrast, FELL recorded eleven (11) defect locations, including leak locations at joints, defects at both changes in material, and both previously installed defects at longitudinal and circumferential locations.

Two (2) of the 11 defects may have been influenced by a metallic flange in each of the ferno fittings, but separation of FELL results, indicates that 'no impact' was made on any other defects identified.

Once fully set-up with the FELL probe positioned in the pipe, FELL took 4 minutes, 18 seconds to complete its survey.


Aqua Assets (424)
Syd:(02)97080808 Newc:(02)49400410
Website: www.aquaassets.com.au www.aquaassets.com.au
Email:enquiries@aquaassets.com.au enquiries@aquaassets

Inspection Report

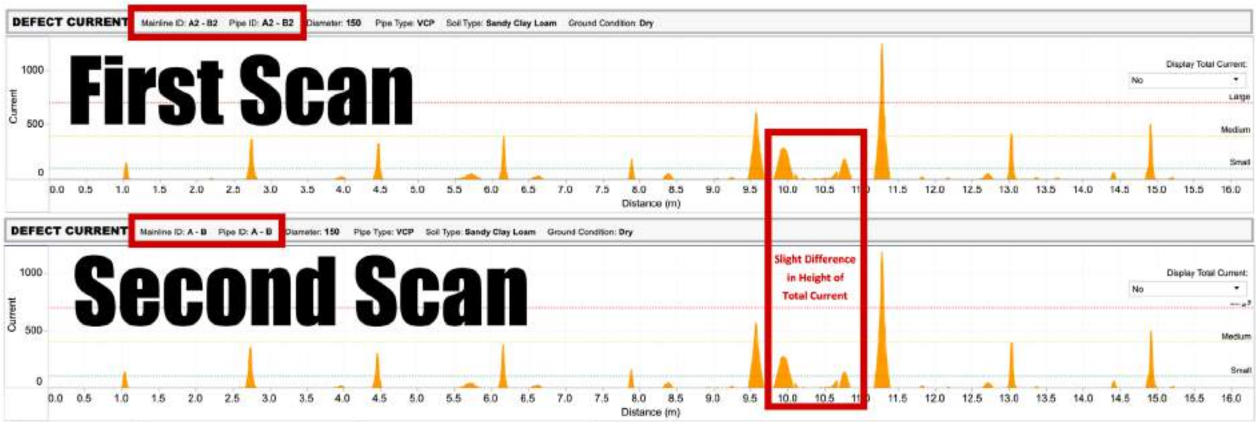
Date:	Asset owner's job ref.:	Asset Owner:	Operator :	Section number:	Pipe Asset Id:
6/12/2019	2003052	SYDNEY WATER	DALE SMITH	1	TEST
Time of inspection: 11:53:45	Cleaning:	Standard: WSA 05-2008 2.2	LRP Inside Face of the Wall	Conduit Unit Length	Method of Inspection Television Camera

Town:
Suburb: POTTS HILL
Street: LEWIS ST END
Asset Location: Private property, industrial site
Catchment:
Asset Owner: SYDNEY WATER
Precipitation.:
Flow control
US MH: A
Survey Dir: downstream
DS MH: B
Inspect Lenght : 15.89 m
Purpose of inspection : Structural Condition Inspection
Use of Conduit: Sewage
Type of Conduit: Gravity sewer
Year Layed:
Shape : Circular
Dia/Height: 150 mm
Width:
Pipe Material: PVC-Plasticised
Remarks :

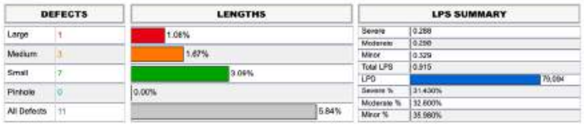
1:135 Position	Observation
0.00	Start node, maintenance hole, Nodename: A
0.00	Water level, clear flow (the invert is visible), depth 0%
0.50	Jointing material intrusion, reduction in cross sectional area: <5%, TAPE , from 12 to 12 o'clock
2.71	Joint displaced radially, radial displacement 5-10mm , at 12 o'clock
9.86	Change of conduit material. New material, PVC
10.22	Longitudinal fracture , width 3mm , at 9 o'clock
11.16	Circumferential fracture , width 3mm , from 9 to 12 o'clock
11.68	Change of conduit material. New material, Vitrified Clay
15.89	Finish node, maintenance hole, Nodename: B

STR no def	STR peak	STR mean	STR total	STR grade	SER no def	SER peak	SER mean	SER total	SER grade
4	160	10.2	162	5	0	0	0	0	1

6_12_2019_ELECTROSCAN TRIAL_2003052 // Page: 1


DEFECT CURRENT Mainline ID: A2 - B2 Pipe ID: A2 - B2 Diameter: 150 Pipe Type: VCP Soil Type: Sandy Clay Loam Ground Condition: Dry

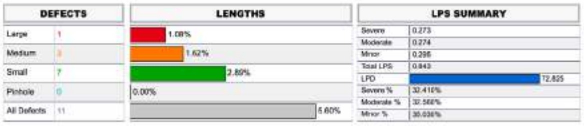
DEFECT CURRENT Mainline ID: A - B Pipe ID: A - B Diameter: 150 Pipe Type: VCP Soil Type: Sandy Clay Loam Ground Condition: Dry



DEFECTS	
Large	1
Medium	3
Small	7
Pinhole	0
All Defects	11

LENGTHS
1.08%
1.67%
3.09%
0.00%
5.84%

LPS SUMMARY	
Severe	0.288
Moderate	0.298
Minor	0.329
Total LPS	0.915
LPD	79,094
Severe %	31.430%
Moderate %	32.600%
Minor %	35.980%



DEFECTS	
Large	1
Medium	3
Small	7
Pinhole	0
All Defects	11

LENGTHS
1.08%
1.62%
2.89%
0.00%
5.60%

LPS SUMMARY	
Severe	0.273
Moderate	0.274
Minor	0.296
Total LPS	0.843
LPD	72,825
Severe %	32.410%
Moderate %	32.560%
Minor %	35.036%

79,094 LPD

DIFFERENCE
6,269 LPD
8.6%

72,825 LPD

NOTE

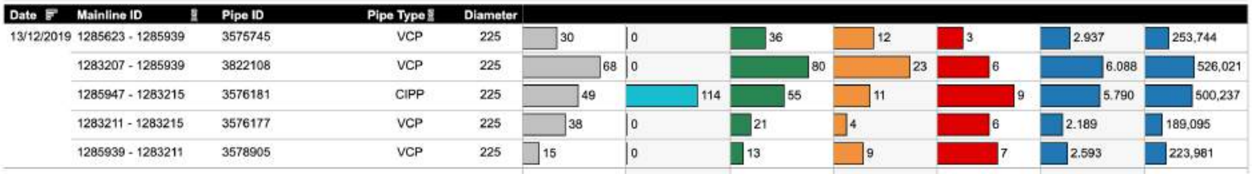
Electro Scan completed a second survey, immediately following its first scan successfully demonstrating its repeatability.

2. ABBOTSFORD

The Abbotsford pilot area was add in response to a developing situation where a private resident had reported a sewer back-up into their basement, in an area know for frequent overflows.

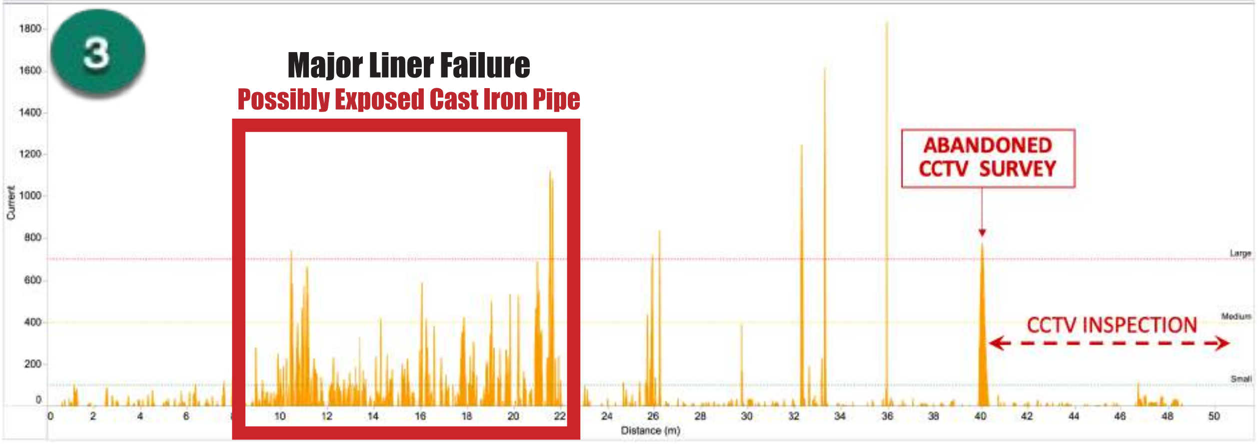
Each sewer main surveyed was 225mm diameter pipes, consisting of 5 pipes, including four (4) VCP and one (1) CIPP, with FELL finding over 409 defect with a maximum leakage rate totaling 19.596 l/s.

Scans	Distance	Pinhole	Small	Medium	Large	Total Defects	LPS	LPD
5	200	114	205	59	31	409	19.596	1,693,078



Date	Mainline ID	Pipe ID	Pipe Type	Diameter							
13/12/2019	1285623 - 1285939	3575745	VCP	225	30	0	36	12	3	2.937	253,744
	1283207 - 1285939	3822108	VCP	225	68	0	80	23	6	6.088	526,021
	1285947 - 1283215	3576181	CIPP	225	49	114	55	11	9	5.790	500,237
	1283211 - 1283215	3576177	VCP	225	38	0	21	4	6	2.189	189,095
	1285939 - 1283211	3578905	VCP	225	15	0	13	9	7	2.593	223,981

DEFECT CURRENT Mainline ID: **1285947 - 1283215** Pipe ID: **3576181** Diameter: **225** Pipe Type: **CIPP** Soil Type: **Sandy Clay Loam** Ground Condition: **Dry**

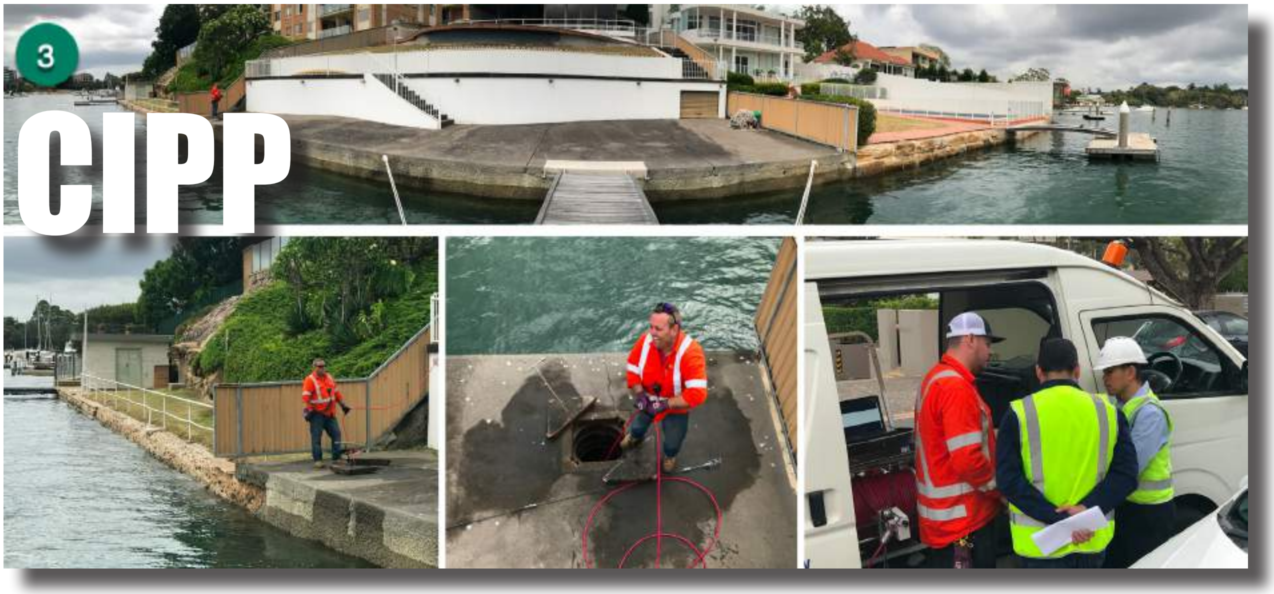


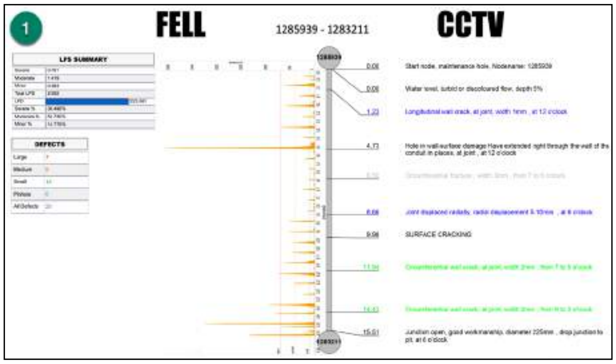
Major Liner Failure

Possibly Exposed Cast Iron Pipe

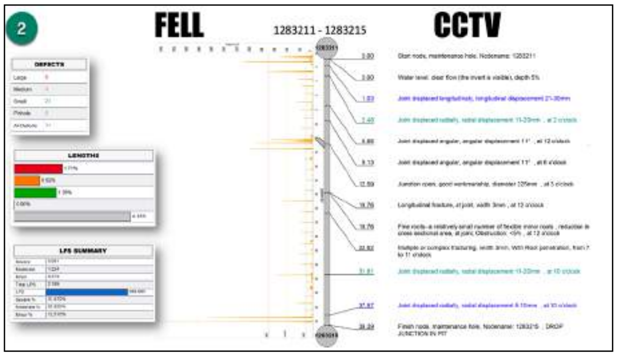
ABANDONED CCTV SURVEY

CCTV INSPECTION

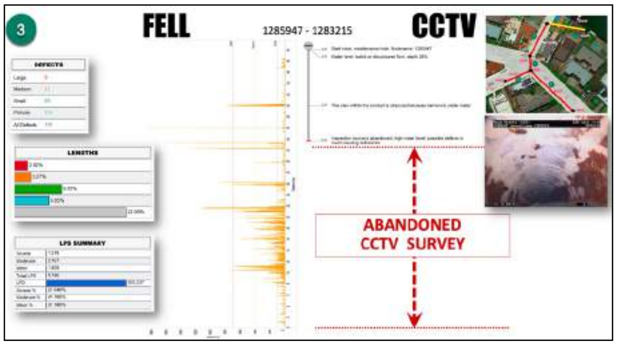



1
FELL
1285939 - 1283211
CCTV
LFS SUMMARY
DEFECTS
SURFACE CRACKING

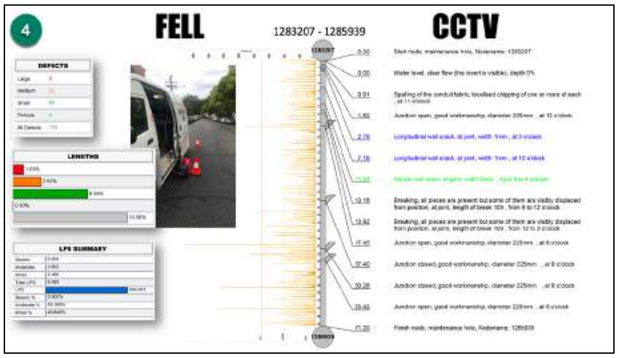

VCP


2
FELL
1283211 - 1283215
CCTV
DEFECTS
LENGTHS
LFS SUMMARY

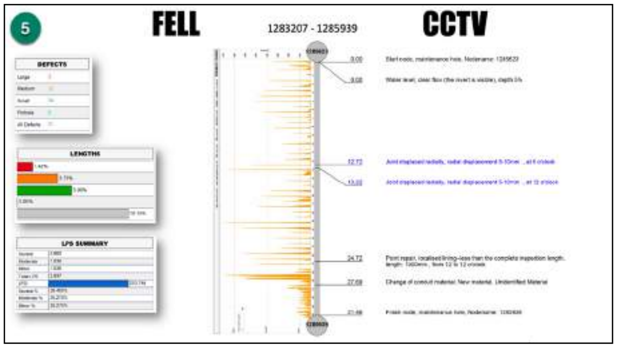

VCP


3
FELL
1285947 - 1283215
CCTV
DEFECTS
LENGTHS
LFS SUMMARY
ABANDONED
CCTV SURVEY

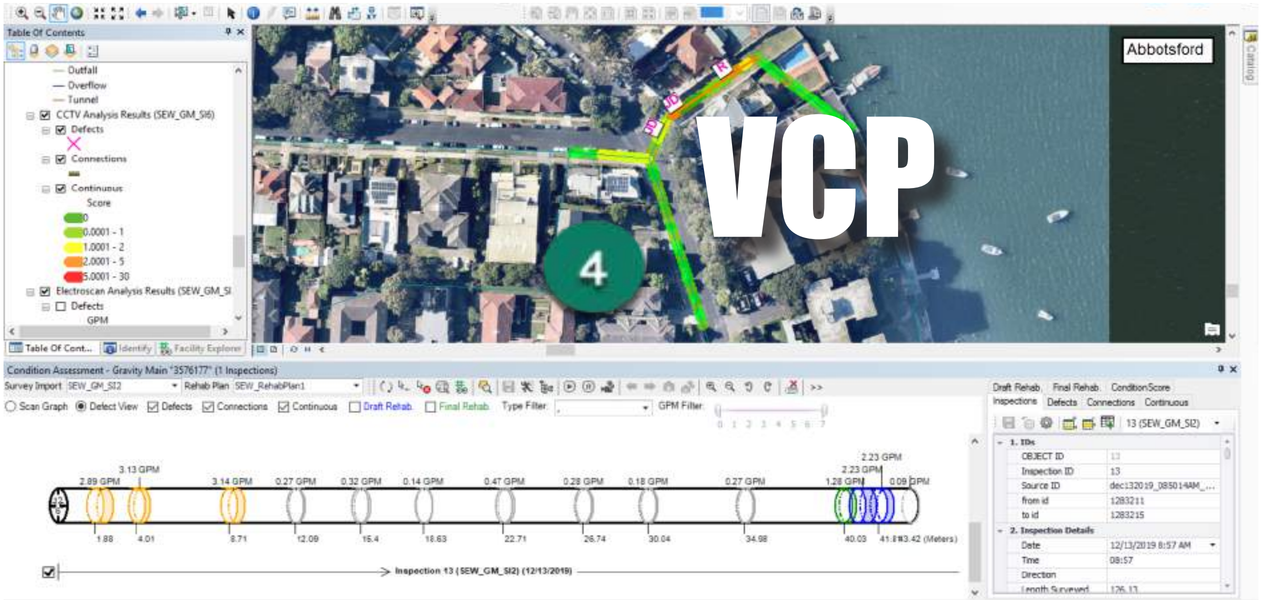

CIPP


4
FELL
1283207 - 1285939
CCTV
DEFECTS
LENGTHS
LFS SUMMARY


VCP


5
FELL
1283207 - 1285939
CCTV
DEFECTS
LENGTHS
LFS SUMMARY


VCP



Condition Assessment - Gravity Main "3576177" (1 Inspections)

Survey Import SEW_GM_SI2 Rehab Plan SEW_RehabPlan1

○ Scan Graph ● Defect View ☑ Defects ☑ Connections ☑ Continuous ☐ Draft Rehab ☐ Final Rehab Type Filter GPM Filter

☑ Inspection 13 (SEW_GM_SI2) (12/13/2019)

13 (SEW_GM_SI2)

1. IDs

OBJECT ID	13
Inspection ID	13
Source ID	dec132019_085014AM_...
from id	1283211
to id	1283215

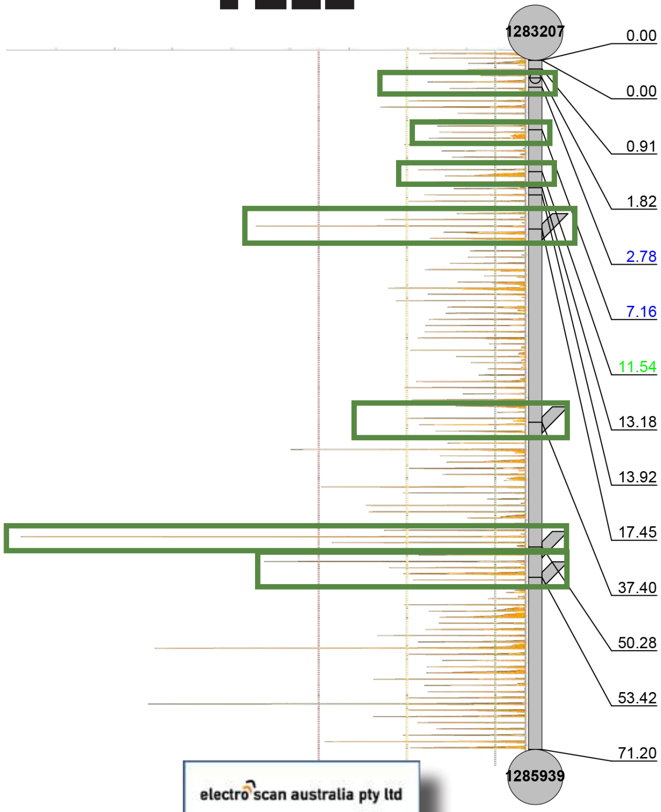
2. Inspection Details

Date	12/13/2019 8:57 AM
Time	08:57
Direction	
Length Surveyed	126.13

4

FELL

CCTV



0.00	Start node, maintenance hole, Nodename: 1283207
0.00	Water level, clear flow (the invert is visible), depth 0%
0.91	❶ Spalling of the conduit fabric, localised chipping of one or more of each , at 11 o'clock
1.82	Junction open, good workmanship, diameter 225mm , at 12 o'clock
2.78	❷ Longitudinal wall crack, at joint, width 1mm , at 3 o'clock
7.16	❸ Longitudinal wall crack, at joint, width 1mm , at 10 o'clock
11.54	❹ Simple wall crack, at joint, width 2mm , from 8 to 4 o'clock
13.18	❺ Breaking, all pieces are present but some of them are visibly displaced from position, at joint, length of break 100 , from 9 to 12 o'clock
13.92	❻ Breaking, all pieces are present but some of them are visibly displaced from position, at joint, length of break 100 , from 12 to 3 o'clock
17.45	Junction open, good workmanship, diameter 225mm , at 9 o'clock
37.40	Junction closed, good workmanship, diameter 225mm , at 9 o'clock
50.28	Junction closed, good workmanship, diameter 225mm , at 9 o'clock
53.42	Junction open, good workmanship, diameter 225mm , at 9 o'clock
71.20	Finish node, maintenance hole, Nodename: 1285939

electro scan australia pty ltd

FELL
TOTAL LEAKAGE DEFECTS
109

AQUA 2020 ASSETS

CCTV
TOTAL LEAKAGE DEFECTS
6

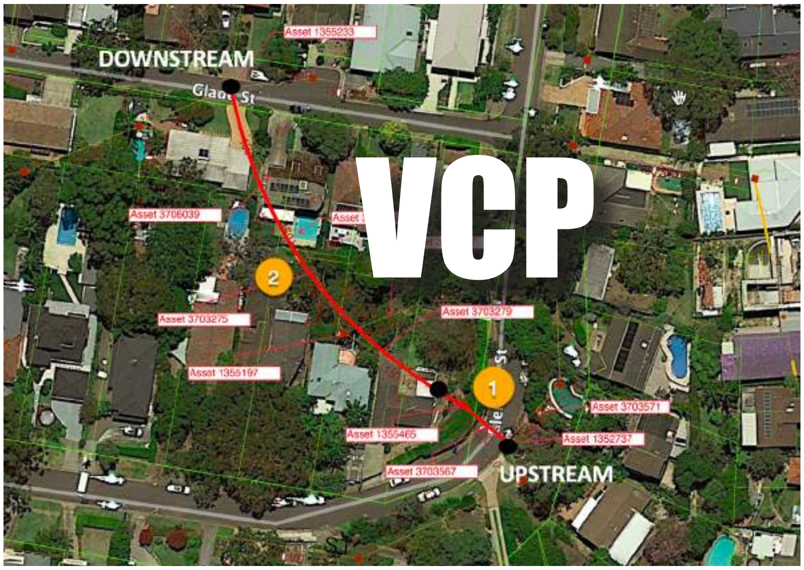
LEAKS AT EACH JUNCTION

NO LEAKS AT JUNCTIONS

3. BALGOWLAH HEIGHTS

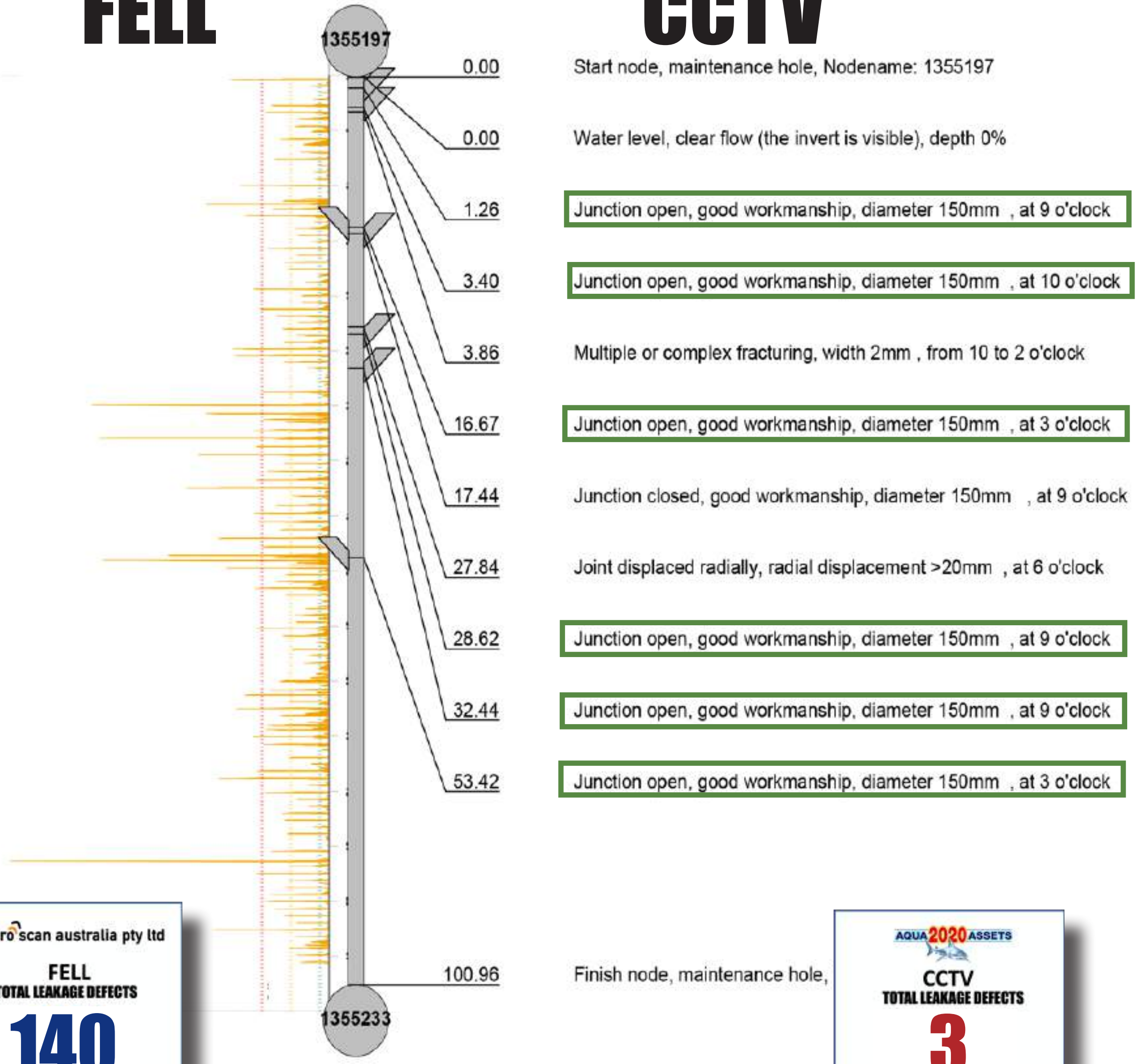
Despite a collapse found by CCTV in #1, difficult to access manhole entry was easily overcome to allow both CCTV and FELL inspections; however FELL automatically surveyed leaks at nearly every VCP pipe joint, fractures, and junctions.

With FELL and CCTV inspections beginning at a manhole located in a residential backyard patio, with a steep slope, the jet truck was positioned at the downstream manhole and successfully jetted up to the upstream manhole.



2

FELL **CCTV**

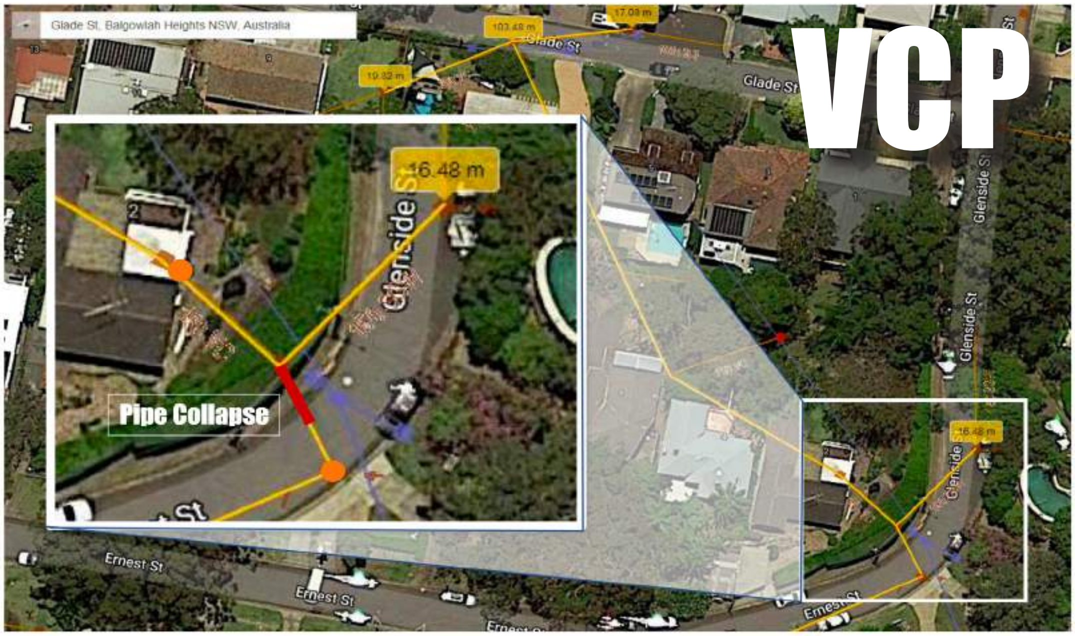


0.00	Start node, maintenance hole, Nodename: 1355197
0.00	Water level, clear flow (the invert is visible), depth 0%
1.26	Junction open, good workmanship, diameter 150mm , at 9 o'clock
3.40	Junction open, good workmanship, diameter 150mm , at 10 o'clock
3.86	Multiple or complex fracturing, width 2mm , from 10 to 2 o'clock
16.67	Junction open, good workmanship, diameter 150mm , at 3 o'clock
17.44	Junction closed, good workmanship, diameter 150mm , at 9 o'clock
27.84	Joint displaced radially, radial displacement >20mm , at 6 o'clock
28.62	Junction open, good workmanship, diameter 150mm , at 9 o'clock
32.44	Junction open, good workmanship, diameter 150mm , at 9 o'clock
53.42	Junction open, good workmanship, diameter 150mm , at 3 o'clock
100.96	Finish node, maintenance hole,

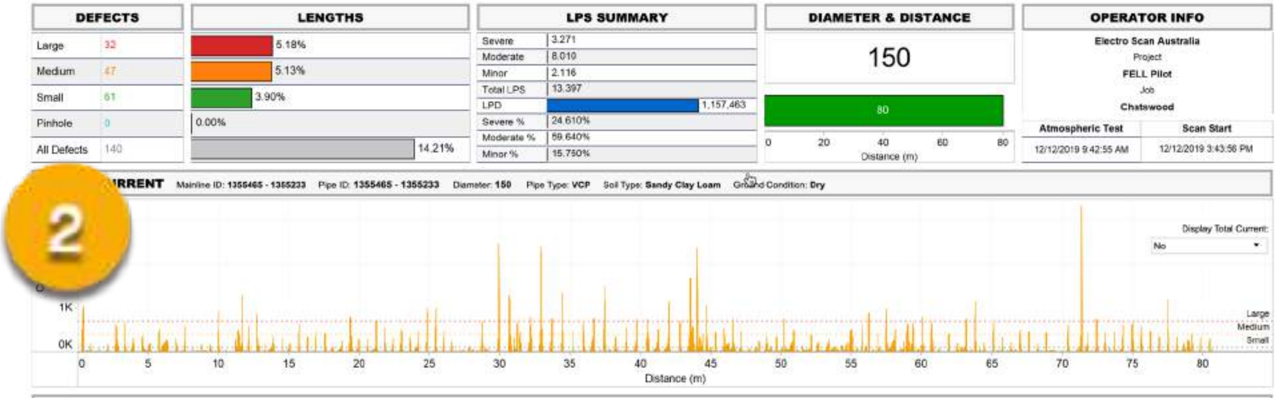
electroscan australia pty ltd
FELL
TOTAL LEAKAGE DEFECTS
140

AQUA2020ASSETS
CCTV
TOTAL LEAKAGE DEFECTS
3

1



2



DEFECTS		LENGTHS
Large	32	5.18%
Medium	47	5.13%
Small	61	3.90%
Pinhole	0	0.00%
All Defects	140	14.21%

LPS SUMMARY	
Severe	3.271
Moderate	8.010
Minor	2.116
Total LPS	13.397
LPD	1,157,463
Severe %	24.610%
Moderate %	59.640%
Minor %	15.750%

DIAMETER & DISTANCE

150

80

OPERATOR INFO

Electro Scan Australia
Project
FELL Pilot
Job
Chatswood

Atmospheric Test	Scan Start
12/12/2019 9:42:55 AM	12/12/2019 3:43:56 PM

…RRENT Mainline ID: **1355465 - 1355233** Pipe ID: **1355465 - 1355233** Diameter: **150** Pipe Type: **VCP** Soil Type: **Sandy Clay Loam** Ground Condition: **Dry**

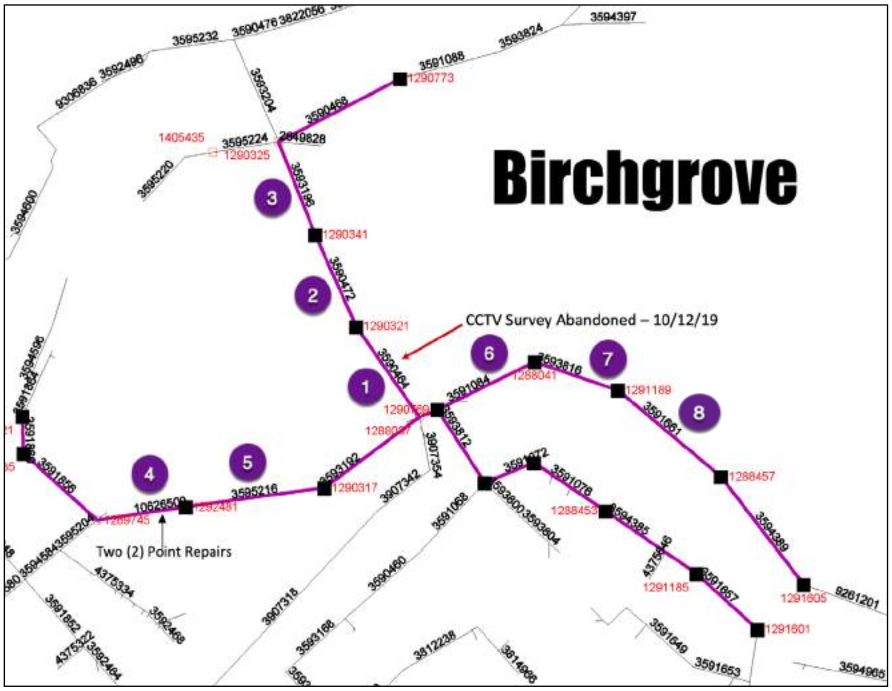
Display Total Current: No

4. BIRCHGROVE

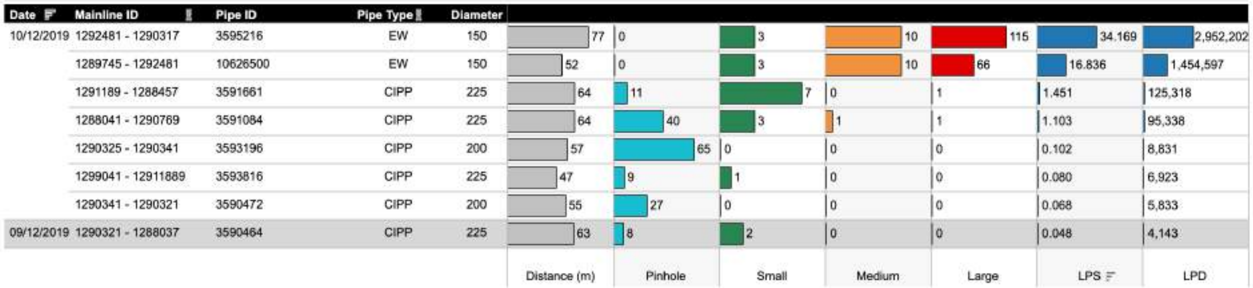
The Birchrove area was a challenge due to significant roots and debris that had to be removed, with some lines Cleaned and Televised three or more times. The area saw FELL's highest measured Liters per Second (LPS) defect flows for its two (2) Earthenware pipes (#4 & #5), with the remainder pipes CIPP.

FELL accurately located a major point repair in #4 and successfully surveyed #1 where CCTV was attempted the following day, resulting in an Abandoned Survey.

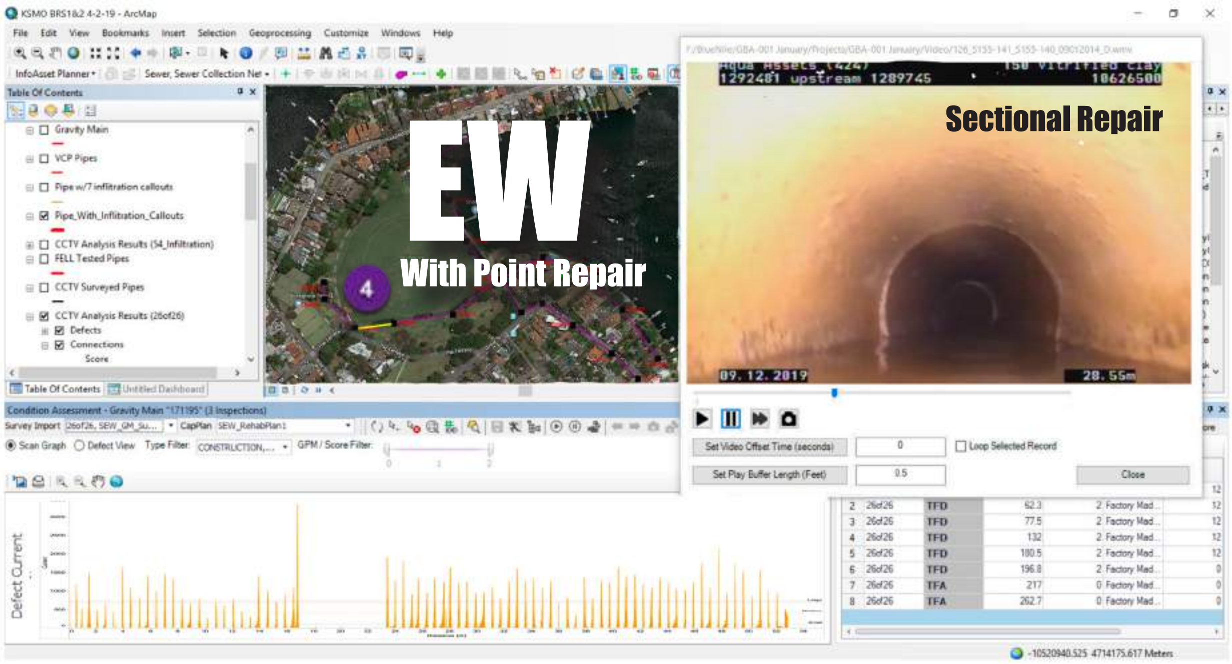
Each of CIPP had a high number of pinhole leaks, with CCTV not recording any active infiltration.



Scans	Distance	Pinhole	Small	Medium	Large	Total Defects	LPS	LPD
8	479	160	19	21	183	383	53.856	4,653,183



Date	Mainline ID	Pipe ID	Pipe Type	Diameter	Distance (m)	Pinhole	Small	Medium	Large	LPS	LPD
10/12/2019	1292481 - 1290317	3595216	EW	150	77	0	3	10	115	34.169	2,952,202
	1289745 - 1292481	10626500	EW	150	52	0	3	10	66	16.836	1,454,597
	1291189 - 1288457	3591661	CIPP	225	64	11	7	0	1	1.451	125,318
	1288041 - 1290769	3591084	CIPP	225	64	40	3	1	1	1.103	95,338
	1290325 - 1290341	3593196	CIPP	200	57	65	0	0	0	0.102	8,831
	1299041 - 12911889	3593816	CIPP	225	47	9	1	0	0	0.080	6,923
	1290341 - 1290321	3590472	CIPP	200	55	27	0	0	0	0.068	5,833
09/12/2019	1290321 - 1288037	3590464	CIPP	225	63	8	2	0	0	0.048	4,143



○ Scan Graph ○ Defect View Type Filter: CONSTRUCTION,...

Set Video Offset Time (seconds): 0

☐ Loop Selected Record

Set Play Buffer Length (Feet): 0.5

2	26of26	TFD	62.3	2	Factory Mad...	12
3	26of26	TFD	77.5	2	Factory Mad...	12
4	26of26	TFD	132	2	Factory Mad...	12
5	26of26	TFD	180.5	2	Factory Mad...	12
6	26of26	TFD	196.8	2	Factory Mad...	0
7	26of26	TFA	217	0	Factory Mad...	0
8	26of26	TFA	262.7	0	Factory Mad...	0

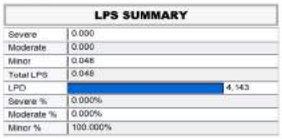
-10520940.525 4714175.617 Meters

1

FELL

1290769 - 1290321

CCTV



LPS SUMMARY	
Severe	0.000
Moderate	0.000
Minor	0.048
Total LPS	0.048
LPD	4,143
Severe %	0.000%
Moderate %	0.000%
Minor %	100.000%

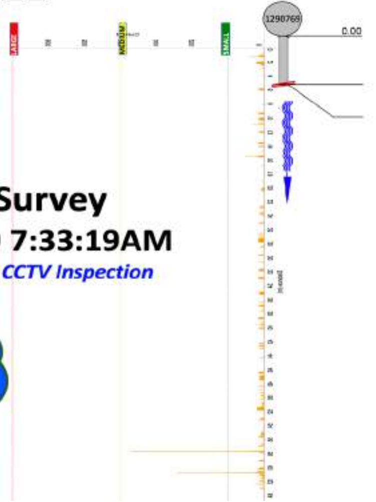
DEFECTS	
Large	0
Medium	0
Small	2
Pinhole	8
All Defects	10

FELL Survey

8/12/2019 7:33:19AM

2 Days Before CCTV Inspection

FELL
10 Total Defects
4,143 LPD



CCTV Survey

10/12/2019 10:41AM

2 Days After FELL Inspection

CCTV
Abandoned
Survey

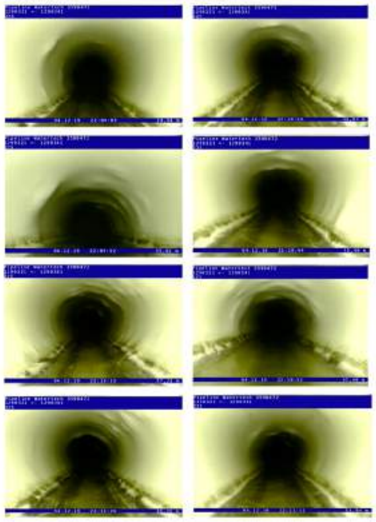
2

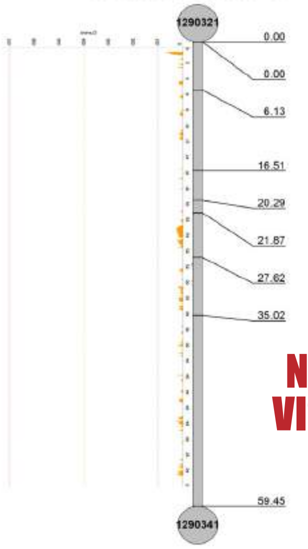
FELL

1290321 - 1290341

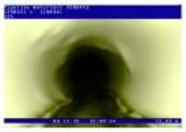
CCTV

NO CCTV OBSERVATIONS - BULGES





0.00	Start node, maintenance hole, Nodename: 1290321
0.00	Water level, turbid or discoloured flow, depth 15%
6.13	Water level, turbid or discoloured flow, depth 10%
16.51	The lining is bulged , reduction in cross sectional area: 5-20% , from 10 to 3 o'clock
20.29	The lining is bulged , reduction in cross sectional area: <5% , from 11 to 4 o'clock
21.87	The lining is bulged , reduction in cross sectional area: <5% , from 9 to 1 o'clock
27.62	The lining is bulged , reduction in cross sectional area: <5% , from 8 to 3 o'clock
35.02	The lining is bulged , reduction in cross sectional area: <5% , from 8 to 3 o'clock
59.45	Finish node, maintenance hole, Nodename: 1290341



NO CIPP LEAKS VISUALLY NOTED BY CCTV

7 Two CCTV Contractors Survey Same CIPP Liner, 6-Days Apart

Asset No. 3593816 | Start MH 1291189 - Finish MH 1299041

STR GRADE 1

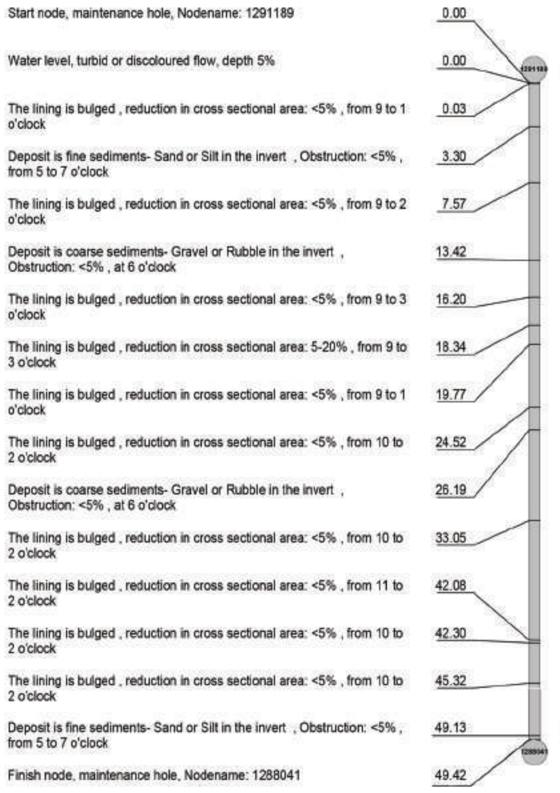
4 December 2019

CCTV Contractor #1

STR GRADE 5

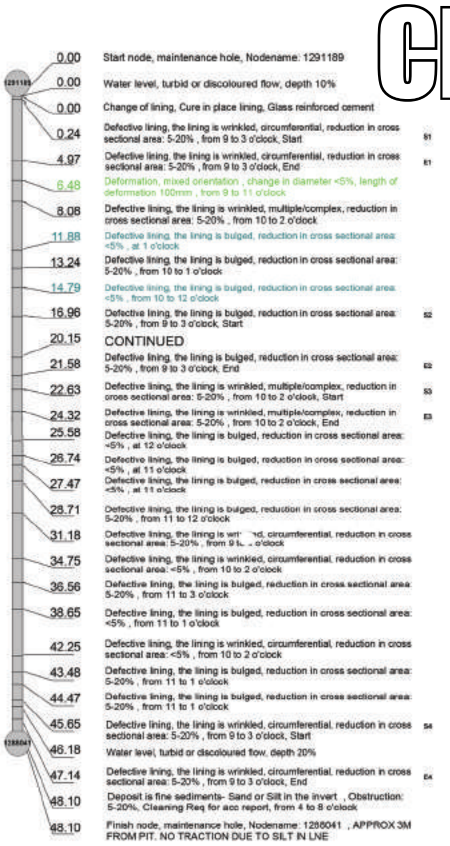
28 November 2019

CCTV Contractor #2

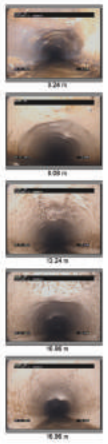


Start node, maintenance hole, Nodename: 1291189	0.00
Water level, turbid or discoloured flow, depth 5%	0.00
The lining is bulged , reduction in cross sectional area: <5% , from 9 to 1 o'clock	0.03
Deposit is fine sediments- Sand or Silt in the invert , Obstruction: <5% , from 5 to 7 o'clock	3.30
The lining is bulged , reduction in cross sectional area: <5% , from 9 to 2 o'clock	7.57
Deposit is coarse sediments- Gravel or Rubble in the invert , Obstruction: <5% , at 6 o'clock	13.42
The lining is bulged , reduction in cross sectional area: <5% , from 9 to 3 o'clock	16.20
The lining is bulged , reduction in cross sectional area: 5-20% , from 9 to 3 o'clock	18.34
The lining is bulged , reduction in cross sectional area: <5% , from 9 to 1 o'clock	19.77
The lining is bulged , reduction in cross sectional area: <5% , from 10 to 2 o'clock	24.52
Deposit is coarse sediments- Gravel or Rubble in the invert , Obstruction: <5% , at 6 o'clock	26.19
The lining is bulged , reduction in cross sectional area: <5% , from 10 to 2 o'clock	33.05
The lining is bulged , reduction in cross sectional area: <5% , from 11 to 2 o'clock	42.08
The lining is bulged , reduction in cross sectional area: <5% , from 10 to 2 o'clock	42.30
The lining is bulged , reduction in cross sectional area: <5% , from 10 to 2 o'clock	45.32
Deposit is fine sediments- Sand or Silt in the invert , Obstruction: <5% , from 5 to 7 o'clock	49.13
Finish node, maintenance hole, Nodename: 1288041	49.42

CIPP



0.00	Start node, maintenance hole, Nodename: 1291189	
0.00	Water level, turbid or discoloured flow, depth 10%	
0.00	Change of lining, Cure in place lining, Glass reinforced cement	
0.24	Defective lining, the lining is wrinkled, circumferential, reduction in cross sectional area: 5-20% , from 9 to 3 o'clock, Start	S1
4.97	Defective lining, the lining is wrinkled, circumferential, reduction in cross sectional area: 5-20% , from 9 to 3 o'clock, End	E1
6.48	Deformation, mixed orientation , change in diameter <5%, length of deformation 100mm , from 9 to 11 o'clock	
8.08	Defective lining, the lining is wrinkled, multiple/complex, reduction in cross sectional area: 5-20% , from 10 to 2 o'clock	
11.88	Defective lining, the lining is bulged, reduction in cross sectional area: <5% , at 1 o'clock	
13.24	Defective lining, the lining is bulged, reduction in cross sectional area: 5-20% , from 10 to 1 o'clock	
14.79	Defective lining, the lining is bulged, reduction in cross sectional area: <5% , from 10 to 12 o'clock	
16.96	Defective lining, the lining is bulged, reduction in cross sectional area: 5-20% , from 9 to 3 o'clock, Start	S2
20.15	CONTINUED	
21.58	Defective lining, the lining is bulged, reduction in cross sectional area: 5-20% , from 9 to 3 o'clock, End	E2
22.63	Defective lining, the lining is wrinkled, multiple/complex, reduction in cross sectional area: 5-20% , from 10 to 2 o'clock, Start	S3
24.32	Defective lining, the lining is wrinkled, multiple/complex, reduction in cross sectional area: 5-20% , from 10 to 2 o'clock, End	E3
25.58	Defective lining, the lining is bulged, reduction in cross sectional area: <5% , at 12 o'clock	
26.74	Defective lining, the lining is bulged, reduction in cross sectional area: <5% , at 11 o'clock	
27.47	Defective lining, the lining is bulged, reduction in cross sectional area: <5% , at 11 o'clock	
28.71	Defective lining, the lining is bulged, reduction in cross sectional area: 5-20% , from 11 to 12 o'clock	
31.18	Defective lining, the lining is wri[illegible]d, circumferential, reduction in cross sectional area: 5-20% , from 9 t[illegible] o'clock	
34.75	Defective lining, the lining is wrinkled, circumferential, reduction in cross sectional area: <5% , from 10 to 2 o'clock	
36.56	Defective lining, the lining is bulged, reduction in cross sectional area: 5-20% , from 11 to 3 o'clock	
38.65	Defective lining, the lining is bulged, reduction in cross sectional area: <5% , from 11 to 1 o'clock	
42.25	Defective lining, the lining is wrinkled, circumferential, reduction in cross sectional area: <5% , from 10 to 2 o'clock	
43.48	Defective lining, the lining is bulged, reduction in cross sectional area: 5-20% , from 11 to 1 o'clock	
44.47	Defective lining, the lining is bulged, reduction in cross sectional area: 5-20% , from 11 to 1 o'clock	
45.65	Defective lining, the lining is wrinkled, circumferential, reduction in cross sectional area: 5-20% , from 9 to 3 o'clock, Start	S4
46.18	Water level, turbid or discoloured flow, depth 20%	
47.14	Defective lining, the lining is wrinkled, circumferential, reduction in cross sectional area: 5-20% , from 9 to 3 o'clock, End	E4
48.10	Deposit is fine sediments- Sand or Silt in the invert , Obstruction: 5-20%, Cleaning Req for acc report, from 4 to 8 o'clock	
48.10	Finish node, maintenance hole, Nodename: 1288041 , APPROX 3M FROM PIT. NO TRACTION DUE TO SILT IN LNE	



CCTV Contractor #1

STR no def	STR peak	STR mean	STR total	STR grade	SER no def	SER peak	SER mean	SER total	SER grade
0	0	0	0	1	4	5	0.4	20	2

CCTV Contractor #2

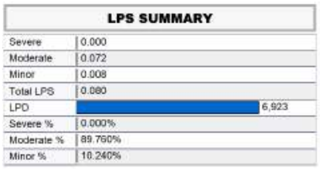
STR no def	STR peak	STR mean	STR total	STR grade	SER no def	SER peak	SER mean	SER total	SER grade
20	60	7.71	371	5	1	30	0.62	30	3

CCTV ABOVE

- No matching CCTV Observations
- 17 vs. 31 CCTV Observations.
- No leaks recorded by either TV Contractor.

FELL BELOW

- 9 PINHOLE LEAKS
- 1 SMALL LEAK
- LPS - 0.8 | LPD - 6,923



LPS SUMMARY	
Severe	0.000
Moderate	0.072
Minor	0.008
Total LPS	0.080
LPD	6,923
Severe %	0.000%
Moderate %	89.760%
Minor %	10.240%

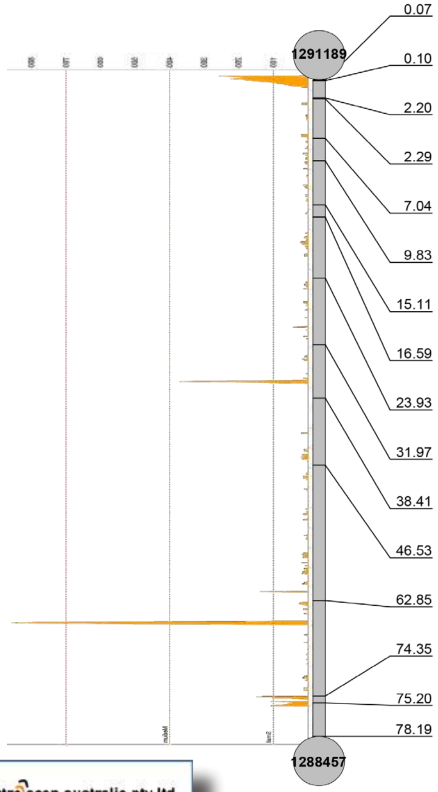
8

Asset No. 3591661 | Start MH 1291189 - Finish MH 1288457

CIPP

FELL

CCTV



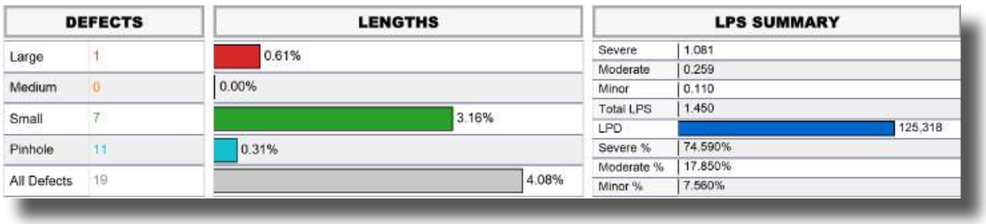
0.07	Start node, maintenance hole, Nodename: 1291189
0.10	Water level, turbid or discoloured flow, depth 5%
2.20	Water level, turbid or discoloured flow, depth 15%, RAGS
2.29	Junction open, good workmanship, diameter 150mm , at 2 o'cloc
7.04	Water level, turbid or discoloured flow, depth 5%
9.83	Deposit is fine sediments- Sand or Silt in the invert at 6 o'clock Obstruction:
15.11	Defective junction, roots are growing into and/or down the connec conduit, magnitude of obstruction <5% , at 12 o'clock
16.59	Deposit is fine sediments- Sand or Silt in the invert at 6 o'clock Obstruction:
23.93	Deposit is fine sediments- Sand or Silt in the invert at 6 o'clock Obstruction:
31.97	Lining has become detached , reduction in cross sectional area: < from 12 to 12 o'clock
38.41	Deposit is fine sediments- Sand or Silt in the invert at 6 o'clock Obstruction:
46.53	Defective junction, roots are growing into and/or down the connect conduit, magnitude of obstruction <5% , at 1 o'clock
62.85	Deposit is fine sediments- Sand or Silt in the invert at 6 o'clock Obstruction:
74.35	Defective junction, roots are growing into and/or down the connect conduit, magnitude of obstruction 5-20% , at 12 o'clock
75.20	Deposit is fine sediments- Sand or Silt in the invert at 6 o'clock Obstruction:
78.19	Finish node, maintenance hole, Nodename: 1288457

electro scan australia pty ltd

FELL
TOTAL LEAKAGE DEFECTS
19

AQUA 2020 ASSETS

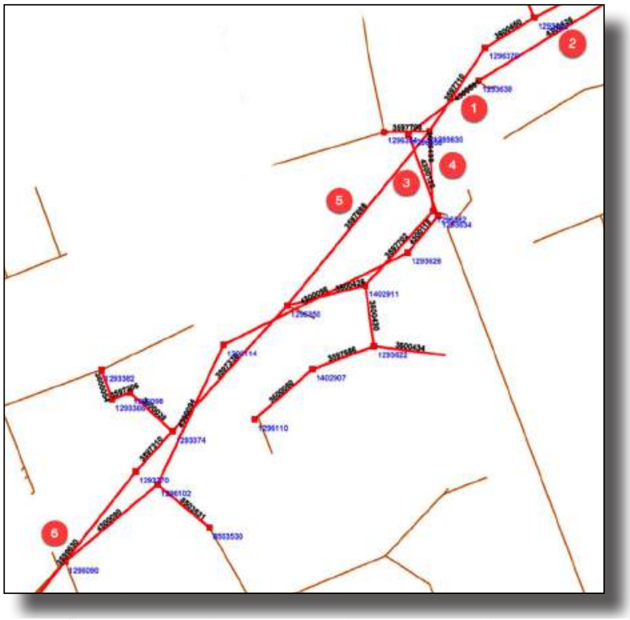
CCTV
TOTAL LEAKAGE DEFECTS
2



DEFECTS		LENGTHS
Large	1	0.61%
Medium	0	0.00%
Small	7	3.16%
Pinhole	11	0.31%
All Defects	19	4.08%

LPS SUMMARY	
Severe	1.081
Moderate	0.259
Minor	0.110
Total LPS	1.450
LPD	125,318
Severe %	74.590%
Moderate %	17.850%
Minor %	7.560%

5. CHATSWOOD



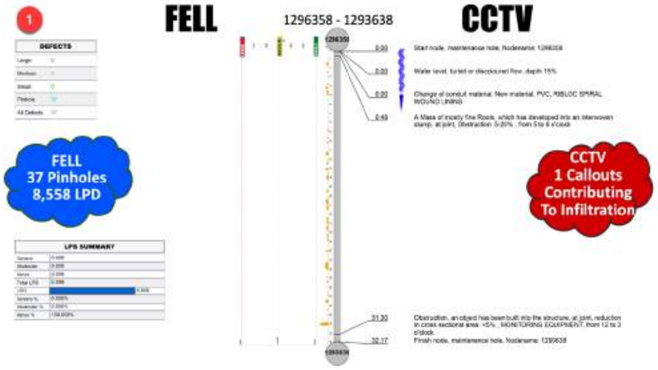
The Chatswood area was known for previously high bacteria readings in an open stormwater canal, with difficulty locating the sources despite multiple visual inspections.

As a result, Electro Scan was assigned to investigate six (6) pipes totaling 346m (1,135ft), ranging from 150mm (6 inches) to 400mm (16 inches) in diameter, running in close proximity to a stormwater open canal, with television inspection separately attempted to compare and contrast results.

In addition to surveying its two longest sewer mains (i.e. 97m and 85m), Electro Scan survey its only Spiral Wrap Liner with a Rib-Loc system (#1) and a deteriorated sectional CIPP as part of a VCP (#3). While there were a number of CCTV observations, few if any material sources of infiltration were visually located.

Scans	Distance	Pinhole	Small	Medium	Large	Total Defects	LPS	LPD
6	346	37	187	116	102	442	27.574	2,382,410

Date	Mainline ID	Pipe ID	Pipe Type	Diameter	Distance (m)	Pinhole	Small	Medium	Large	LPS	LPD
12/12/2019	1293066 - 1293370	3599630	VCP	300	97	0	37	62	59	11.932	1,030,946
10/12/2019	1296350 - 1293630	3597698	VCP	300	85	0	95	41	2	5.035	435,098
	1296362 - 1293630	3597702	VCP	150	29	0	6	10	34	7.544	651,775
09/12/2019	1293634 - 1296354	4300122	VCP	400	31	0	14	2	6	1.996	172,469
	129638 - 1296638	4300426	VCP	400	74	0	35	1	1	0.967	83,564
	1296354 - 1293630	3597706	SRP	400	30	37	0	0	0	0.099	8,558



Start node, maintenance hole, Nodename: 1296358

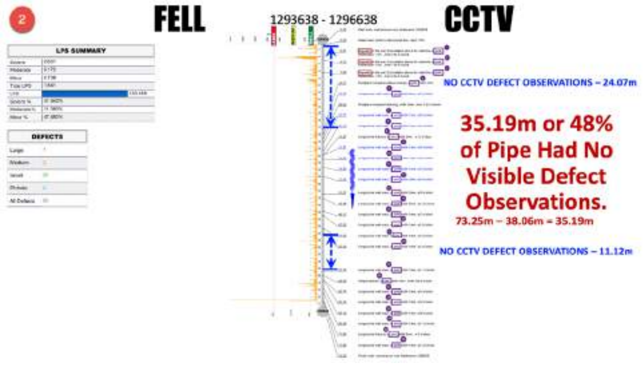
Water level, turbid or discoloured flow, depth 15%

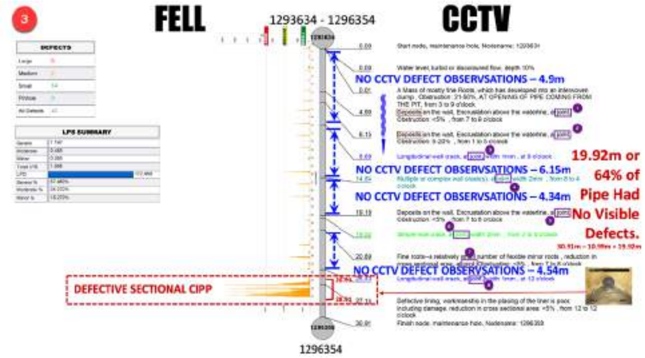
Change of conduit material. New material: PVC, RIBLOC SPIRAL WOUND LINING

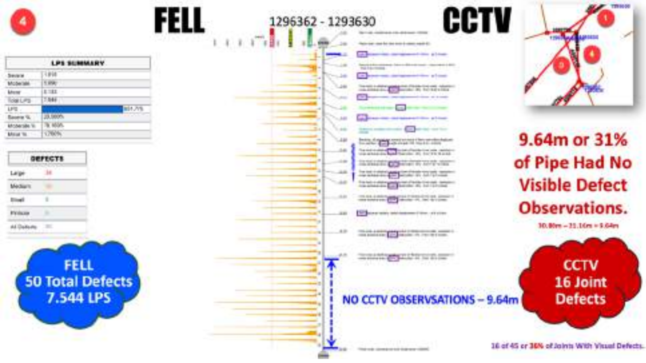
A Mass of mostly fine Roots, which has developed into an interwoven clump, at joint, Obstruction: 5-20% , from 5 to 6 o'clock

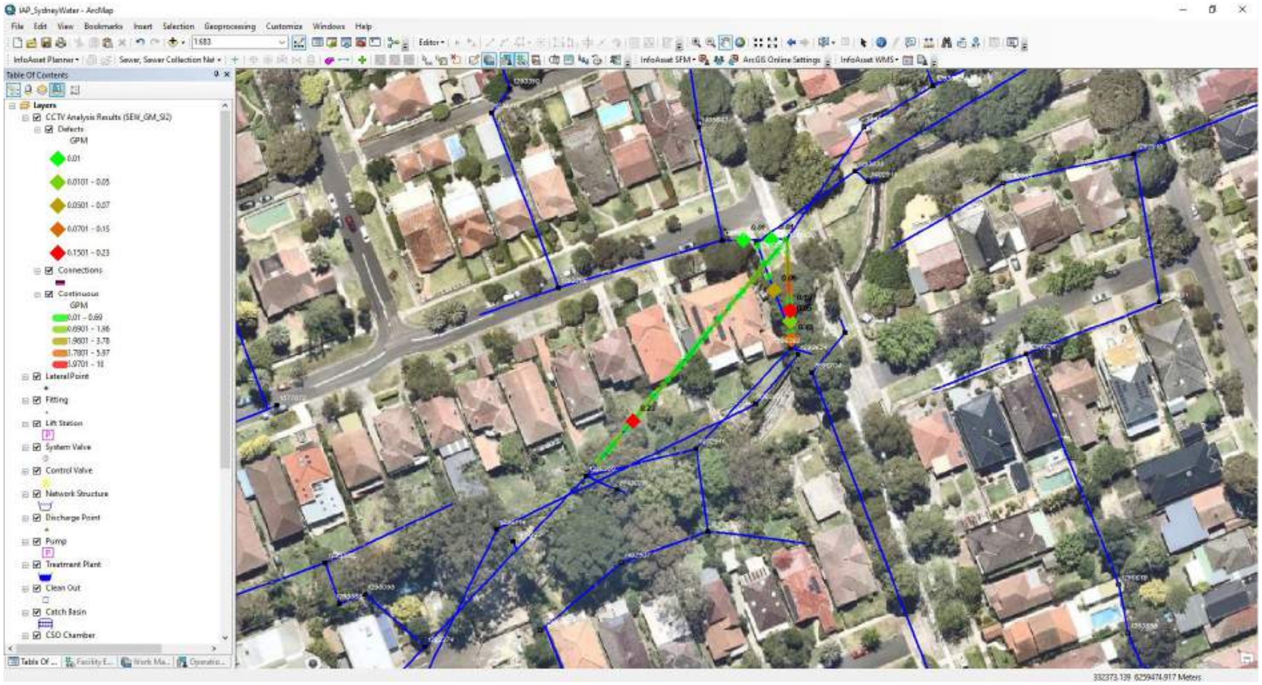
Obstruction, an object has been built into the structure, at joint, reduction in cross sectional area: <5% , MONITORING EQUIPMENT, from 12 to 3 o'clock

Finish node, maintenance hole, Nodename: 1293638


2
FELL
1293638 - 1296638
CCTV
LPS SUMMARY
DEFECTS
NO CCTV DEFECT OBSERVATIONS – 24.07m
35.19m or 48% of Pipe Had No Visible Defect Observations.
73.25m – 38.06m = 35.19m
NO CCTV DEFECT OBSERVATIONS – 11.12m


3
FELL
1293634 - 1296354
CCTV
DEFECTS
LPS SUMMARY
Start node, maintenance hole, Nodename: 1293634
Water level, turbid or discoloured flow, depth 10%
NO CCTV DEFECT OBSERVSATIONS – 4.9m
NO CCTV DEFECT OBSERVSATIONS – 6.15m
NO CCTV DEFECT OBSERVSATIONS – 4.34m
NO CCTV DEFECT OBSERVSATIONS – 4.54m
19.92m or 64% of Pipe Had No Visible Defects.
30.91m – 10.99m = 19.92m
DEFECTIVE SECTIONAL CIPP
Finish node, maintenance hole, Nodename: 1296354
1296354


4
FELL
1296362 - 1293630
CCTV
1
3
4
LPS SUMMARY
DEFECTS
9.64m or 31% of Pipe Had No Visible Defect Observations.
30.80m – 21.16m = 9.64m
FELL
50 Total Defects
7.544 LPS
NO CCTV OBSERVSATIONS – 9.64m
CCTV
16 Joint
Defects
16 of 45 or 36% of Joints With Visual Defects.


IAP_SydneyWater - ArcMap
File
Edit
View
Bookmarks
Insert
Selection
Geoprocessing
Customize
Windows
Help
1:683
Editor
InfoAsset Planner
Sewer, Sewer Collection Net
InfoAsset SFM
ArcGIS Online Settings
InfoAsset WMS
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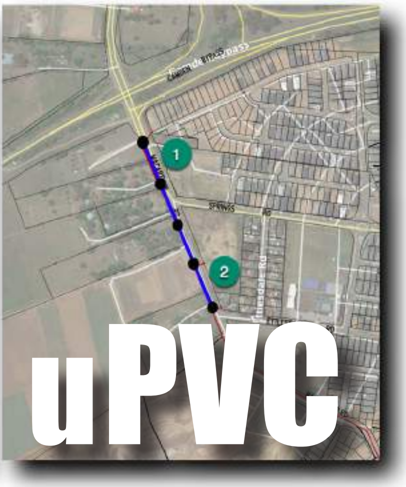
Layers
CCTV Analysis Results (SEN_GM_SI2)
Defects
GPM
0.01
0.0101 - 0.05
0.0501 - 0.07
0.0701 - 0.15
0.1501 - 0.23
Connections
Continuous
GPM
0.01 - 0.69
0.6901 - 1.86
1.9801 - 3.78
3.7801 - 5.97
5.9701 - 10
Lateral Point
Fitting
Lift Station
System Valve
Control Valve
Network Structure
Discharge Point
Pump
Treatment Plant
Clean Out
Catch Basin
CSO Chamber
Table Of ...
Facility E...
Work Ma...
Operatio...
332373.139 6259474.917 Meters

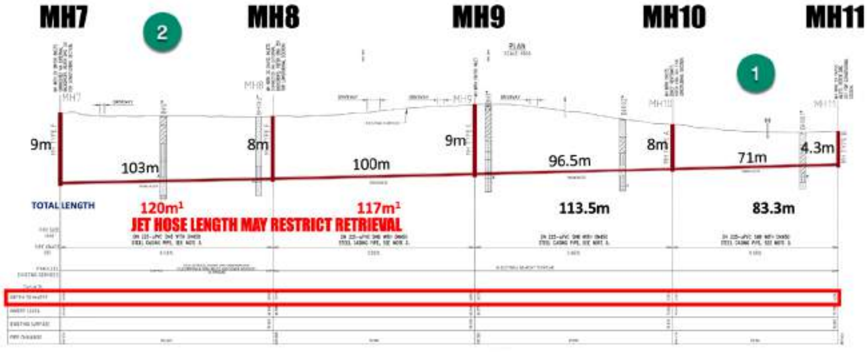
6. SPRING FARM

Representing Electro Scan's first known survey of unplasticised polyvinylchloride (uPVC) pipe, two new installations were assessed that were some of the deepest manholes inspecting, requiring confined-space safety measures, despite no manhole entry was required.

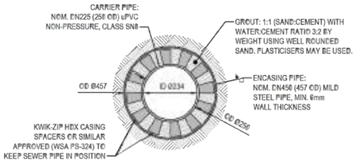
It should be noted that FELL technology measures the variation of electric current across surfaces, which is why smaller defects in surface materials like cement and vitrified clay pipe are not recorded, but why they are included in plastics, including PVC, High Density Polyethylene (HDPE), PE, PP, and SRP pipes.

While Spring Farm's uPVC had near perfect readings, several small spikes suggests that slight water leaks may occur at locations designated by FELL reporting. We also understand that there is a material change within 1m of the manhole, and that pipes has not yet passed vacuum testing.





NOTE
1. A general rule is to double the depth to invert, plus 5m to calculate a minimum required distance for Jet Hose or CCTV Coaxial cable. MH7-MH8 = 120+17+5 = 142, MH8-MH9 = 117 + 17+5 = 139.

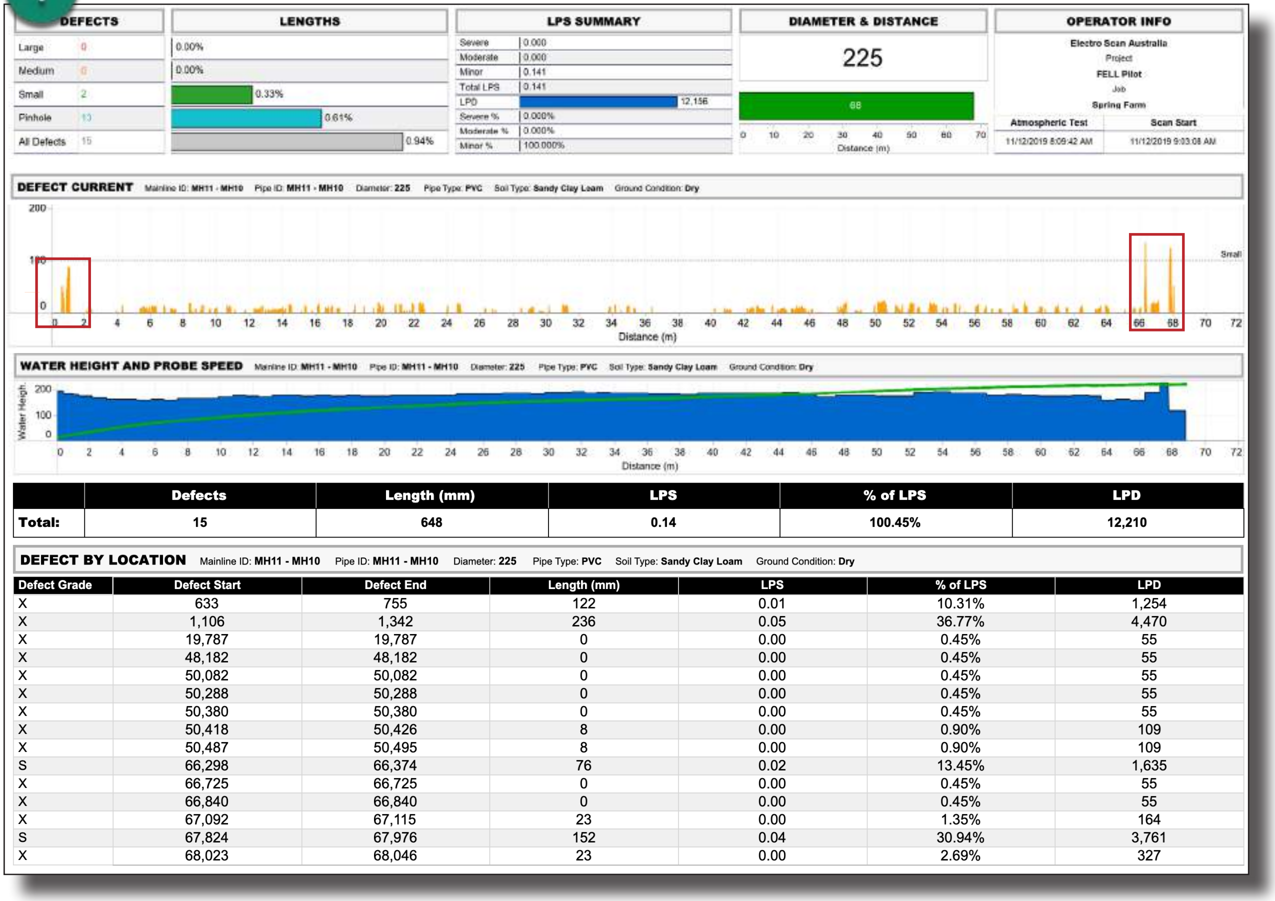


SECTION A - DN 225-uPVC SN8
WITH DN450 STEEL ENCASING PIPE
SCALE: 1:10

Corkscrew device to retrieve jet hose without person entry.

MH11- MH-10

1



DEFECTS

Large	0
Medium	0
Small	2
Pinhole	13
All Defects	15

LENGTHS

0.00%
0.00%
0.33%
0.61%
0.94%

LPS SUMMARY

Severe	0.000
Moderate	0.000
Minor	0.141
Total LPS	0.141
LPD	12,156
Severe %	0.000%
Moderate %	0.000%
Minor %	100.000%

DIAMETER & DISTANCE

225

OPERATOR INFO

Electro Scan Australia
Project
FELL Pilot
Job
Spring Farm

Atmospheric Test	Scan Start
11/12/2019 8:09:42 AM	11/12/2019 9:03:08 AM

DEFECT CURRENT Mainline ID: **MH11 - MH10** Pipe ID: **MH11 - MH10** Diameter: **225** Pipe Type: **PVC** Soil Type: **Sandy Clay Loam** Ground Condition: **Dry**

WATER HEIGHT AND PROBE SPEED Mainline ID: **MH11 - MH10** Pipe ID: **MH11 - MH10** Diameter: **225** Pipe Type: **PVC** Soil Type: **Sandy Clay Loam** Ground Condition: **Dry**

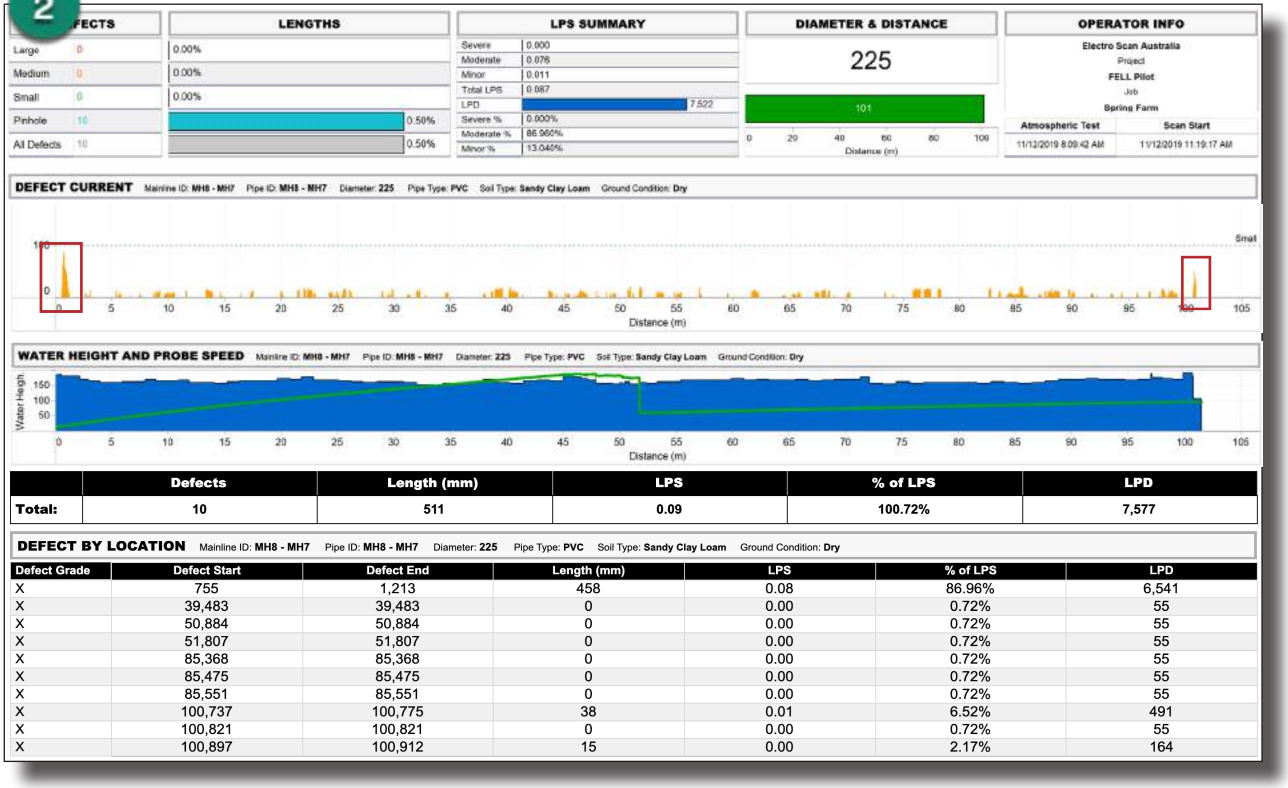
	Defects	Length (mm)	LPS	% of LPS	LPD
Total:	15	648	0.14	100.45%	12,210

DEFECT BY LOCATION Mainline ID: **MH11 - MH10** Pipe ID: **MH11 - MH10** Diameter: **225** Pipe Type: **PVC** Soil Type: **Sandy Clay Loam** Ground Condition: **Dry**

Defect Grade	Defect Start	Defect End	Length (mm)	LPS	% of LPS	LPD
X	633	755	122	0.01	10.31%	1,254
X	1,106	1,342	236	0.05	36.77%	4,470
X	19,787	19,787	0	0.00	0.45%	55
X	48,182	48,182	0	0.00	0.45%	55
X	50,082	50,082	0	0.00	0.45%	55
X	50,288	50,288	0	0.00	0.45%	55
X	50,380	50,380	0	0.00	0.45%	55
X	50,418	50,426	8	0.00	0.90%	109
X	50,487	50,495	8	0.00	0.90%	109
S	66,298	66,374	76	0.02	13.45%	1,635
X	66,725	66,725	0	0.00	0.45%	55
X	66,840	66,840	0	0.00	0.45%	55
X	67,092	67,115	23	0.00	1.35%	164
S	67,824	67,976	152	0.04	30.94%	3,761
X	68,023	68,046	23	0.00	2.69%	327

MH8- MH-7

2



FECTS

Large	0
Medium	0
Small	0
Pinhole	10
All Defects	10

LENGTHS

0.00%
0.00%
0.00%
0.50%
0.50%

LPS SUMMARY

Severe	0.000
Moderate	0.076
Minor	0.011
Total LPS	0.087
LPD	7,522
Severe %	0.000%
Moderate %	86.960%
Minor %	13.040%

DIAMETER & DISTANCE

225

OPERATOR INFO

Electro Scan Australia
Project
FELL Pilot
Job
Spring Farm

Atmospheric Test	Scan Start
11/12/2019 8:09:42 AM	11/12/2019 11:19:17 AM

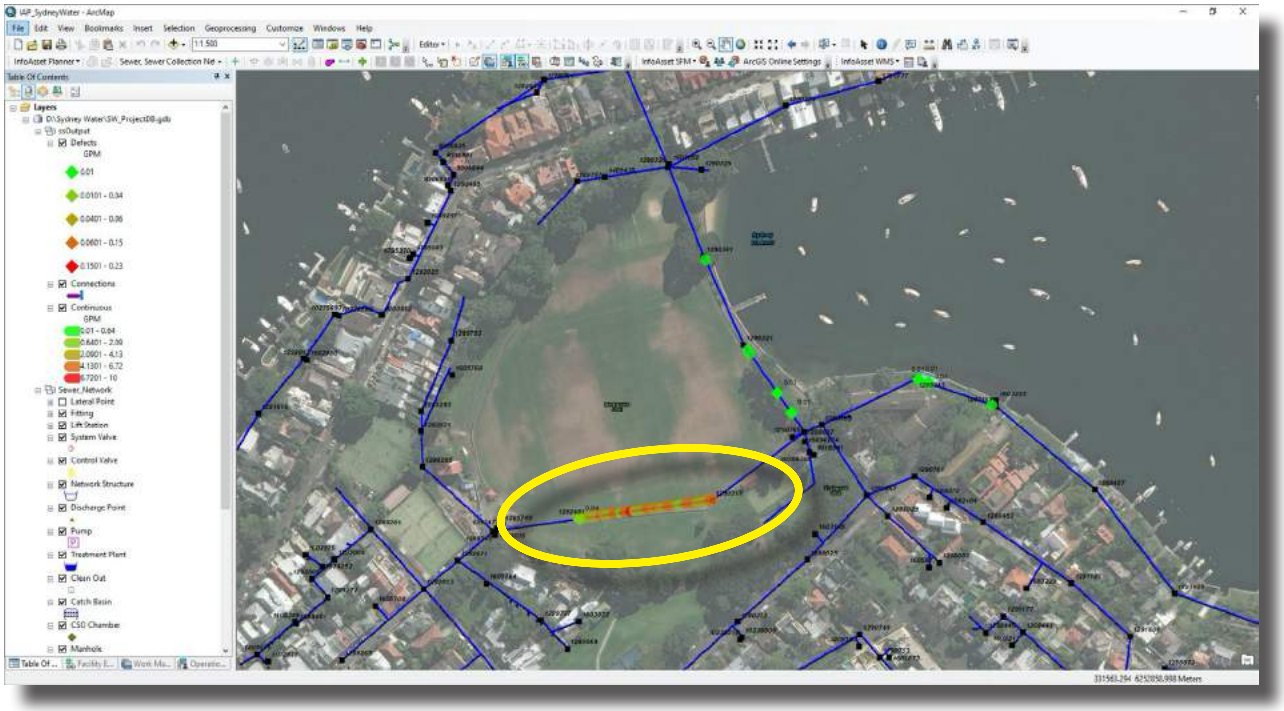
DEFECT CURRENT Mainline ID: **MH8 - MH7** Pipe ID: **MH8 - MH7** Diameter: **225** Pipe Type: **PVC** Soil Type: **Sandy Clay Loam** Ground Condition: **Dry**

WATER HEIGHT AND PROBE SPEED Mainline ID: **MH8 - MH7** Pipe ID: **MH8 - MH7** Diameter: **225** Pipe Type: **PVC** Soil Type: **Sandy Clay Loam** Ground Condition: **Dry**

	Defects	Length (mm)	LPS	% of LPS	LPD
Total:	10	511	0.09	100.72%	7,577

DEFECT BY LOCATION Mainline ID: **MH8 - MH7** Pipe ID: **MH8 - MH7** Diameter: **225** Pipe Type: **PVC** Soil Type: **Sandy Clay Loam** Ground Condition: **Dry**

Defect Grade	Defect Start	Defect End	Length (mm)	LPS	% of LPS	LPD
X	755	1,213	458	0.08	86.96%	6,541
X	39,483	39,483	0	0.00	0.72%	55
X	50,884	50,884	0	0.00	0.72%	55
X	51,807	51,807	0	0.00	0.72%	55
X	85,368	85,368	0	0.00	0.72%	55
X	85,475	85,475	0	0.00	0.72%	55
X	85,551	85,551	0	0.00	0.72%	55
X	100,737	100,775	38	0.01	6.52%	491
X	100,821	100,821	0	0.00	0.72%	55
X	100,897	100,912	15	0.00	2.17%	164



INNOVYZE® InfoAsset Planner®

The Innovyze® suite of products is an established strategic IT solution used on a daily basis to help manage Sydney Water's complex underground and surface water network.

A key aspect of Innovyze's latest release of InfoAsset Planner® has been the seamless integration with strategically aligned applications, including Electro Scan's Critical Sewer® cloud application containing the most advance pipe diagnostic capability for assessing, prioritising, and certifying repairs, rehabilitation, and replacement of gravity and pressurised sewer and stormwater pipes, force mains, and customer laterals.

Innovyze®
Empowering water experts

InfoAsset™
Planner

In addition to interfacing data through a certified Application Programmers Interface (API) exchanging data between Electro Scan & InfoAsset, InfoAsset has a solution suite of applications to streamline asset decision support, quantifying rehabilitation effectiveness, and modeling asset deterioration.

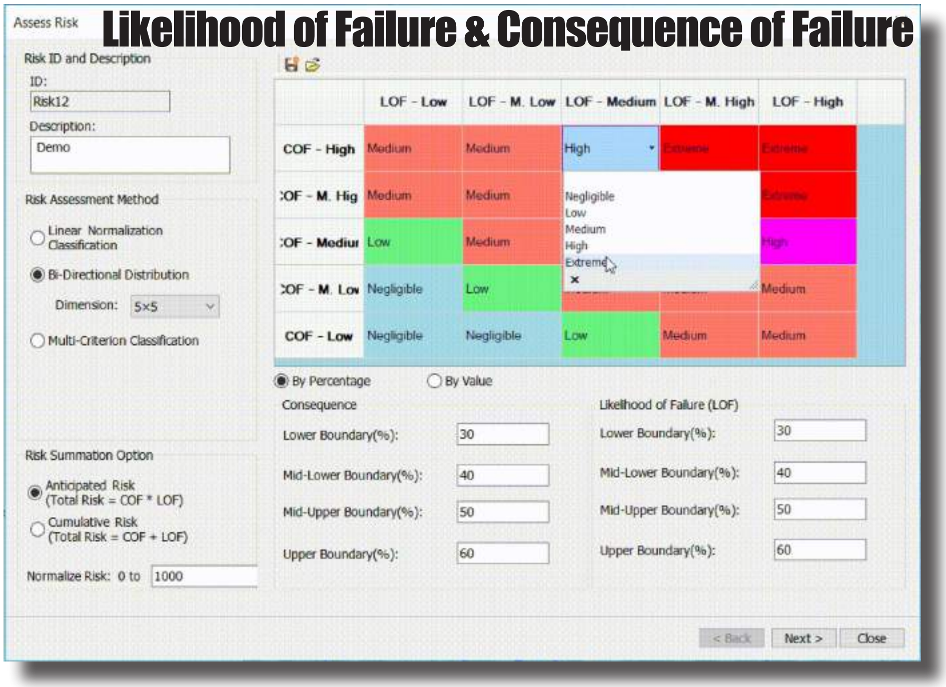
DECISION SUPPORT

Prioritizing and grouping pipes into comprehensive sewer rehabilitation and replacement projects is complex and challenging.

Often involving a multitude of variables and complex ongoing analyses, risk is often defined as:

= [(Likelihood of failure) x (Consequence of failure)]

Where the likelihood of failure (LoF) is the probability of an asset failure occurring, and consequence of failure (CoF) is defined as the relative impact on the level of service resulting from a specific asset failure.



Likelihood of Failure & Consequence of Failure

Risk ID and Description

ID: Risk12

Description: Demo

Risk Assessment Method

○ Linear Normalization Classification

● Bi-Directional Distribution

Dimension: 5x5

○ Multi-Criterion Classification

	LOF - Low	LOF - M. Low	LOF - Medium	LOF - M. High	LOF - High
COF - High	Medium	Medium	High	Extreme	Extreme
:OF - M. Hig	Medium	Medium	Negligible Low Medium High Extreme ×		Extreme
:OF - Mediur	Low	Medium			High
:OF - M. Low	Negligible	Low			Medium
COF - Low	Negligible	Negligible	Low	Medium	Medium

● By Percentage ○ By Value

Consequence

Lower Boundary(%): 30

Mid-Lower Boundary(%): 40

Mid-Upper Boundary(%): 50

Upper Boundary(%): 60

Likelihood of Failure (LOF)

Lower Boundary(%): 30

Mid-Lower Boundary(%): 40

Mid-Upper Boundary(%): 50

Upper Boundary(%): 60

Risk Summation Option

● Anticipated Risk (Total Risk = COF * LOF)

○ Cumulative Risk (Total Risk = COF + LOF)

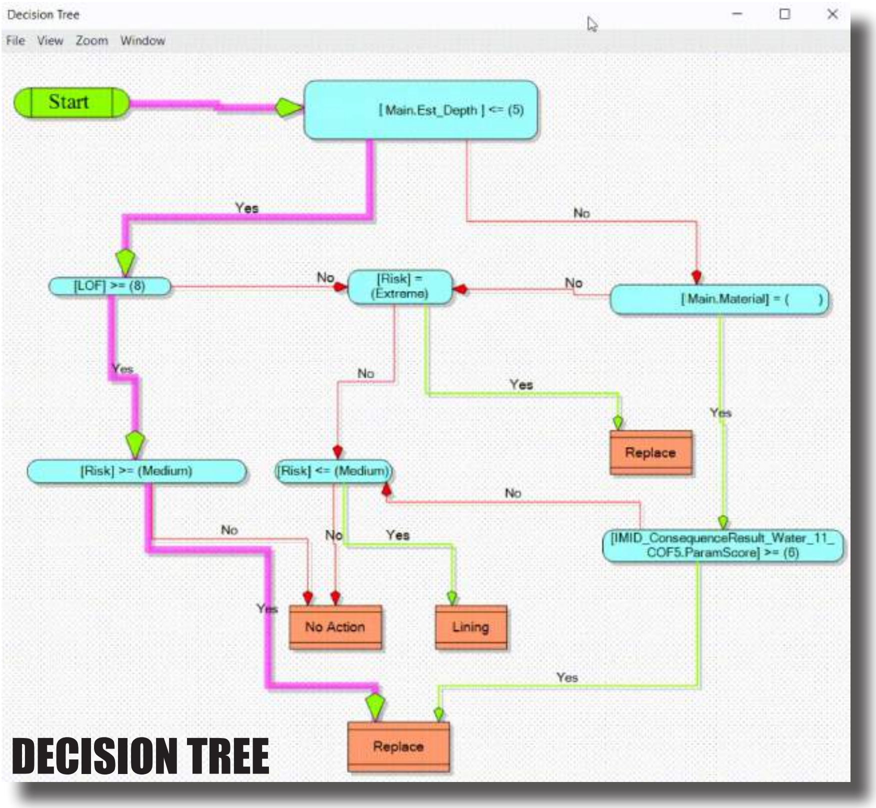
Normalize Risk: 0 to 1000

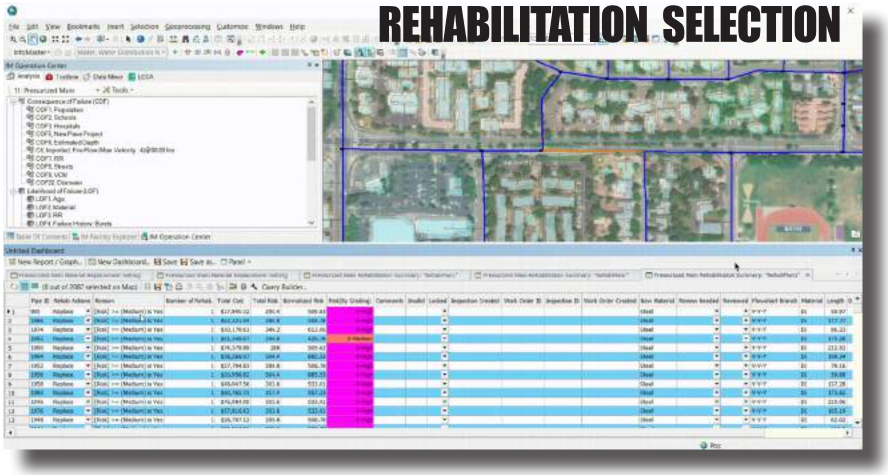
Even with sophisticated LoF and CoF evaluations and the resulting risk scores for each sewer main, other key operation & maintenance and CAPEX factors, specific to the individual collection system asset, must be considered. These include such considerations as available hydraulic models reflecting recent Point Precipitation Estimates, hydrogeological conditions including seasonal variances (e.g., groundwater levels), and proximity to environmentally-sensitive areas, etc.

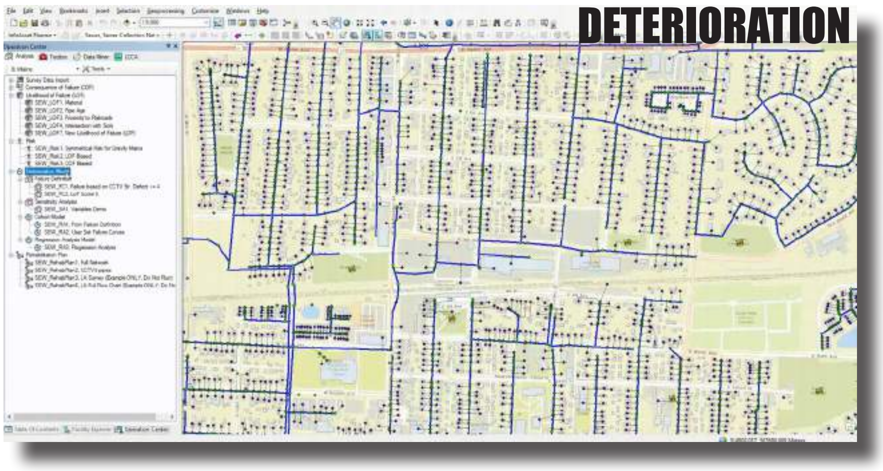
Limitations of desktop analysis, as driven by individual asset inventories, including key factors like age, pipe material, diameter, and pipe depth, does not appear to lend itself to ultimate rehabilitation decisions; yet, supplemented by unbiased and unequivocal field condition assessment data, like leak profile data produced by low voltage conductivity, may be a key solution to arriving at cost effective, sustainable, and resilient capital plans, that can be environmentally audited for effectiveness.

More importantly, the success or failure of previous rehabilitation selections must be evaluated based on measured reductions in infiltration – *before* and *after* rehabilitation – using back-testing from previous models and selection parameters to update future planning horizons for optimized results.

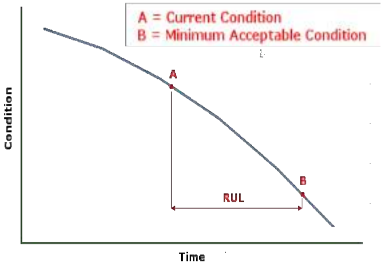
Finally, as machine-intelligent technologies improve, assessing assets throughout their useful life will delivery key deterioration data needed to amortise or depreciate physical assets to support more advanced accounting systems and asset Remaining Useful Life (RUL).







Remaining Userful Life



SUMMARY

In general, any new product, business process, or professional service that becomes a viable solution for the water industry, must satisfy five (5) key requirements, including:

1. Have ability to demonstrate consistently superior and unambiguous results as compared to current methodologies,
2. Prove its capability to operate on a cross-section of assets, either achieving minimum or better-than-current methodologies,
3. Represent an overwehlming value for money,
4. Have a reputable local representative or authorized service provider, and
5. Possess valid commercial/market/product/ technical references that can be corroborated third party, unimpeachable sources.

TRIAL ELECTRO SCAN TRIAL PROJECT

As stated earlier the goal & objective of Sydney Water's Trial Electro Scan Project was to test and document the practical application, field operation, and ease of reporting of Low Voltage Conductivity also known by the US EPA as Focused Electrode Leak Location (FELL) technology, utilising ASTM F2550-13 (2018), compared to traditional Closed-Circuit Television (CCTV) utilising WSA 05—2008 2.2 Conduit Inspection Reporting Code of Australia standards, in a variety of "live" Sydney Water in-field conditions.

KEY QUESTION

Does FELL technology deliver repeatable leak location and severity measurements not provided by traditional CCTV visual inspection? Can FELL technology be used to more accurately locate infiltration and exfiltration? What are FELL's advantages & disadvantages to current operations? How should new (possible) quality standards be introduced during start-up & operation of Sydney Water's Regional Delivery Consortium (RDC)?

While the last question may be discussed in another venue, preliminary field results tend to answer to previous questions appeared to be answered in the affirmative, and in many cases answered in a rather convincing and unequivocal manner.

KEY FINDINGS

Evaluation of the Sydney Water Potts Hill's Test Pipe observed that FELL technology successfully detected both pre-arranged defects, similar to CCTV inspection; however, FELL technology. Additionally, identified and measured numerous other defects at material changes transitioning from clay pipe-to-plastic pipe, and defects at each joint.

In Chatswood, numerous sources of potential exfiltration were identified in close proximity to a local river bed, not seen by CCTV, including defects in a Spiral Wrap Pipe.

In Birchgrove, an area of persistent tidal and wet weather infiltration (despite significant rehabilitation), found severe defects in recently lined cast iron pipes. One pipe where CCTV was attempted, but abandoned due to a significant bulge in Cured-In-Place Pipe (CIPP) liner, was successfully scanned in a single set-up by. FELL.

Customer Complaint sewer overflow -related locations in Abbotsford and Balgowlah Heights found numerous defects not found by CCTV, including a CIPP lined pipe abandoned by. CCTV and successfully survey by FELL.

New Unplastised Plastic Pipe (uPVC) evaluated in Spring Farm, already undergoing vacuum air testing, confirmed one pipe with no significant defects and one pipe with a single significant defect for a new pipe.

This trial project may have a possible significant impact on the future way Sydney Water determines pipe condition, especially for water tightness.

ADVANTAGES OF LOW VOLTAGE-BASED FELL INSPECTION

1. Accurately quantify leaks in liters per second.
2. Automatically finds precise pipe location (1cm).
3. Unbiased, unambiguous, repeatable results.
4. Tested by American EPA, British WRc, German IKT, and Japanese JASCOMA.
5. Average 2-3x faster than CCTV.
6. No third-party data interpretation required.
7. Approved for gravity sewers & pressurized pipes.
8. Able to test rising mains (i.e. force mains).
9. Able to test siphons.
10. Able to test small (76mm) & large (2000mm) diameter pipes.
11. Bypass pumping not required.
12. Tests joints, including bell & spigot & open ended.
13. Tests customer connections and junctions.
14. Creates baseline LPS Pipe Rating, Before Rehabilitation, for comparison After
15. Tests CIPP & Post-Rehab % Effectiveness
16. Referenced in EPA Consent Decrees
17. ASTM F2550, 3rd Ed. 2018
18. AWWA M77, 1st Ed. 2019
19. Data in cloud, 10min or less, worldwide
20. Add FELL to standard CCTV vans
21. CCTV Kits available for Aries, Cues, IBAK, iPEK, Rausch, and other CCTV devices.
22. Masterclass by WRc, developers of NASSCO codes.
23. Utilized by IKT in recent CIPP study.
24. Integrates w/Innovyze® InfoAsset®.

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Electro Scan's Chuck Hansen & Sydney Water's Jerry Sunarho.

Matt Campos, Holly Tonner, and Chuck Hansen.

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Today, Hansen works with the world's leading utilities to re-engineer their decision support systems to take advantage of machine learning and machine-intelligent technologies to streamline and enhance decision making. A licensed instrument-rated pilot and baritone saxophonist who has played with numerous artists & bands, including Huey Lewis, Toby Keith, and Tower of Power, Mr. Hansen earned his B.Sc. from U.C. Berkeley (1978) and M.B.A. from UCLA (1982).

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