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Update from Christchurch on Condition Assessment of Sewer Drains

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ABSTRACT: On February 22, 2011 Christchurch, New Zealand experienced a magnitude 6.4 earthquake, killing 185 people in one of the country's deadliest peacetime disasters. The total cost to insurers has been estimated between $15–20 billion making it New Zealand's costliest natural disaster and the third-costliest earthquake, worldwide. The earthquake caused widespread damage, especially in the central city and eastern suburbs, with buildings and infrastructure already weakened by a previous earthquake occurring September 4, 2010. The February 22nd earthquake caused significant liquefaction affecting the eastern suburbs producing 400,000 tons of silt.

While a conglomerate of diverse partners formed the Stronger Christchurch Infrastructure Rebuild Team (SCIRT) to assess the damage and undertake emergency repairs of public infrastructure and right of way, little focus has been dedicated to the condition assessment of underground infrastructure of property homeowners and educational institutions. While smaller diameter pipes were oftentimes inspected using high resolution push cameras, the inability of visual inspection techniques to adequately identify and quantify cracks and defects led consultants for the Ministry of Education to utilize a new technology known as electro scanning to reassess previously televised drains.

This paper describes the limitations of using closed-circuit television (CCTV) camera equipment and compares side-by-side results resulting from electro scanning. By measuring the variation in electric current flowing through defects in non-conductive pipe walls, this paper explores the type of data, field set-up requirements, and diagnostic information resulting from both legacy CCTV and new electro scan technologies.

1 - Introduction

Infiltration of groundwater into a sewer through defects in a pipe can considerably increase the operation and capital costs of a sewer system and promote its structural degradation. Exfiltration of sewage, i.e. outflows from a sewer pipe, may additionally cause degradation of aquifers and shoreline waters. As a result, the accurate location, measurement, and characterization of all pipe defects that are potential sources of water leakage are essential inputs for cost-effective design of infiltration/exfiltration mitigation projects.

By measuring the flow of electricity through the pipe wall of non-conductive sewer and storm water pipes, electro scan technology is allowing municipalities a quantitative view of infiltration in their collection systems for the first time. By integrating simple geophysical principles with a state of the art cloud-based data collection and reporting system municipalities are now able to prioritize pipe rehabilitation based on 100% complete information about pipe structural condition, rather than merely recording what may be visually interpreted from a CCTV inspection given standardized coding structures.

This study undertook the electro-scanning of a cross section of small diameter sewer and storm water pipes in and around Christchurch City Council and the Cantebury region of New Zealand in an effort to perform condition assessment of earthquake damaged collection systems. Both CCTV and Electro Scan analysis was performed on all pipes, with comparisons presented below.

2 - The Case of Christchurch, New Zealand

Multiple earthquakes occurred in Christchurch, New Zealand over a three year period which casued widespread destruction of infrastructure. To assist in its overall triage approach to assessing its infrastructure damage, the Electro Scan technology was employed to quantify those ‘unseen’ pipe defects that could contribute to infiltration, roadway subsidence, exfiltration, and eventual structural collapse of pipes. In total, approximately 528 km of Christchurch’s 1700 km wastewater system was severely damaged (see Figure 1). This lead to a large portion of the eastern city being completely unavailable for regular wastewater service, requiring property owners and commercial businesses to rely exclusively on portable chemical toilet service for over six (6) months while emergency rehabilitation efforts restored basic services (see Figure 2).

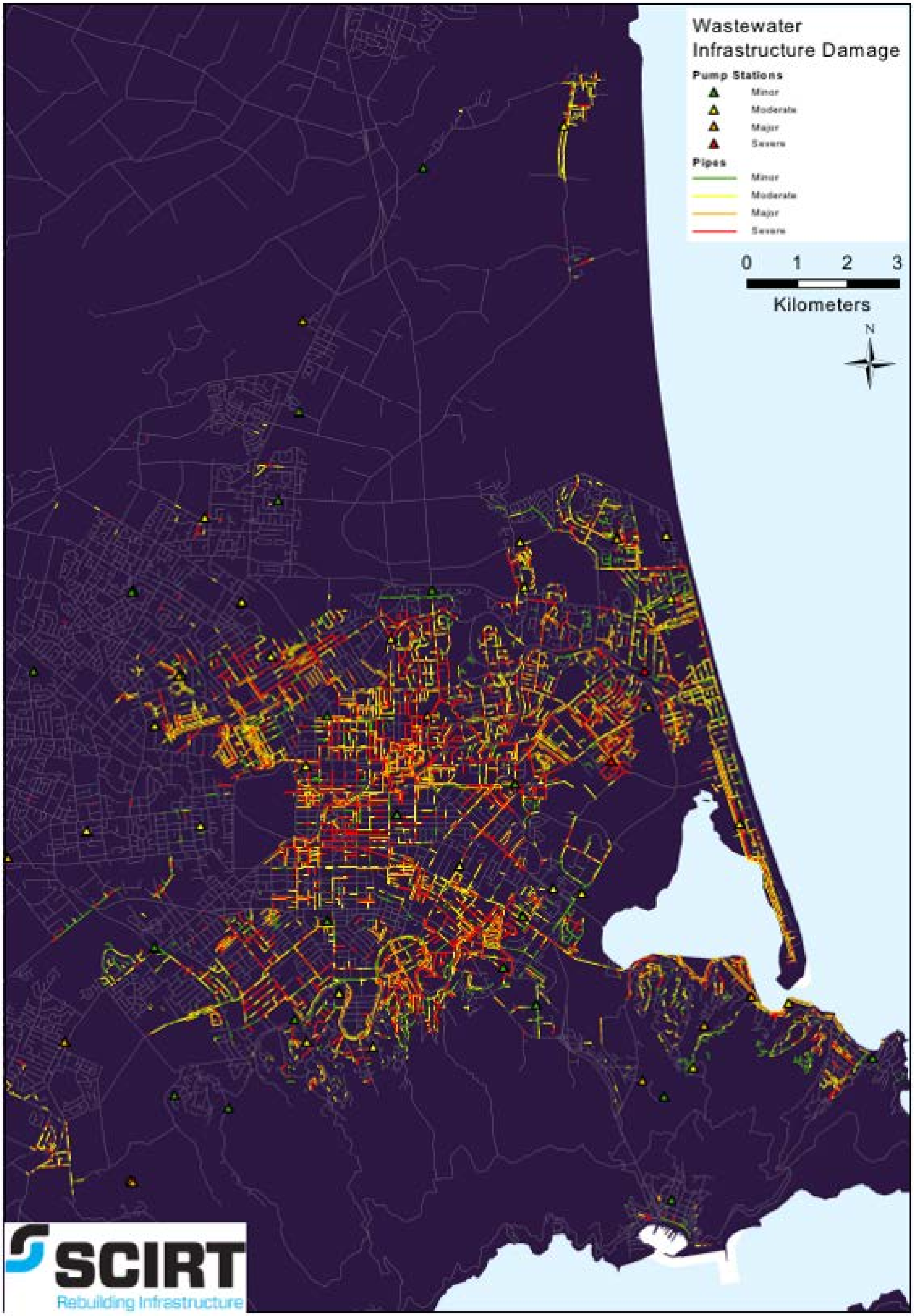


Figure 1 – Damage to Christchurch Wastewater Collection System, Initial Estimate

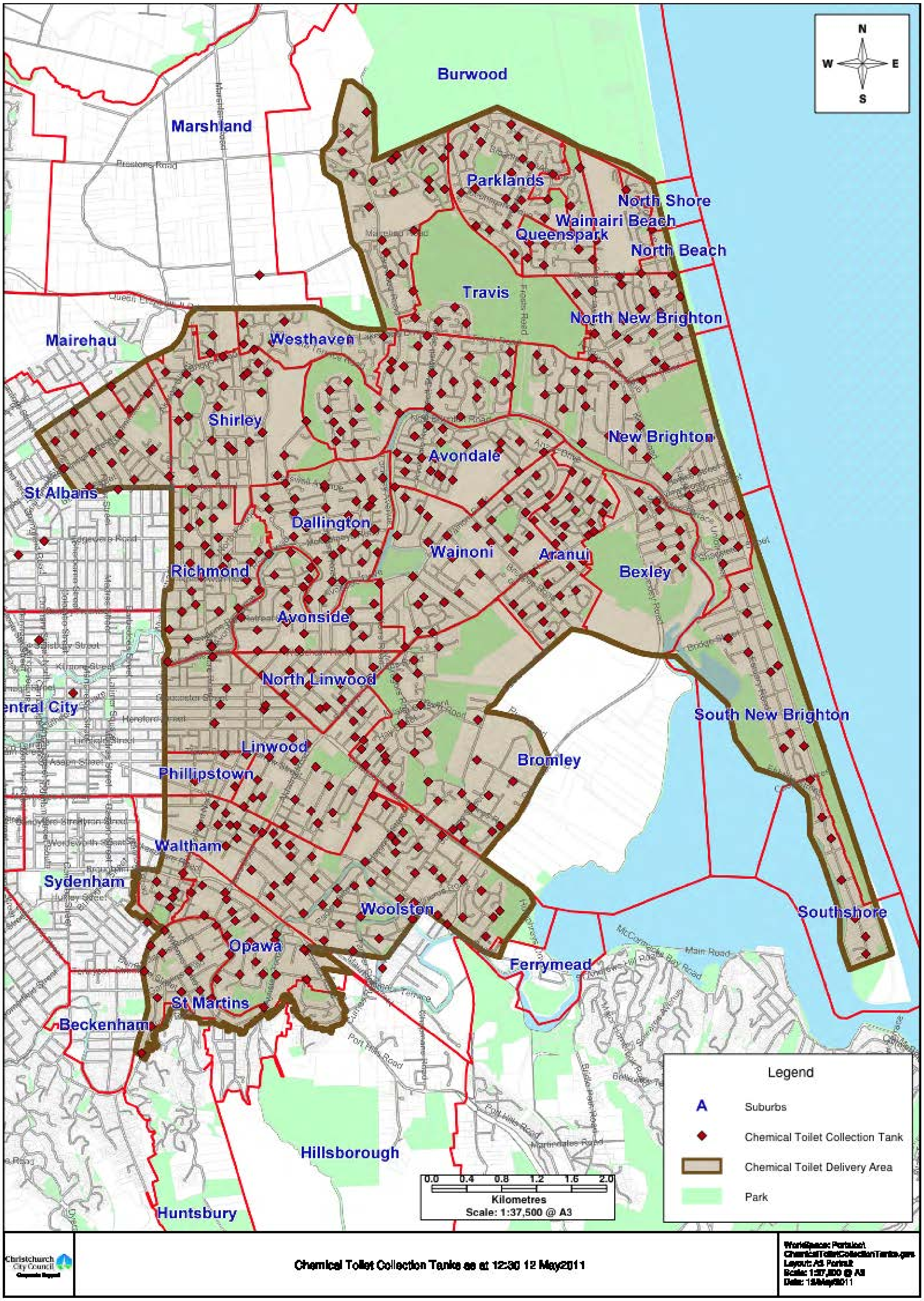


Figure 2: Chemical Toilet Distribution Area in Eastern Christchurch

By late 2011 rudimentary wastewater service had been restored to most areas of the ‘green zone’ in the city thanks to the 24x7 operation of sewer debris removal teams. However, the task facing wastewater officials in the city was now to prioritize long term rehabilitation of the severely damaged infrastructure.

A widespread program of CCTV inspection was undertaken to assess the physical condition of the pipes. However, due to the nature of damage to the system caused by the earthquakes, it soon became apparent that more robust data was required. In mid-2012 SCIRT, the Christchurch City Council, and the New Zealand Ministry of Education, each commissioned electro-scanning inspection trials to verify existing CCTV data and begin collecting more robust information about the damage.

3 - Closed Circuit Television Inspection

CCTV was carried out with a color television camera and commonly used procedures and descriptions. All condition assessment reports were created in accordance with the New Zealand Pipe Inspection Manual, the industry standard for CCTV inspection in New Zealand – comparable to NASSCO PACP Standards in the United States and WRc Standards in the United Kingdom.

The CCTV observation locations were recorded to the nearest hundredth of a meter, but due to system calibration and zeroing of data readings, some positional differences were noted for some features indicated by electro-scan. An example of a standard New Zealand Pipe Inspection Manual formatted report is shown below.

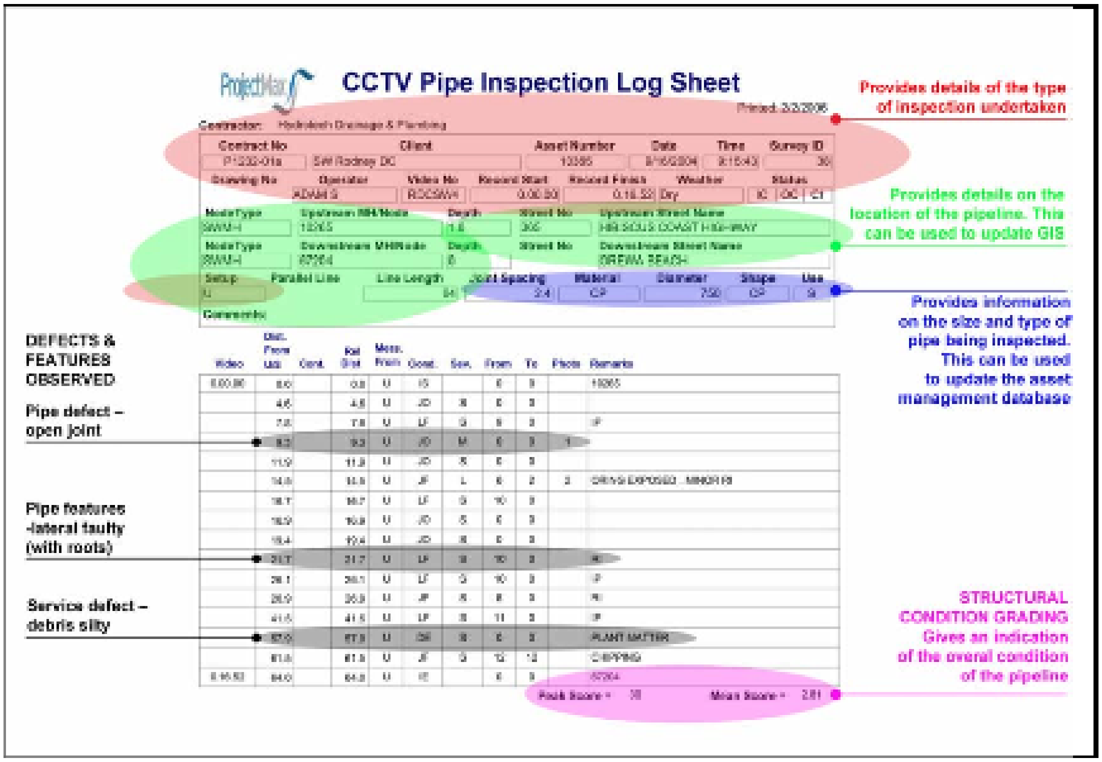


Figure 3 – Standard New Zealand Pipe Inspection Manual Reporting Format

4 - Electro Scan: Principle of Operation

Most sewer pipe materials such as clay, plastic, concrete, reinforced concrete, resin linings, and brick are poor conductors of electrical current. As a result, if a defect exists in the wall of a pipe, then the leakage of electrical current will indicate the source of a potential water leak, whether or not water infiltration or exfiltration actually occurs at the time of the electro-scan.

Electro-scanning is carried out by applying an electrical potential (voltage) between an electrode (probe) in an electrically nonconductive pipe and an electrode on the surface, which is usually a metal stake pushed into the ground (ground stake). A simplified electrical circuit for this procedure is shown in Figure 4. The water in the pipe is at a level that ensures that the pipe is full at the probe location.

Provided electrical current is prevented from flowing along the inside of the pipe, the electrical resistance of the current path between the probe in the pipe and the ground stake is very low except through the electrically nonconductive pipe wall.

In contrast, the high electrical resistance of a pipe wall allows only a very small electrical current to flow between the two electrodes unless there is a defect in the pipe such as a crack, defective joint, or faulty service connection. The greater the electric current flow through the defect in the wall of the pipe, the larger the size of the defect.

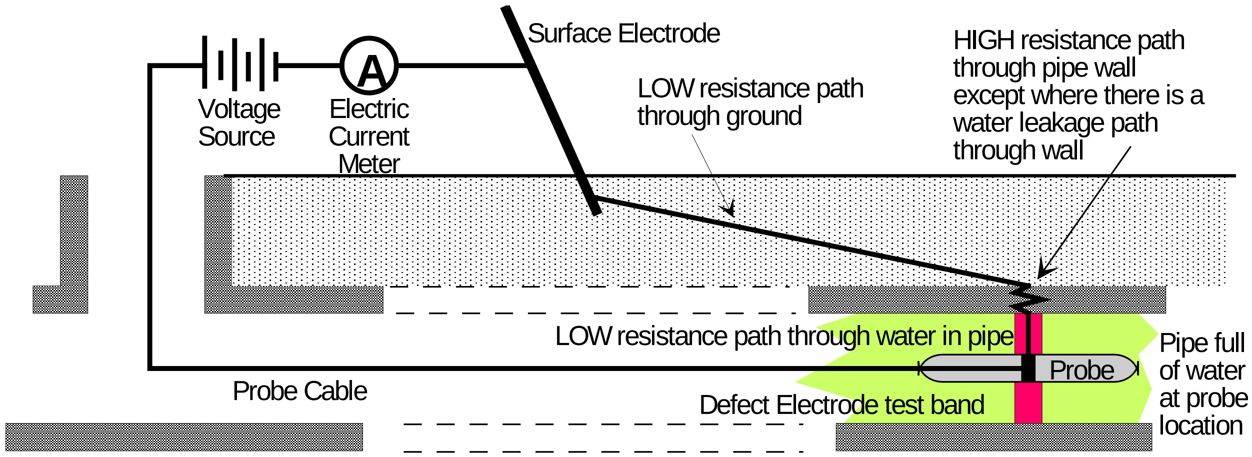
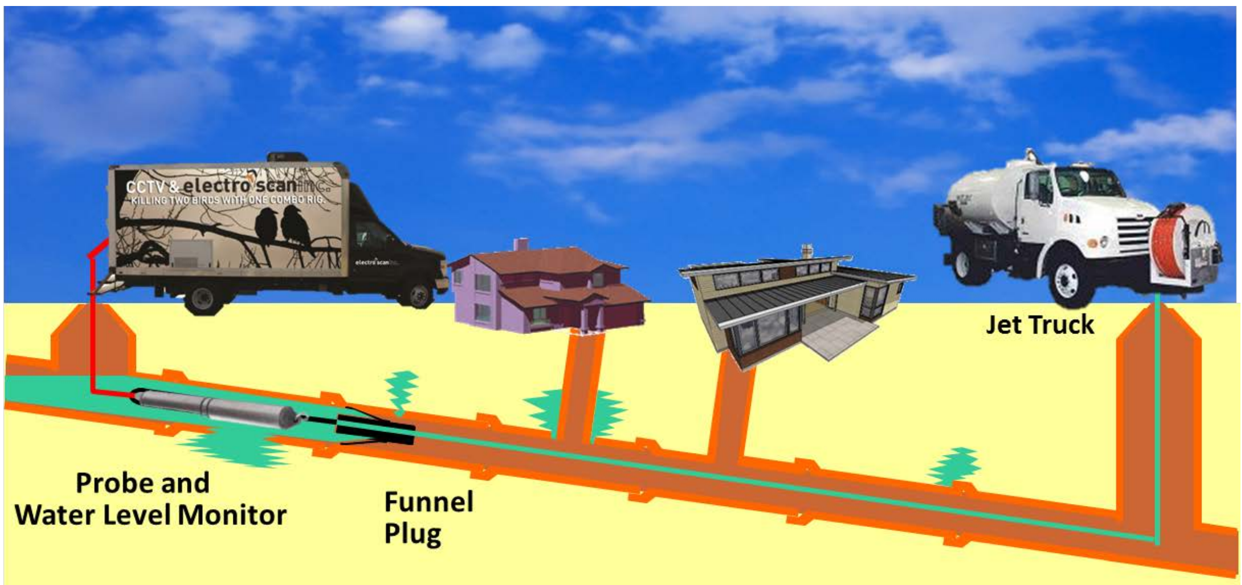


Figure 4 - Electrical Schematic of Electro-Scanning.

Electro-scanning is carried out by pulling the probe through the pipe at a speed of 10 m/minute (30 ft/minute) and measuring the variation of electric current flowing between the probe and the fixed electrode on the surface. When the probe is close to a pipe defect the electric current increases because the defect decreases the electrical resistance of the pipe wall. The probe is designed to measure only that electric current which flows through a circular test band around the pipe wall. The test band is about 30 mm (1 inch) wide and located at the middle of the probe.

As the probe is pulled through the pipe the electric current flow and the position of the probe in the pipe are recorded and displayed in real time as a “current trace” on a notebook computer (Figure 5). When the middle of the probe is within 20 to 30 mm of a defect in the pipe wall the electric current through the pipe wall increases, attaining a maximum value when the center of the probe is radially aligned with the defect.



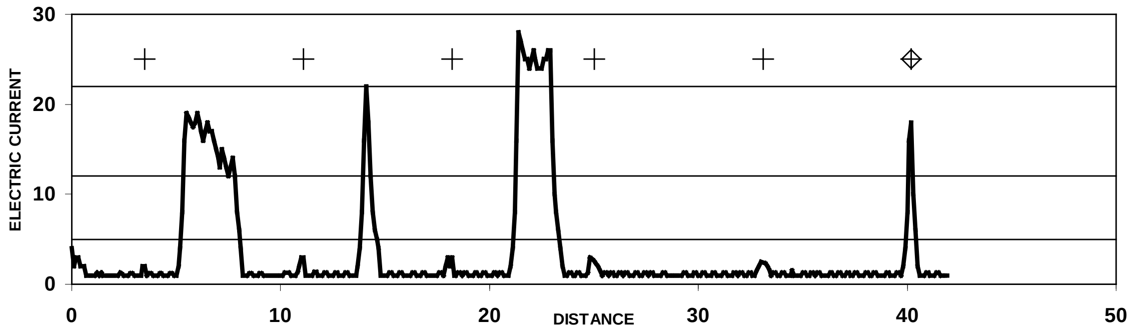


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Figure 5. Electro-Scan Testing and Current Trace

Regions on the current trace where the probe electrode current levels are above a threshold level are defects in the wall of the pipe. The location and length of a defect indicates the location and longitudinal length of a defect along the pipe. The maximum current level of the anomaly is a measure of the amount of current flow through the defect and is related to the size of the defect.

In Christchurch, electro-scanning is currently being applied to assess pipe damage as a result of earthquake activity and after-shocks in the region. Although a widespread pipeline condition assessment program has been undertaken in the vicinity of the city, operators have been faced with a number of difficulties, including: a) determining the structural condition of pipes damaged so badly that they are completely filled with wastewater, b) identifying and assessing the multitude of defects graded as 'minor' under NZ Pipe Inspection Manual CCTV Standards which in aggregate are contributing substantially to infiltration, c) calculating infiltration potential in pipe sections and collection sub-basins to prioritize rehabilitation, d) processing the multitude of data from dozens of CCTV crews performing simultaneous inspections throughout the city, and e) in cases of new pipe construction and relining, the need to certify that rehabilitation as, indeed, eliminated all sources of leaks in pipes, especially at manhole and service re-connections.

Although the severity of these issues were exacerbated by seismic activity, they are represented common issues facing all collection system condition assessment programs throughout the world.

Electro Scan is being deployed to help overcome the difficulties often associated with condition assessment, especially by: 1) investigating fully surcharged pipes without rigorous and expensive requirements for cleaning and bypass pumping, 2) objectively measuring the size and shape of 100% of the defects in each pipe segment scanned, even those routinely overlooked, missed, or classified as 'minor' in a standard CCTV inspection, 3) using electricity to measure the potential infiltration of each defect and compute potential infiltration flows for a pipe segment and sub-basin, 4) utilizing integrated cloud-based software reporting to organize data and prioritize rehabilitation in real time, quantifying an estimated liters per second (i.e. gallons per minute) for hydraulic modeling purposes.

5 - Results of CCTV and Electro Scan Investigation Comparisons

The results of the 690m of strategic investigations performed in pipes of varying materials and sizes in and around Christchurch have thus far **shown Electro Scan to identify an average of 7.1 times as many pipe defects as CCTV reports on the same pipe sections**. The pipes surveyed thus far were selected with variety in mind:

- Pipe sections with CCTV grading ranging from severely damaged to those considered to be in good condition.
- Pipe materials ranging from PVC to Clay to Asbestos Cement.
- Sewer mainlines as well as lateral connections.
- Soil conditions ranging from predominately silt, to sand, to clay.
- Locations of pipe sections ranging from urban to rural.

A total of fifteen (15) pipe sections were investigated, totaling 690m in length. Electro Scan identified a total of 284 pipe defects in these pipe sections, compared to 40 pipe defects identified by the use of CCTV. In total, Electro Scan estimated a Total Peak Potential Infiltration level of 301.3 Liters per Minute for the sum of pipe sections in the study; representing a potential contribution to wastewater treatment effluent operation of 433,872 liters, each day. The summary of defects identified in each pipe section is listed below in Table 1.

Pipe Section	Project	Length (m)	# of CCTV Defects	# of Electro Scan Defects	Estimated LPM Infiltration
SW 9 to SW 8	Ministry of Education	18.75	5	10	14.3
SW 7 to SW 8	Ministry of Education	37.51	0	10	9.6
Heaton 5 to Heaton 6	Ministry of Education	19.98	2	17	22.2
Heaton 6 to Heaton 7	Ministry of Education	51.01	4	12	10.7
MHA to MHB	Selwyn	56.72	0	8	6.3
MHB to MHC	Selwyn	22.2	1	32	18.2
MHC to MHD	Selwyn	48.64	0	25	8.1
MHF to MHD	Selwyn	83.82	2	7	40.7
MHE to MHF	Selwyn	82.41	3	82	50
35080	Akaroa	79.64	1	13	53.1
35081	Akaroa	45.45	0	6	11.3
36014	Akaroa	14.39	0	1	1.2
19763	SCIRT	30.7	7	15	10.7
19760	SCIRT	40.3	3	4	2.4
35550	Ashburton	57.6	12	42	42.5
	Totals	689.12	40	284	301.3

Table 1 – Summary of New Zealand Electro Scan Strategic Trials

While the total number of Electro Scan-identified defects of 284 compared to the total number of CCTV identified-defects of 40 represents an average of 7.1 times as many pipe defects idenfied with Electro Scan than with CCTV, there were a wide range of other differences noted between CCTV and Electro Scan:

- For example, in pipe section 19760 Electro Scan identified only 33% more defects (one additional defect). In this case Electro Scan confirmed the CCTV hypothesis that this pipe was in relatively good condition. With only 2.4 liters per minute of infiltration potential, it was the second best condition pipe identified in the study by Electro Scan standards.

- However, in one case – pipe section MHE to MHF in Selwyn – Electro Scan identified 2733% more defects than CCTV (79 additional defects). This asbestos cement pipe had significant areas of visually non-obvious corrosion as well as a multitude of seemingly minor structural cracks that added up to contribute to the second largest infiltration potential of the project, measured at 50 liters per minute. Since the sub-basin containing this pipe section was immediately adjacent to a large river it is likely that under peak flow conditions this single 82 meter section of pipe was contributing an extra 72,000 liters per day of groundwater infiltration to the system. As is apparent in Figure 6 below, under a standard CCTV inspection program this pipe section would not have been classified as a high priority for rehabilitation with only 3 defects identified.

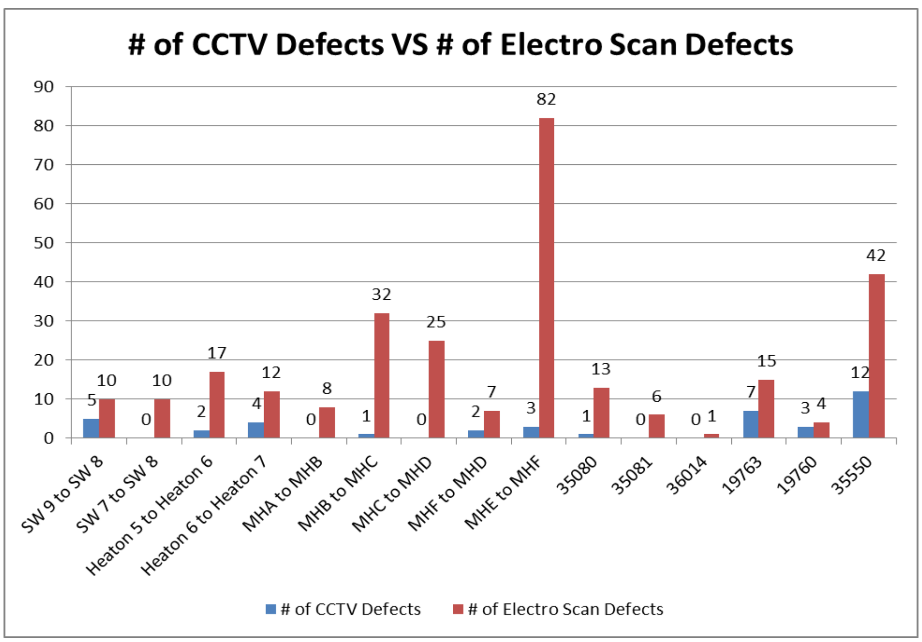

Figure 6 – Number of CCTV and Electro Scan Defects Identified per Pipe Section

However, the physical number of defects alone is not the most important factor in designing an effective rehabilitation program. Although number of defects is a good metric for determining potential for catostophic pipe collapse, if groundwater infiltration reduction is a high priority it is the potential flow through each defect that must be taken into account. Figure 7 below illustrates the liters per minute of infiltration for each pipe section as well as the number of CCTV and Electro Scan defects identified. The figure is sorted by how rehabilitation would be prioritized by

CCTV alone. By this standard the pipe with the highest potential infiltration (section 35080) would be very low priority for rehabilitaion with only a single minor defect identified visually.

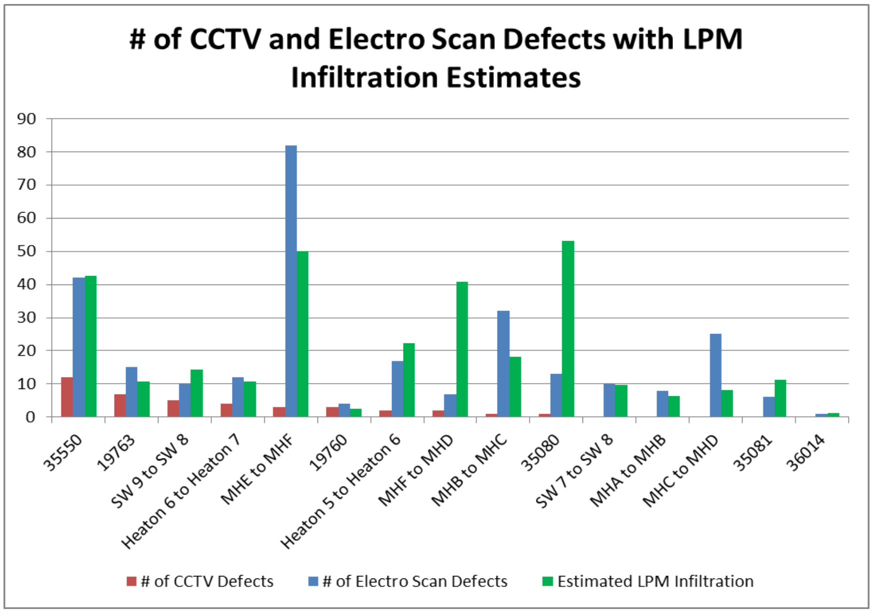

Figure 7: Number of CCTV and Electro Scan Defects and LPM Infiltration Estimates

This figure is sorted by how rehabilitation would be prioritized by CCTV alone. By this standard the pipe with the highest potential infiltration (section 35080) would be very low priority for rehabilitaion with only a single minor defect identified visually. Since this pipe section is in a tidal zone, a regular 53.1 liters per minute of infiltration potential would be systematically overlooked.

6 - Detailed Investigation of the Leakiest Pipes

One part of this particuar strategic trial of Electro Scan in New Zealand was to verify the presence of defects by looking for evidence in CCTV videos that may have been missed in the written report. Since the New Zealand Pipe Inspection Manual has certain thresholds of visual evidence for making defect call outs and minor evidence can often be missed in the field a detailed frame-by-fram analysis of each pipe’s CCTV video was undertaken. In the course of this investigation a multitude of visual evidence was uncovered about the defects identified by Electro Scan.

Each video was slowed to frame-by-frame speed while a trained CCTV operator returned the video to each location where Electro Scan identified a defect and a screenshot was taken. The initial CCTV reports only identified visual evidence of 14% of defects identified by Electro Scan. However, upon detailed inspection of the CCTV videos at a frame-by-frame rate visual evidence of over 80% of the defects identified by Electro Scan, the other 20% being defects in joints which showed no visual evidence of defect.

Although such a painstaking analysis of visual evidence (approxemately 1.5 to 2hrs per pipe section depending on length) would be possible in every day CCTV inspection, once the operators knew the location of defects in the pipe from Electro Scan readings (approxemately 10 to 20 minutes per pipe section to collect data) they were able to idenify much more detailed visual evidence of pipe failures. Some examples of screenshots from this detailed CCTV review are provided below.

7 - Conclusion

Overall in the approximately 700 meters of strategic Electro Scan investigations performed in Christchurch, New Zealand in Q3 of 2012 the technology was able to identify 7.1 more defects than initial CCTV investigations. Additionally, the technology quantified 301.3 liters per minute of groundwater infiltration potential in the 15 pipe sections investigated. Over 61% of this infiltration potential was identified from the 4 worst pipes. Additionally, the accuracy of the Electro Scan readings allowed a more detailing analysis of the existing CCTV videos, revealing visual evidence of over 80% of those defects pinpointed by Electro Scan.

Ultimately this trial details a potential method for the most accurate condition assessment of damaged wastewater and storm water pipes:

1) Collection of Electro Scan data @ 10 meters per minute to pinpoint defects within 1 cm and prioritize the worst 10 to 20% of pipes in a system, followed by
2) Detailed CCTV investigation of those defects identified by Electro Scan to design a rehabilitation strategy @ 1 to 2 hours per pipe section.

8 - References

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Harris, R.J., and Tasello, J., (2004) – Sewer Leak Detection - Electro-Scan Adds a New Dimension: Case Study - City of Redding, California, ASCE Pipelines Conference

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