USEPA Sewer Electro Scan Field Demonstration Revisited

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ABSTRACT

Potential Rain Dependent Infiltration (RDI) flows are a critical parameter for the design and prioritization of sewer collection system infiltration mitigation projects. An estimate of RDI flows may be obtained from the defect current measured by an electro scan of a pipe. RDI flow has been calculated for the pipes electro scanned during the USEPA sponsored field demonstration. The field demonstration included CCTV inspection of the pipes. For pipe defects that are potential sources of RDI, the comparison with CCTV showed that electro scan is highly reliable, identified 2.1 times more defects and that many of the defects missed by CCTV were potentially the largest sources of infiltration. The distribution of the electro scan estimated RDI flow was significantly more variable than that shown by CCTV. This reveals the potential use of electro scan to target and design rehabilitation projects that will significantly reduce RDI at considerably lower cost.

KEYWORDS: electro scan, rain dependent infiltration, sewer infiltration, sewer rehabilitation, sanitary sewer overflow

INTRODUCTION

In August 2010 the United States Environmental Protection Agency (USEPA) sponsored a field demonstration of electro scan at Gracemor, Kansas. The project was part of an USEPA research program "Innovation and Research for Water Infrastructure for the 21st Century." The results of the study were published in July 2011 (USEPA 2011). A technical paper (Tuccillo, M.E., et al, 2011) presented the results of the electro scan demonstration.

A quote from the paper (Tuccillo, M.E., et al, 2011):

"Electro scan technology can be used to estimate the magnitude and location of potential leaks along a pipeline, helping utilities better understand and control sources of infiltration/exfiltration. It directly measures leak potential, independent of external conditions that are temporal in nature (e.g., seasonal, wet weather). Its use of direct measurements provides a quantitative analysis of leak potential without relying on visual observation."

However the report did not discuss a comparison of key closed circuit television inspection (CCTV) and electro scan metrics that are the major parameters used to assess the potential leakage of individual pipe segments.

Of the 7,009 ft of pipe inspected by CCTV and the 8,685 ft of pipe electro scanned at Gracemor, 4,070 ft was both CCTV inspected and electro scanned. The objective of the USEPA study was

to use the CCTV as a baseline for comparison with the electro scans. As such the number, type, and severity of defects found by CCTV and electro scanning were compared for the 4,070 ft of pipe comprising 17 pipe segments. Using the data collected during an USEPA sponsored field demonstration project, the paper describes the use of CCTV and electro scan parameters to quantify the leak potential of sewer pipe segments.

In order to compare the pipe condition assessment metrics provided by CCTV and electro scan with respect to potential pipe leakage this paper presents:

- The CCTV Overall Pipe Rating Index (OPRI) for each pipe segment (NASSCO 2001) and a electro scan metric: Defect Flow (electro scan). Neither of these metrics was described in the USEPA report (USEPA 2011).
- A direct comparison of each of the defects observed by the CCTV and the defects measured by electro scan is presented to provide an understanding of the relevance of the information provided by each of the technologies.

PIPE CONDITION ASSESSMENT METHODS

Closed Circuit Television Inspection

Defects were identified on the CCTV images and coded using the PACP method. "PACP grades are as follows:

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

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

The following are most of the PACP abbreviations shown on the CCTV inspection reports that were considered to be pipe defects that could leak:

AMH start or end of survey	FM Fracture Multiple	RPZ Repair Other
ATC Tee Connection	FS Fracture Spiral	TFA Tap Factory Made Active
B Broken	JS Joint Separated	TFA Tap Factory Made Capped
CC Crack Circumferential	RFJ Roots Fine Joint	TFD Tap Factory Made Defective
CM Crack Multiple	RMJ Roots Medium Joint	TBD Tap Break-In Defective
FC Fracture Circumferential	RTJ Roots Tap Joint	TBI Tap Break-In

The OPRI was calculated from the individual CCTV PACP codes according to the PACP method (NASSCO 2001). The OPRI is used by PACP to characterize the overall condition of individual pipe segments. It is calculated by adding the severity grade of each defect in a pipe segment and dividing this total by the number of individual defects in the pipe segment. This index uses the same 1 to 5 scale as the defect grades discussed previously. An OPRI of 0 indicates that no defects were observed in the pipe segment.

Electro Scan

Electro scans are a measure of the variation of electric current flow through a sewer pipe wall. This electricity flow is used to locate and measure defects that are potential water leakage paths either into or out of the pipe. The electro scan is carried out by applying an electric voltage between an electrode in the pipe, called a probe, and an electrode on the surface, which is usually a metal stake pushed into the ground. As the probe is pulled through the pipe the electrical current flow through the pipe wall at the center of the probe and the position of the probe in the pipe are recorded and displayed in real time as a "current trace" on a notebook computer. An example of an electro scan is show in Figure 4.

The electro scanning was carried out according to the protocol described by American Society for Testing and Materials (ASTM) Standard F2550-06 (ASTM, 2006). The principle of operation, methods of deployment and data collection are fully described in the above standard and in (Harris et al 2006) and (Harris et al 2004)

Rain Dependent Infiltration Potential Flow Rate

One of the major reasons for carrying out a sewer pipe evaluation is to obtain an estimate of the potential infiltration of ground water into a pipe. High rainfall events cause the height of the water table in a sewer pipe trench to increase above the level of the pipe so that any defects in the pipe that can leak allow water to infiltrate into the pipe. This phenomenon is commonly known as Rain Dependent Infiltration (RDI). It is not uncommon for RDI to increase the flow in a sewer collection system by three to five times the normal flow. This puts a strain on the treatment facilities and increases costs. RDI can also overload the collection system and is one of the major causes of sanitary sewer overflows (SSO's). The flow of water from the trench into the sewer also transports solids from the trench that can cause loss of support for the pipe and subsequent failure. For the above reasons an estimate of the potential water flow through a defect in a pipe is a critical parameter for the assessment of pipe condition.

The flow of water (liter/sec, gpm -gallons/minute) through an orifice (a pipe defect) depends on: the area of the orifice (the size of the defect); the shape of the orifice (flow through a crack can be two or more times less than through a circular hole of the same area); and the pressure of the water at the orifice (the head of water above the defect).

The majority of defects in a sewer pipe are cracks or slots such as defective pipe joints or tap connections. For a crack or slot having a particular area the thinner the slot the lower the flow rate. Assuming that the smallest significant crack is 0.635 mm (0.025 in) wide, flow measurements were carried out for slots 0.635 wide from 17 mm (0.7 in) to 72 mm (2.8 in) long. For a 304.8 mm (12 in) head of water the flow rate per slot area was found to be 0.0012 +/-0.0002 litre/sec/mm². Wider slots have a greater flow rate per slot area, so if in fact the pipe defect is wider the flow rate estimate for such a defect will be lower than actual.

Torricelli's law states: $v = \sqrt{(2gh)}$

Where \mathbf{v} is the speed of efflux of a fluid through a sharp-edged hole at the bottom of a tank filled to a depth \mathbf{h} and \mathbf{g} is the acceleration due to gravity. This law is considered applicable to an empty buried sewer pipe with the water table above the pipe. As such the flow rate through a defect in the pipe is dependent on the square root of the height of the water table above the pipe defect. Since the defect can occur at any location around the circumference of the pipe a good estimate is considered to be the height of the water table in the sewer trench above the centerline of an empty pipe.

Another consideration with respect to the variation of the water table height is the supply of water into the sewer trench. This is dependent on a number of parameters including the permeability of the soil surrounding the trench, the permeability of the trench backfill material and the height of the regional water table relative to the depth of the trench. These parameters are usually not known. For the purpose of this flow rate estimate it is considered to be reasonable to assume that permeability of the surrounding materials is greater than that of the pipe. That is infiltration into the pipe does not affect the height of water above the pipe.

In most cases the height of the water table above the center line of the pipe when RDI events take place is not known. However for the purpose of making an estimate of the potential contribution of a pipe defect to RDI the following has been adopted: a uniform water table height of 308 mm (12 in) above the centerline of the pipe; and the defect is a crack about 0.635 mm wide. Under these conditions measurements have shown that water will flow into the pipe at the rate of 0.0012 liter/sec/mm².

That is: Defect Flow (liter/sec) = 0.0012 x defect area (mm²)(1)

Measure of Defect Area from Electro Scan

For the electro scan system operating in a pipe manufactured from material with low electrical conductivity with respect to the water in the pipe, it can be shown that the change in the Defect Current through a defect in the pipe, ΔI , is largely related to the electrical resistance, **R**, of the water filling the defect.

From Ohms Law: $\Delta I = Vo/R$ (2) Where: Vo is the open circuit voltage of the electro scan system and is constant.

By definition: Conductivity = length of conductor / (area of conductor x uniform resistance of conductor)

That is: $\sigma_w = T / (A R)$ (3) Where: σ_w = conductivity of the water in the pipe T = pipe wall thickness A = the area of the defect

From (1) and (2): $\Delta I = A \sigma_w Vo/T$ (4)

Transforming (4): $A = \Delta I T / \sigma_w Vo$ (5)

For: $\sigma_w = 110$ microSeimens/mm (sewage conductivity) T = pipe wall thickness in mm For the electro scan system: Vo = 10 Volt ΔI = increase in defect current in 10⁻⁴ Amp

Substituting in (5): $A = (\Delta I * 10^{-4} T) / (110 * 10^{-6} * 10) \dots (6)$

That is: $A = 0.0909 * \Delta I T mm^2$ (7)

Estimate of Potential Flow Through a Defect

The water flow through a defect estimate from the increase in the defect current of an electro scan (DFes) from (1) and (7) is: DFes liter/sec = $0.0012 * 0.0909 \Delta I T \dots (8)$

That is: DFes liter/sec = $0.000109 \quad \Delta I T \quad \dots \quad (9)$ For slots 0.635mm (0.025in) wide and a water table height of 308mm(12in)

Table 1 shows defect flow per ΔI for common pipe sizes. The estimated error for each of the variables are: Flow/sec/ mm² : 17%; Sewer Conductivity: 20% (this can be measured by the probe); Pipe Thickness: 1% (standards for manufacture); electro scan applied voltage: 1% (measured); increase in defect current flow: 10%. The total error for DFes is approximately +/-40%. This margin of error is not considered detrimental to the usefulness of the estimate.

Clay Pipe D	iameter	meter Clay Pipe Thickness		Area per ΔI	DFes per ∆I*				
mm	inch	mm	inch	sq mm	liter/sec	gallon/min	gallon/day		
200	8	21.6	0.85	1.96	0.0024	0.036	51		
250	10	25.4	1	2.31	0.0028	0.042	60		
300	12	30	1.18	2.73	0.0033	0.049	71		

Table 1. Water Flow per Increase in Defect Current Flow

Note * Flow for slot 0.635 mm (0.025 in) wide and water head 308 mm (12 in)

Severity Grading of Potential Flow

From consideration of some electro scans for which RDI flow monitoring information is available an attempt has been made to grade the severity of DFes at the following levels: Small: less than 4 liter/min (1gpm); Medium: from 4 to 15 liter/min (1 to 4 gpm); Large: greater than 15 liter/min (4 gpm)

Electro Scan Processing

The electro scan current trace recorded in the field is analyzed using a computer program in the following steps:

- Removal of the defect current offset above zero. This process enables a computer program to automatically pick and grade the electro scan "anomalies" as described below.
- Setting an electro scan "threshold" level. Electro scan values above the threshold level are called "anomalies". For this study the threshold level selected was 1.0 and is shown as the lowest unbroken horizontal line on the electro scans.(See Figure 4)

- Calculating the defect area for each anomaly.
- Calculating the potential infiltration flow rate for each of the anomalies according to the selected parameters. For this study the assumptions were: head of water above the center line of the pipe was a constant 308 mm (12 in); the defects were about 0.635 mm (0.25 in) wide
- Grading the potential infiltration flow rate for each defect as Large, Medium or Small. For this study the Large-Medium boundary and Medium-Small boundary flow levels were set at 4 gpm and 1 gpm respectively and are shown as unbroken horizontal lines on the electro scan.(See Figure 4)
- Plotting joint locations. Anomalies that occur at regular intervals are usually due to joint defects. To assist with the identification of these joint anomalies the analysis program plots "+" on the electro scan at the joint interval. The analysis program detects anomalies that occur at the "+" marks and plots a "◊" over the "+". These anomalies are considered to be associated with a joint defect. Other anomalies are usually due to structural faults or defective taps.
- Taps (Service Connections). The regular spacing of the pipe joints is often interrupted by a larger spacing of a foot or more, called a "joint interval offset". For instance for a pipe joint interval of 5 ft, pipe joints maybe identified as occurring at ...106, 111, 116, 122, 127, 132,.... There is a regular 5 ft pipe joint interval between 106 and 116 and 122 and 132. The pipe joint spacing between 116 and 122 is 6 ft. This joint interval offset is usually caused by the insertion of one or more pipe sections containing a tee junction for a tap(s). Consequently, defects that occur at these joint interval offsets are labeled as "faulty service X".
- Tabulation of defect flows. The analysis program generates a Potential Defect Flow Summary table of the defect flows with respect to size and type and calculates the total defect flow for each pipe segment. The total defect flow per pipe section can be misleading for estimating the pipe segments with the largest potential RDI. For instance a pipe section 500 ft long with a total DFes of 20 gpm is contributing less DFes per length of pipe than a 100 ft pipe segment with the same total DFes. So that pipe segments can be compared with each other the following parameter is calculated and shown on the Potential Defect Flow Summary:

DFes per 100 ft of pipe

= $(100 \text{ x sum of DFes in pipe segment}) / (\text{length of pipe segment}) \dots (10)$

A computer application is commercially available that will automatically carry out this analysis. It also has the capability to store the electro scans in a secure database and present tables and graphs of the results. One example is the cloud application Critical SewersTM available at www.electroscan.com.

FIELD OPERATIONS

CCTV Inspection

A total of 7009 ft was CCTV inspected in the Gracemor area. A full description is given in the USEPA Report (USEPA 2011) *Production Rate and Cost*

The production rate for CCTV from the USEPA Report was 2003ft per 8 hour day or 250 ft/hour. CCTV total cost for the Gracemor area was \$19,614 or \$2.80 per ft.

Electro Scanning

9,755 ft of pipe was electro scanned in the Gracemor area the week of August 23 - August 27, 2010. Refer to USEPA report (USEPA 2011) for the location of the pipe segments and details of equipment setup and deployment.

Production Rate and Cost

Production rates for each day of electro scanning were calculated from the length of pipeline electro scanned and the time stamps on the electro scan computer files and are shown in Table 2. Down time for troubleshooting, equipment repair and confined space entry was included in the productivity calculations. Work duration did not include time spent in consultation at the beginning of the day or lunch breaks.

Date	Work Duration	Length Electro Scanned	Production Rate		
	(hour)	(ft)	(ft/hour)		
Aug. 23, 2010	6.75	1813	267		
Aug. 24, 2010	7.08	2572	363		
Aug. 25, 2010	6.67	2581	387		
Aug. 26, 2010	6.83	2278	334		
Total	27.3	9244	339		
Aug. 27, 2010	4.25	511	170^{1}		

Table 2. Electro Scanning Production Rate

¹ Slower production rate due to lack of jet cleaning truck for stringing line and surcharging pipe.

The following is the typical field cost of electro scanning:

Field technician: \$70/hr, Field assistant: \$45/hr, Vehicle and equipment: \$250/hr, Jet truck: \$250/hr, Water: \$47/hr, Total field cost:\$662/hr

Electro Scanning Rate (for this project): 340 ft/hr (2,720 ft per 8 hour day) Field Cost: \$1.95/ft Reporting \$100/hr at 6 scans per hour with average length of 330 ft: \$0.05/ft, Total Cost: \$2.00/ft Planning, mobilization and other project fixed costs are not included in the cost per foot because the influence they have is so dependent on the total number of feet for the project. The electro scanning cost shown in the USEPA Study included mobilization from Dallas, Texas and living away from home expenses. These costs were not part of the \$2.88/ft CCTV cost for this study because the CCTV contractor was local.

Duplicate Runs

The repeatability of electro scans was evaluated by rescanning 306 ft long pipe segment 101 to100. The two scans were very similar. See USEPA report (USEPA 2011) for details.

RESULTS

CCTV Results

Defects that were identified on the CCTV images were coded using the PACP method (NASSCO 2001) and are shown in Figures 4 to 20. The tap locations observed by the CCTV inspection are shown as triangle symbols (\triangle). CCTV PACP defect codes are listed and are shown on the graph plotted to the right according to the severity grade as diamonds (\blacklozenge) Only the CCTV PACP codes that are potential sources of leakage (e.g., joints, taps, manholes, pipe

defects) are shown. Thus a direct comparison can be made between the capabilities of CCTV and electro scan to detect sources of potential infiltration.

The OPRI for each pipe segment was compiled from the CCTV defects showing potential leaks according to the PACP method (NASSCO 2001) and are shown in Table 3 and Figure 3.

Electro Scan Results

The electro scans and the defect type identifications carried out for the USEPA study where presented to the project managers prior to the release of the CCTV results. The analysis presented in this paper used these electro scan results and the CCTV PACP defects without any omissions or additions.

Summary of Defects

The electro scan for each pipe segment is shown as a graph of the defect electrode current (in units of 0.0001 Amp) vs. distance along the pipe from the center of upstream manhole (in units of ft). The DFes for each electro scan anomaly is also plotted. Symbols and comments are appended to the electro scan describing the type of defect such as defective joint, faulty tap (faulty service X) or manhole connection and pipe defect. The electro scans of the pipe segments are shown in Figures 4 to 20.

The results of the electro scan processing are shown in Table 3 and graphically in Figures 1 and 2. In Table 3 the type of defect has been categorized as joint or other since at this time the processing software can only identify joint defects with an acceptable degree of certainty. The data in Table 3 shows that the source of about 80% of the potential RDI flow is from defects that are not joints. These sources are most likely due to faulty taps and faulty manhole to pipe connections. It can also be shown from the Table 3 data that repairing the "Other" defects in the worst pipe segments (096 to 095, 104 to 102, 114 to 107, 118 to 117) that is 26% of the total pipe length, has the potential to reduce RDI flow by 40%. Figure 1.2 makes readily apparent the effect of repairing all of the "Other" defects (mainly defective manhole connections and defective taps). Only the blue bars representing the joint defects would remain in Figure 1.2. That is 80% of the potential RDI would be removed.

There is a significant difference in the appearance of Figure 1 and Figure 2. It will depend on the objectives of the pipe condition assessment project whether DFes per Pipe Segment or DFes per 100ft is used. It is consider that the DFes per 100 ft of Pipe shown in Figure 2 is the most appropriate parameter to prioritize pipe segments for rehabilitation. Figure 2 shows that there is considerable variation of potential RDI flow between the pipe segments.

Comparison of Electro Scanning to CCTV

To enable a direct comparison of the electro scans with CCTV the PACP codes have been plotted on the electro scans shown in Figures 4 to 20. When making these comparisons it should be understood that the distances along the pipe segment shown by CCTV and electro scan may not exactly correspond. The distance between manholes of the pipe segments was measured with a distance wheel at the time the electro scan was recorded in the field and were within 1 ft of the distance recorded by the electro scan. The manhole to manhole distances shown on the CCTV reports showed the same distance within one foot for 9 of the 17 pipe segments. The others varied by 2 to 4 ft.

Pipe	MH	DFes per Pipe Segment							DFes per 100ft of Pipe					CCTV
Segment	Dist.	gpm						gpm						OPRI
	4070	Large	Med	Small	Joint	Other	Total	Large	Med	Small	Joint	Other	Total	Leaks
095 to 094	190	0.0	11.4	4.2	3.8	11.9	15.7	0.0	6.0	2.2	2.0	6.3	8.3	1.63
096 to 095	407	51.3	9.3	5.1	4.2	61.5	65.7	12.6	2.3	1.3	1.0	15.1	16.1	2.24
102 to 101	294	5.3	2.8	1.8	1.8	8.1	9.9	1.8	0.9	0.6	0.6	2.8	3.4	3.00
103 to 102	235	0.0	5.3	4.2	2.3	7.2	9.4	0.0	2.2	1.8	1.0	3.1	4.0	0.00
104 to 102	292	5.8	10.0	3.1	6.9	12.0	18.9	2.0	3.4	1.0	2.4	4.1	6.5	2.25
106 to 105	240	0.0	6.5	1.8	5.6	2.8	8.3	0.0	2.7	0.8	2.3	1.1	3.5	2.33
107 to 106	300	0.0	1.0	2.1	2.1	1.0	3.1	0.0	0.3	0.7	0.7	0.3	1.0	4.00
114 to 107	196	4.7	13.4	5.8	3.8	20.2	24.0	2.4	6.9	3.0	1.9	10.3	12.2	2.20
115 to 114	162	0.0	3.6	5.1	1.1	7.5	8.6	0.0	2.2	3.1	0.7	4.6	5.3	2.33
116 to 115	204	0.0	8.9	6.4	6.1	9.2	15.3	0.0	4.3	3.2	3.0	4.5	7.5	2.56
117 to 116	213	0.0	1.9	1.0	0.0	2.9	2.9	0.0	0.9	0.5	0.0	1.4	1.4	2.20
118 to 117	163	10.0	13.8	1.4	4.9	20.3	25.2	6.1	8.5	0.9	3.0	12.5	15.5	2.18
119 to 118	176	9.6	4.7	2.2	2.5	14.1	16.5	5.4	2.7	1.3	1.4	8.0	9.4	2.71
120 to 119	323	0.0	13.4	3.5	3.8	13.1	16.9	0.0	4.1	1.1	1.2	4.1	5.2	2.89
125 to 116	291	0.0	5.0	5.6	2.1	8.5	10.6	0.0	1.7	1.9	0.7	2.9	3.6	3.20
127 to 125	220	0.0	10.4	5.2	3.0	12.6	15.6	0.0	4.7	2.4	1.4	5.7	7.1	2.29
128 to 127	164	0.0	9.8	1.1	1.9	8.9	10.8	0.0	5.9	0.7	1.2	5.4	6.6	2.20

Table 3. Electro Scan Potential Defect Flow Summary and OPRI



Figure 1.1 Total Defect Flow for Water Table 12in Above the Pipe – by Defect Size



Figure 1.2 Total Defect Flow for Water Table 12 in Above the Pipe – by Defect Type



Figure 2.1 Defect Flow per 100 ft of Pipe for Water Table 12 in Above the Pipe – by Defect Size



Figure 2.2 Defect Flow per 100 ft of Pipe for Water Table 12 in Above the Pipe – by Defect Type

For each CCTV defect that was categorized as a potential leak the electro scan was examined to determine if an electro scan defect was also shown at the same location (See Table 4). This defect by defect comparison shows that electro scan identified defects at 82% of the defects shown by CCTV with a variation between 100% and 25%. Inspection of the CCTV images for the worst case, pipe segment 117 to 116, shows that structural defects at 73.3 and 78.6 were sub-horizontal hair line fractures. Although these defects may indicate that the pipe is under stress it is unlikely that these defects are potential leaks and explains the absence of an electro scan defect. It is probable that the other non-coincidence may show a similar explanation. This high degree of co-incidence shows electro scan is a reliable indicator of pipe defects that are potential leaks. Previous studies that compared electro scan defects with pipe joint pressure testing (Harris et al 2006) and actual excavation of the pipe trench at electro scan defect locations (Harris et al 2004) also showed a very high co-incidence of electro scan defects with pipe defects that can leak.

Pipe	Defects: Electro Scan Coincident with CCTV							
Segment	yes	no	Percent					
95 to 94	8	0	100%					
96 to 95	17	0	100%					
102 to 101	3	1	75%					
103 to 102	0	0	100%					
104 to 102	7	1	88%					
106 to 105	5	1	83%					
107 to 106	1	0	100%					
114 to 107	4	1	80%					
115 to 114	3	0	100%					
116 to 115	16	1	94%					
117 to 116	1	3	25%					
118 to 117	8	3	73%					
119 to 118	6	1	86%					
120 to 119	5	4	56%					
125 to 116	5	1	83%					
127 to 125	3	4	43%					
128 to 127	5	1	83%					
Total	97	22	82%					

 Table 4. Defect by Defect Comparison of CCTV and Electro Scan

The number and type of defect identified by CCTV and electro scan for each pipe segment is shown in Table 5. The total number of pipe defects detected by electro scan is 2.1 times more than that shown by CCTV. This shows that electro scan is considerably more effective than CCTV in identifying potential sources of infiltration/exfiltration.

The total number of "Joint" type defects identified by electro scan is 4.8 times greater than that shown by CCTV. All of the joints categorized as defective by CCTV were identified by the appearance of roots at the joint. This is a secondary phenomenon and is dependent on trees being present in the vicinity of the pipe, the depth of the pipe and whether the pipe has been cleaned.

Of the 34 manhole pipe entries (MH Entry) electro scan showed 30 to be defective compared with one observed by CCTV. For this set of pipe segments the MH Entry pipe defects were generally the largest defects. This shows that an assessment of potential infiltration sources based only on CCTV would not have included the major source of infiltration/exfiltration.

Electro scan showed 42 defective taps compared with 45 observed by CCTV. This is considered a very close comparison especially since electro scan does not claim to be highly reliable at identifying an electro scan anomaly as due to a tap. It is likely that a number of defects identified as pipe defects by electro scan were in fact defective taps

Pipe	CCTV					Electro Scan					
Segment	Joints	Taps	Pipe	MH	Total	Joints	Taps	Pipe	MH	Total	Diff
095 to 094	7		1		8	23	1	4	2	30	375%
096 to 095	3	10	4		17	5	6	5	2	18	106%
102 to 101	1	1	2		4	4		2	2	8	200%
103 to 102					0	5	5	1	2	13	N/A
104 to 102	1	5	2		8	5	1	3	2	11	138%
106 to 105	2		4		6	9		1	1	11	183%
107 to 106			1		1	3		7	1	11	1100%
114 to 107	1	3	1		5	11	2	5	2	20	400%
115 to 114		2	1		3	14	4	3	2	23	767%
116 to 115	3	6	7	1	17	7	2	4	2	15	88%
117 to 116	1	1	3		5		2		1	3	60%
118 to 117	3	3	5		11	2	4	2	2	10	91%
119 to 118		3	4		7	3	2	3	2	10	143%
120 to 119	2	3	4		9	6	4	1	1	12	133%
125 to 116		3	2		5	17	3	3	2	25	500%
127 to 125	1	3	3		7	7	4	4	2	17	243%
128 to 127	1	2	2		5	4	2	4	2	12	240%
Total	26	45	46	1	118	125	42	52	30	249	211%
Diff						481%	93%	113%	3000%	211%	

 Table 5. Comparison of the Number and Type of Pipe Defect

As a means of comparing the severity of the pipe defects observed by CCTV and those measured by electro scan the OPRI compiled according to the PACP method (NASSCO 2001) and the DFes per 100 ft of pipe for water table 12 in above the pipe are shown in Figure 3. The comparison shows that different pipe segments as the major contributors to potential leakage. The OPRI shows that pipe segments 107 to 106 and 125 to116 have the highest value and pipe segments 103 to 102 and 095 to 094 have the lowest value. The electro scan DFes per 100 ft shows that pipe segments 096 to 095 and 118 to 117 have the highest value and pipe segments 107 to 106 and 117 to 116 have the lowest value. The pipe segment 107 to 106 has the highest OPRI and the lowest DFes per 100 ft. Examination of the PACP codes for this pipe segment shows that it has one Grade 5 defect.

Since the DFes per 100 ft takes into account many more defects that can leak, if not all of them, than CCTV, it can be reasonably assumed that electro scan provides a much more reliable diagnostic for potential RDI than CCTV.



Figure 3. Comparison of the Defect Flow per 100 ft of Pipe with the Overall Pipe Index for Defects that are Potential Leaks

SUMMARY AND CONCLUSIONS

From the measured flow from 0.635mm (0.25 in) slots with a 3089mm (12 in) head of water and with the assumption of a 12 in head of water above the center line of an empty pipe the flow through the defect (DFes) has been calculated from the increase in the electro scan defect current with an error of about +/- 40%. This calculation of flow will be lower than actual if the average width of the pipe defects is greater than 0.635mm (0.25 in).

The DFes has been used to estimate the total potential RDI for a pipe segment or the potential RDI per 100ft of the pipe segment. The DFes can be calculated from pipe segment electro scans using a commercially available computer application such as the cloud application Critical SewersTM available at www.electroscan.com.

For the USEPA study the CCTV production rate was 250 ft/hour compared with 339 ft/hr for electro scan or 36% greater. The CCTV cost was \$2.8/ft compared with \$2.00/ft for electro scan or 29% lower.

For each CCTV defect that was categorized as a potential leak the electro scan was examined to determine if an electro scan defect was also shown at the same location (See Table 4). This defect by defect comparison showed that electro scan identified pipe defects at 82% of the pipe defects shown by CCTV. This high degree of co-incidence showed electro scan to be a reliable indicator of pipe defects that are potential leaks.

With regard to sewer pipe defects that can leak, the data collected by the USEPA field demonstration showed that: electro scan identified 2.1 times more defects than CCTV including

4.8 times more joint defects, 30 times more defective manhole to pipe joints; and many of the leaky defects missed by CCTV were the largest sources of potential infiltration.

The distribution of the leak potential assessment of the individual pipe segments by electro scan, DFes per 100 ft, was significantly more variable than that shown by OPRI. These results reveal the potential of DFes to target and design rehabilitation projects that could significantly reduce RDI at considerably lower cost. Because of its more reliable identification and quantification of defects that can leak, electro scan is also an effective tool for quality assurance of rehabilitation projects as well as new pipeline construction.

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