OUTCOMES FROM A SEWER MAINTENANCE BACKLOG INVESTIGATION

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ABSTRACT

It is well known that in the past the level of expenditure on the maintenance of existing infrastructure in municipalities has been too low, resulting in the deterioration of the infrastructure condition. It has become evident that municipalities need to focus its maintenance expenditure on those assets that need it most, and also to quantify the extent of maintenance required, so that appropriate planning and budgeting can be implemented to address the backlog.

At the end of 2011 Phase Two of a six year maintenance backlog investigation on the sewerage network of Nelson Mandela Bay Municipality (NMBM) was concluded. The challenge was to conduct an accurate analysis of the infrastructure network in terms of Scope, Risk and Cost and to correctly allocate priorities for the systematic eradication of the maintenance backlog.

The approach taken was a theoretical model in combination with a physical inspection. The theoretical model involved the development of a GIS based IT tool using the characteristics of each sewer to predict the risk of sewer failure, thereby calculating an Inspection Priority. The physical inspection involved a condition assessment of the Priority sewers in order to verify or improve the theoretical model, and was carried out by CCTV survey. The result was a planning tool which can be used to budget and programme for further investigation, preventative maintenance and backlog elimination.

1. VIEWS OF INFRASTRUCTURE BACKLOG

1.1 The Need for Maintenance of Infrastructure and Backlog Eradication

The provision of basic sanitation can be summarized as a system for disposing of wastewater which is acceptable and affordable to the users, safe, hygienic and easily accessible, and which does not have an unacceptable impact on the environment.

It is well known that in the past the level of expenditure on the maintenance of existing infrastructure in municipalities has been too low, resulting in the deterioration of the infrastructure condition. An increasingly high number of sewer failures are occurring within municipalities which cause blockages in pipelines, surcharging of manholes, flooding of community areas and leads to degradation of neighbouring services. These occurrences are extremely disruptive to the public, have a negative effect on the environment and create unsafe and unhygienic living conditions in communities.

One of the most serious problems that can occur as a result of sewer failure is the development of sinkholes that could result in damage to property and threaten public safety. The consequences of a sewer failing are progressive:

• Groundwater pollution
• Bedding support lost
• Infiltration and hydraulic overloading
• Void formation (sinkholes)
• Overloaded pipes collapse
• Voids collapse as sinkholes

Sewer failure generally starts with poorly made joints or joints that become defective during service and start leaking. At high flows the effluent leaks from faulty joints saturating the surrounding soil. At low flows the groundwater infiltrates into the sewer and brings bedding material

with it, thus reducing the support around the sewer, the formation of cavities and the structural collapse of pipes or the 'day lighting' of the cavities through to the surface as sinkholes.

This problem is extremely disruptive as the entire network upstream of the localised collapse is put out of action. It is also very costly, because the entire section of sewer where the collapse had occurred would need to be replaced or re-lined with a structural trenchless rehabilitation system which is expensive compared to preventative maintenance.

Figure SEQ Figure * ARABIC 1: Signs of a leaking sewer pipe

Figure SEQ Figure * ARABIC 2: Erosion due to a collapsed sewer

Figure SEQ Figure * ARABIC 3: 'Day lighting' of the cavities

1.2 Current Maintenance Backlog in the NMBM

The assessment of the Maintenance Backlog of the NMBM sewerage infrastructure was initiated by the Municipality's Planning and Research Silo. NMBM appointed local engineering consultants to devise a method of assessing the backlog, to physically assess the backlog, and to report the findings of the assessment.

To date, municipal engineers have quantified the sewer backlog by empirical methods. The approved maintenance budgets have been subtracted from the proposed maintenance budgets, and the difference between the two has been quantified as the backlog on a cumulative basis:
• Proposed Budget – Approved Budget = Backlog

Although this approach provides a reasonable estimate of the magnitude of the backlog, it does not provide an approach that identifies the worst areas nor does it provide a programme to which the backlog should be eliminated.

Since the approved maintenance budget has consistently been less than the proposed maintenance budget, it follows that there should be a significant backlog in maintenance. This backlog has led to a re-active approach to maintenance, meaning that municipal maintenance teams tend to "fight fires" rather than carrying out routine, preventative maintenance in a systematic, controlled manner that prolongs the lifespan of infrastructure. The procedures followed to date further do not provide an indication of the risk to the health and safety of the people and environment in the Metro should any of the components in the sewer system fail.

1.3 An improved Assessment of Maintenance Backlog

It is clear that a more suitable and comprehensive assessment of infrastructure condition and maintenance requirements is needed. For this reason the objective of this investigation was to conduct an assessment of the sewerage network maintenance backlog, to quantify the magnitude of the backlog in terms of Scope, Risk and Cost, and to prepare a programme for the systematic elimination of the backlog.

The Geographical area that was covered in this investigation is the area of jurisdiction of the NMBM, and included the following drainage areas:
• Despatch
• Uitenhage
• Kwanobuhle
• Port Elizabeth.

2. METHODOLOGY

2.1 Prioritisation of sewers

In order to prepare a programme for the systematic elimination of the backlog a method was needed to focus the maintenance expenditure on those assets that need it most. A prioritisation of the existing sewerage network was required.

From literature reviews it became clear that international methodologies focused mostly on assessment of sewer condition by Closed Circuit Television Camera (CCTV) survey. Very little has been published on the pre-CCTV stage, presumably because the authorities and utilities that publish their work have the financial resources to survey all or most of their infrastructure, thereby eliminating the need to identify those sewers that need to be surveyed and those that do not.

Due to financial constraints it is not possible to CCTV all the existing infrastructure in South Africa. Therefore, another method for identification of critical sewers was required. Two methods were identified that authorities used in the past to classify sewers:
1. Probability of failure
2. Consequence of failure

The aim of the first method is to identify those factors that contribute to a sewer failure. Identification is followed by an empirical prioritisation of the factors in order of their contribution towards failure and can then be used to predict the probability of failure of the sewer. Examples of critical factors that affected the probability of failure are:
• Age
• Depth

The second method endeavours to identify those sewers that, should failure occur, would result in the most severe consequential disruption to the public and property, and would incur the greatest rehabilitation cost. Examples of critical factors that affected the consequence of failure are:
• Diameter
• Type of effluent

In the past only one of the two methods has been used. It was decided that this investigation should combine the two methods to assess the existing condition of the sewer network holistically, and to focus the inspection, maintenance and rehabilitation programmes and budgets where most needed, i.e. in those areas where failure is imminent which would result in severe disruption to the public and/or damage to property.

The approach was initially to determine the sewerage maintenance backlog by means of a theoretical approach. During the early stages of the investigation, it was realised that although the theoretical approach is necessary to identify the highest risk sewers, the theoretical approach alone is inadequate for a meaningful assessment of the sewerage network condition. It was then decided that the theoretical approach would need to be combined with a physical inspection of the highest risk sewers in order to verify or improve the theoretical model, so that an accurate condition assessment could be carried out. This physical inspection is discussed further under Section 2.3.

2.2 Theoretical approach

The theoretical approach involved the development of a GIS based IT tool called the Sewer Maintenance Planner (SMP) specifically for this project. The software was developed using Borland C++ and runs under the Windows operating system platform and operates directly on the Arcview Sewer database of the Nelson Mandela Metropolitan Municipality.

The SMP uses the characteristics of each sewer to predict the risk of sewer failure. It does this by calculating a Probability Index and a Consequence Index. These two indices are then plotted on a two dimensional matrix, and the point where the two indices meet on the matrix determines the sewers Inspection Priority. The Inspection Priorities are then grouped together to allocate the sewer into a risk category. This process is illustrated in the flow chart below.
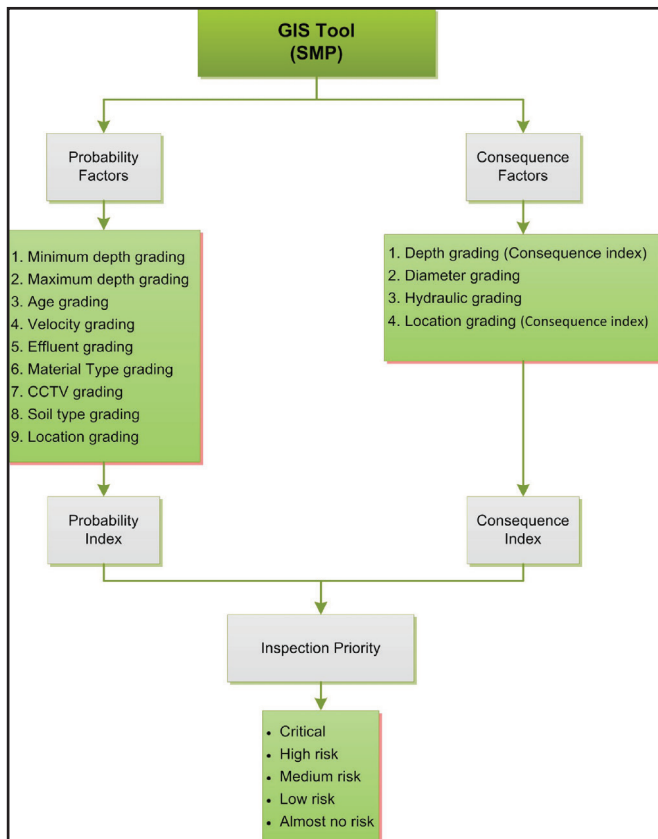
Figure SEQ Figure * ARABIC 4: Methodology for Priority Identification

The Index of each sewer is calculated by grading the individual factors that affect the probability and the consequence of failure of each sewer. These factors are:

Probability Factors:
• Minimum depth
• Maximum depth
• Age
• Velocity
• Effluent type
• Material type
• CCTV score
• Soil type.
• Location relative to a siphon, rising main or gravity main.

Consequence Factors:
• Depth (Consequence index)
• Diameter grading
• Hydraulic load
• Location (Consequence index)

Each of these factors has been graded on a scale of 0-10 for each sewer, and this is the basis on which the Probability Index and Consequence Index is determined. In order to grade these factors, various field inspections were carried out to "calibrate" the SMP. These field inspections included:
• Pipe sample surveys
• Manhole inspections
• CCTV survey (Pilot Study)
• Interviews of NMBM officials and staff
• Collection and scanning of drawings
• Dredging records

These two indices are then plotted on a two dimensional matrix, and the point where the two indices meet on the matrix determines the sewers Inspection Priority, on a scale of 1-16, with 1 being the highest priority.

It would be unwise to use the inspection priority as a condition assessment, because it is merely a method to theoretically calculate the probable status of a sewer condition. As the GIS database is incomplete, actual information of the sewers is lacking. There simply is no better means of assessing the condition of a sewer than to survey it with a CCTV camera and conduct a physical inspection. The inspection priority is therefore used to prioritise the inspection of sewers.

Obviously sewers with a very high probability of failure and catastrophic consequence of failure need to be inspected before any other sewer. Hence an Inspection Priority of 1 is the highest priority and an Inspection Priority of 16 is the lowest priority. This can be seen in a matrix format as shown below.
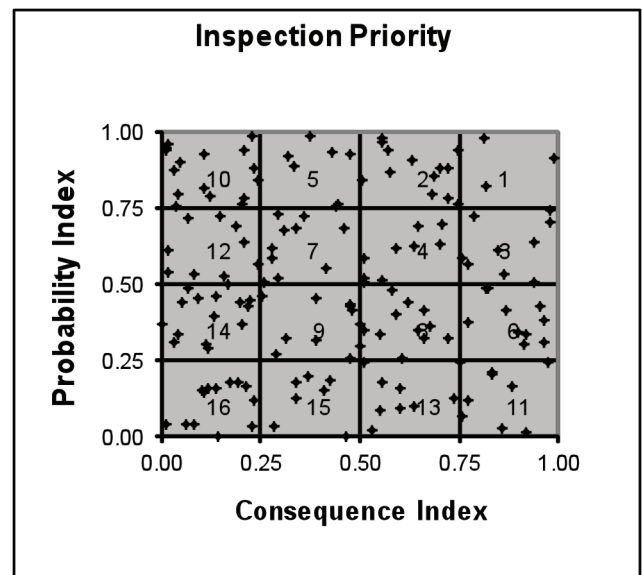

Figure SEQ Figure * ARABIC 5: Inspection Priority Matrix

Each dot in Figure 5 above represents a sewer between two manholes. It illustrates several advantages of using the matrix approach:
• The contribution of both probability and consequence of failure are shown
• Any patterns that have developed along a sewer can be seen
• By using different colours and symbols several sewers can be represented on a single figure
• The various sewers (and sections along them) can be compared on a relative basis.

Inspection Priorities can be further grouped into Risk Categories as shown in Table 1 and 2 below.

Table SEQ Table * ARABIC 1: Risk Categories

Probability Index	Consequence Index					Inspection Priority
	Negligible (>0)	Manageable (>0.25)	Serious (>0.5)	Catastrophic (0.75)		
Very High (>0.75)	10	5	2	1		Critical
High (>0.5)	12	7	4	3		High Risk
Medium (>0.25)	14	9	8	6		Medium Risk
Low (>0)	16	15	13	11		Low Risk
						Almost no Risk

This Risk Category was used to plan CCTV survey operations, i.e. critical sewers done in the first year, followed by high risk sewers, and so on.

2.3 Physical inspection

The physical inspection involved a condition assessment of the Critical and High risk sewers and was carried out by CCTV survey. The length of lines identified under these risk categories by the theoretical approach summed to approximately 700 km.

Table SEQ Table * ARABIC 2: Priority Percentages and Length of Sewer (all diameters)

Risk Category	Inspection Priority	Length (m)	% of Total
Critical	1, 2, 3	148435	3.7%
High risk	4, 5, 6, 10	586498	14.81%
Medium risk	7, 8, 11, 12	831488	20.99%
Low risk	9, 13, 14	2081614	52.55%
Almost no risk	15, 16	315077	7.95%
		3961091	100%

The CCTV survey was conducted by a pipe surveying contractor and was concluded over a period of three years. As it was not possible to survey all the prescribed lines in the given timeframe, it was decided to focus on the larger diameters first and to move to the smaller diameters as the project progressed.

At the end of the three year period, a total of 380 km was surveyed by means of CCTV. This represents approximately 53.7% of the original network identified for survey, and approximately 10% of the total length of the sewerage network in the NMBM (which equals approximately 3961km). Information gathered from the CCTV inspection provided a true reflection of the condition of pipes.

Figure SEQ Figure * ARABIC 6: CCTV Photo 1

Figure SEQ Figure * ARABIC 7: CCTV Photo 2

Results from the CCTV condition assessment were then used to verify or improve the parameters of the theoretical model, and in certain cases correct wrongly recorded data. In addition, due to the continued clean-up of the NMBM Sewerage GIS data sets, the vast majority of the NMBM sewer data fields were populated and could therefore be used to improve the SMP accordingly.

3. OUTPUTS FROM THE INVESTIGATION

The output from the theoretical model, after calibration and improvement by CCTV inspection, provides a more feasible condition assessment of the infrastructure network than was ever available before. Using this information, not only can the maintenance backlog be quantified, but costs can be broken up according to risk categories, thereby providing a clear indication of priority and budget required to repair/replace those assets that need it most in the Metro's sewer network.

3.1 Quantifying the Backlog

The replacement value can be defined as the estimated cost of replacing the asset at current prices. It does not imply that the asset must be replaced but merely gives an indication of the value of assets. The replacement value for the sewerage network was determined by the summation of all the items required to construct new sewers.

REPLACEMENT VALUE OF SEWER INFRASTRUCTURE BY RISK CATEGORY (R)

Table 3: Total Replacement Value by Risk Category

REPLACEMENT VALUE OF SEWER INFRASTRUCTURE BY RISK CATEGORY (R)			
Risk category	Total of Sewer Reticulation	Syphons / Rising mains	Manholes	TOTAL
Critical	R36.993.679.80	R1.863.644.91	R22.081.167.86	R80.938.492.18
High	R194.490.545.28	R9.797.421.69	R116.080.546.54	R320.081.513.51
Medium	R200.184.510.80	R10.235.904.73	R121.278.858.93	R334.899.274.45
Low	R415.299.184.11	R20.921.608.32	R247.887.436.20	R684.107.206.63
Almost no risk	R431.482.216.45	R21.735.909.04	R257.535.601.88	R710.733.757.37
TOTAL	R1.281.419.116.24	R64.554.546.70	R764.866.811.20	R2,110,840,274.14

The maintenance backlog for the sewerage network is based on empirical best estimates of 1% of the replacement cost per annum. Adopting this approach over a five year backlog eradication programme implies that the backlog amounts to 5% of the replacement value. This figure was found to be consistent with the backlogs for Wastewater Treatment Works, sewage pump stations and the water service infrastructure.

Table 5: Repair Cost Estimation

Sewer Backlog	Total Sum of Repair Cost	Total Sum of Estimated Replacement Value	Repairs as % of Replacement Value
Pump Station	R29.725.320.00	R120.724.600.00	24.62%
Sewer Reticulation	R389.102.138.24	R2.110.840.274.14	18.43%
Wastewater Treatment Works	R142.752.104.10	R1.979.608.789.00	7.21%
Grand Total	R561.579.562.34	R4.211.173.663.14	13.34%

3.2 Planning tool for systematic backlog eradication

Since it is physically and financially impossible to inspect each sewer in the NMBM area and to assess their condition based on a CCTV survey, the Sewer Maintenance Planner has been used in the interim to identify sewers that have the highest priority to be surveyed. The result from the physical study provides a database of CCTV line surveys. Each drainage area can be broken down into:
• Lines surveyed by CCTV
• Video footage of pipes inspected
• Manhole to manhole incident reports
• Line reports summarising the condition of the pipeline
• Rehabilitation recommendations.

Figure 8: Inspection Report

Line Report

REDHOUSE - P.E. (Perseverance)

Sewer Line 121

Pipe details

Diameter	Inspected Length	Material	Pipe Position
400mm	407.72	CONCRETE	VELD

Pipe Condition

1. Severe pipe corrosion to pipe invert
2. Critical pipe corrosion at some changes (see CCTV pipe inspection reports)
3. Moderate obstruction
4. Moderate root intrusion
5. Minor fatty deposits

Recommendation

This pipe is in a poor condition and it is recommended that this pipe be replaced.

From this database of verified sewer lines implementation strategies can be drawn up for the rehabilitation of the critical sewer lines. The maintenance requirements that have been identified in this assessment are corrective maintenance, or maintenance that is necessary to repair /replace defective infrastructure. This is different from preventative or routine maintenance that is carried out on a routine basis to maintain the current condition of infrastructure and to lengthen its useful life.

It must therefore be appreciated that the budgets presented in this report are over and above the Municipality's existing maintenance and operations budget.

4. CONCLUSION

A significant backlog in the maintenance of the sewerage network has developed. It is necessary to eradicate the backlog in a project based, systematic manner to avoid the failure of infrastructure with an ever increasing risk of sewer service failures.

A detailed theoretical approach to establishing the maintenance backlog has been undertaken. This study has revealed that a reliable condition assessment cannot be carried out on a theoretical approach alone, and that it must be supported with a CCTV survey and physical inspection of identified sewers.

The SMP is a useful planning tool that should be used to plan CCTV survey, routine dredging, routine maintenance and to identify trouble spots before they manifest themselves.

The GIS database must be updated. The flow of information from the NMBM field operatives (track inspectors, superintendents) to management needs to be reviewed and formalized, to improve the quality of information needed for backlog assessment and decision making purposes.

The eradication of the maintenance backlog of the sewerage network should be carried out according to the following procedure:

a) Identify sewers to be CCTV surveyed with the SMP tool, dredging recommendations and blockage recommendations.
b) CCTV survey of the sewers identified in (a) above
c) Use the CCTV reporting and condition grading to identify the sewers that need rehabilitation
d) Inspect the CCTV footage, inspect the actual line and, review the record drawings to determine the origin, location, extent and severity of the defects:
e) Determine the most suitable method of rehabilitation
f) Call tenders for the rehabilitation of the sewers
g) Update the sewer database on completion of the rehabilitation
h) Repeat the procedure from a) above.