PAPER 10

Proactive and Prioritized Stormwater Drainage Maintenance and Management System

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ABSTRACT

Municipalities are challenged with increasing maintenance costs and budget constraints for the upgrading of municipal services such as roads and stormwater. This has again been highlighted by several flood events during the rainy season causing significant damages to roads, property as well as loss of life. A further aggravating factor is climate change which is causing more sporadic as well as intensive storm events.

The lack of maintaining existing stormwater drainage systems has a significant effect on the drainage system capacity due to blockages and siltation causing excessive runoff on roads which are severely damaged by erosion. Furthermore, the increased urbanisation and densification causes a significant increase in surface runoff which existing drainage systems can no longer accommodate.

A recent project involving a Stormwater Master Plan for Alexandra in the City of Johannesburg has highlighted the need for planned and regular maintenance of stormwater systems as well as upgrading of under capacity drainage systems to prevent excessive and uncontrolled flooding. The stormwater master plan included the visual condition assessment and survey of the existing stormwater drainage system, hydrological modelling and developed a unique and practical approach using a prioritisation algorithm to identify and prioritise the flooding problems and required maintenance activities schedules.

This paper presents a case study which highlights the implications of not maintaining stormwater drainage systems as well as the excessive capital cost required to now replace and upgrade the drainage system which could have been prevented by carrying out regular maintenance. The paper also presents a unique developed algorithm that can be used in prioritising maintenance activities for improved forward planning, budgeting and service delivery.

1. INTRODUCTION

It has been observed over the past few years that weather patterns have changed which causes more sporadic and more intense rainfall events within South Africa as well as other continents. In view of this stormwater drainage systems have become more important to drain excess stormwater and to be fully functional.

A shortcoming often encountered in South Africa is the failure to budget and carry out maintenance of stormwater networks of both artificial as well as natural drainage systems. Artificial drainage networks comprising of kerb inlets , grid inlets ,pipes and culverts. Natural drainage networks mainly comprise streams, rivers and tributaries which receive stormwater from the artificial drainage networks.

An example of a typical urban drainage network is shown in Figure 1.

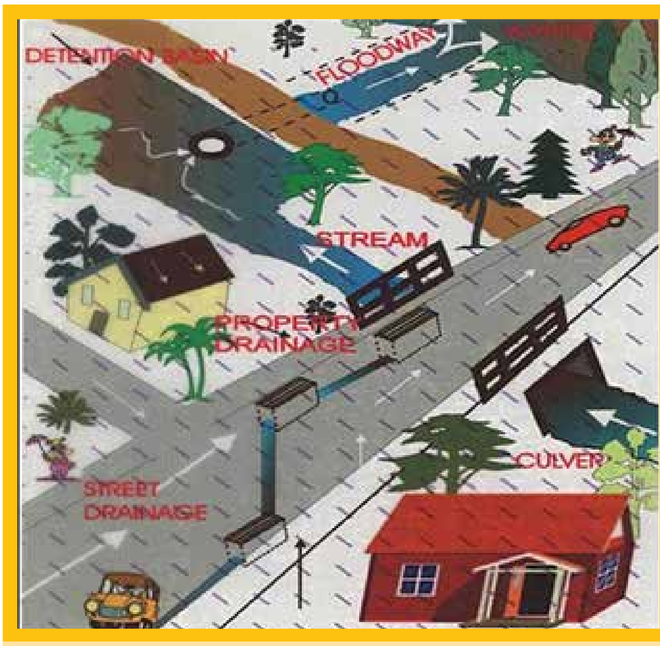

FIGURE 1: Typical urban artificial and natural drainage networks

If the drainage networks are not regularly maintained the hydraulic capacity is significantly reduced and hence flooding of developments and infrastructure occurs. This often causes damage to property as well as liability claims against a municipality.

Therefore, a proactive and prioritised maintenance system has been developed to assist a municipality in able better planning and managing maintenance activities thereby minimising the risk of flooding and potential liability claims. The approach and methodology as well as an example of the prioritization system is discussed and illustrated below.

2. PROACTIVE AND PRIORITISED STORMWATER DRAINAGE MAINTENANCE SYSTEM

A municipality is usually challenged with an insufficient maintenance budget as well as not knowing where urgent and important maintenance activities are required within a municipal area. This in turn causes a reactive rather than a pro-active approach to maintenance activities. ie. Once flooding problems and /or flood damage has occurred emergency maintenance activities are carried out. This is often costly as well as unplanned and in large storm event can cause severe damages to infrastructure and even cause loss of life.

Maintenance activities would typically comprise of cleaning kerb and grid inlets, opening manholes to remove debris and silt from an underground pipes or culverts, removing debris and excessive vegetation from road crossings. A prioritised stormwater maintenance system using a customised algorithm has been developed in order to guide a municipality and maintenance depot to proactively carry out maintenance activities in high priority areas prior to storm rainfall event causing flood damage.

2.1 Drainage network asset register

It is important that a municipality has an up-to-date asset register of the existing drainage network. It has been found that asset registers are usually outdated and/or don't have sufficient detailed information of the drainage network members. This often leads to information gaps which prohibit a detailed assessment and determination of the required maintenance activities. It was found that most stormwater drainage asset registers give the locality and type of a drainage system member but lack in defining the size of the member as well as the invert levels and gradients of underground pipes and culverts.

An asset register should at least have the following information:

a) Pipe/culvert network:

- Geo-referenced member locality, member type (pipe /culvert / channel), member material (concrete, masonry, brick);
- Member condition (functional, partly functional, broken), member size (diameter, width, depth);
- Invert level at start and end of member;
- Member length

b) Kerb and grid inlets

- Geo-referenced locality, grid dimensions (width, length);
- Kerb inlet type (transition, no transition), kerb inlet opening width and height.

An example of the typical drainage network asset register is given in Table 1 below.

2.2 Drainage network member size

A factor, which influences the risk of potential blockage, is the drainage member size. It has been established from both site observations as well as laboratory testing that the smaller the member diameter or cross section the higher the risk of blockage due to siltation and debris.

2.3 Drainage network hydraulic characteristics

An important factor that determines the risk of sedimentation and blockage within a pipe or culvert network is the gradient of the member as well as expected flow velocity. This is important as the flatter the gradient the lower is the flow velocity and hence a higher risk of blockage. It is furthermore

TABLE 1: Drainage network database

Conduit names and manhole references						Existing Main member			
Conduit Name	Inlet (manhole)	Inlet (Invert)	Outlet (manhole)	Outlet (Invert)	Length (m)	Gradient (%)	Type: pipe (P), Box culvert (BC), Channel (CH)	No Of	Diam (survey)
C5-5	N5-10	1498,981	N5-5	1498,925	13,46	0,42%	P	1	450mm Class 75D
C5-10	N5-15	1499,217	N5-10	1498,981	57,314	0,41%	P	1	450mm Class 75D
C5-15	N5-20	1499,501	N5-15	1499,217	68,018	0,42%	P	1	450mm Class 75D
C5-20	N5-25	1503,469	N5-20	1499,501	34,723	11,43%	P	1	650mm Class 75D
C5-20.1	N5-45	1501,438	N5-20	1499,501	31,143	6,22%	P	1	650mm Class 75D
C5-25	N5-30	1511,66	N5-25	1503,469	114,366	7,16%	P	1	700mm Class 75D
C5-30	N5-35	1514,87	N5-30	1511,66	57,904	5,54%	P	1	825mm Class 75D
C5-35	N5-40	1518,052	N5-35	1514,87	52,514	6,06%	P	1	450mm Class 75D
C5-05.1	N5-5	1498,925	05-1	1498,641	45,78	0,62%	p	1	450mm Class 75D
C5-50	N5-55	1500,89	N5-50	1500,438	14,799	3,05%	P	1	750mm Class 75D
C5-50.1	N5-95	1501,063	N5-50	1500,438	38,241	1,63%	P	1	625mm Class 75D
C5-55	N5-60	1502,392	N5-55	1500,89	36,485	4,12%	P	1	900mm Class 75D
C5-60	N5-65	1503,005	N5-60	1502,392	8,457	7,25%	P	1	450mm Class 75D
C5-60.1	N5-140	1502,517	N5-60	1502,392	11,857	1,05%	P	1	450mm Class 75D
C5-65	N5-70	1505,024	N5-65	1503,005	44,255	4,56%	P	1	450mm Class 75D
C5-70	N5-75	1506,071	N5-70	1505,024	27,616	3,79%	P	1	450mm Class 75D

TABLE 2: Minimum gradients for concrete pipes

Pipe Diameter (mm)		Minimum slope (%)	
Nominal	**Inner**	**Full-flow**	**25% flow**
450	0.445	0.48	0.23
525	0.514	0.39	0.19
600	0.585	0.33	0.16
675	0.647	0.29	0.14
750	0.718	0.25	0.12
825	0.788	0.22	0.11
900	0.853	0.20	0.10
1050	0.986	0.17	0.08
1200	1.127	0.14	0.07
1350	1.262	0.12	0.06
1500	1.383	0.11	0.05

shown that once the gradient is below a minimum threshold there is a high risk of sedimentation. Typical minimum gradients for different pipe concrete pipe diameters are given in Table 2.

The hydraulic characteristics of the drainage network can be determined by two possible methods as described below.

2.3.1 Hydraulic characteristics - existing stormwater master plan

If an existing stormwater master plan exists relevant details of the drainage member size, gradient and flow velocity should be readily available. This data can then be extracted and used for determination of the hydraulic characteristics of the existing drainage network.

2.3.2 Hydraulic characteristics - additional hydraulic modelling

If no stormwater master plan exists a hydraulic assessment of the existing drainage network can be carried out by setting up a hydraulic model. The information of the existing drainage network could be obtained from the asset register, where available. The hydraulic model can then be used to establish the expected flow velocities in each of the network members based on the member's size and gradient.

2.4 Road network type and land-use

It has been observed from previous studies that the road type and land-use has a significant impact on the risk of blocking a stormwater drainage network. This is caused by sediment being transported during a storm event which then enters the drainage network via kerb and grid inlets. In view of this a drainage network in a rural area, which is mainly unpaved, will have a higher risk of blockade than in a paved area and hence will have a higher maintenance requirement.

2.5 Prioritisation Algorithm

A prioritisation algorithm has been developed which assists the municipality in carrying out maintenance in a proactive manner rather than reactively. The prioritisation algorithm takes into account five indicators that have an impact on the potential risk of blocking a drainage network and hence are used to prioritise the drainage network reaches that need proactive maintenance.

The following indicators are taken into account:

i. Drainage member size, member gradient, member flow velocity, road type, land-use type.

The prioritisation algorithm now takes into account each of the above

TABLE 3: Drioritisation indicators and weighting

Item	Indicator category	Description	Weighting
1	Member size (mm)	< 300	15
		375-400	12
		450-525	10
		600-750	8
		800-950	6
		1 050-1 200	4
		1 350-1 500	2
		>1 500	1
2	Member gradient (%)	0-1	25
		1-2	20
		2-3	15
		3-4	10
		>4	5
3	Flow velocity (m/s)	<0,5	35
		0,5-1,0	30
		1,0-2,0	25
		2,0-3,0	20
		3,0-4,0	15
		>4,0	10
4	Road type	Gravel (unpaved)	10
		Sealed (dust suppression)	7
		Brick	5
		Paved/Asphalt	1
5	Development	Informal	15
		Business/ Commercial/ Industrial	10
		Urban (semi-formal residential)	5
			2

indicators as well as a weighting of the indicator in causing blockage and sedimentation within a drainage network reach. Each defined indictor and associated weighting is summarised in Table 3 below.

Having defined the above indicators and weighting the blockage potential for a drainage network member, which is a numeric indicator of the expected blockage potential can be calculated using the equation (1) below.

$$Blockage\ potential_{\ member} = (Member\ size_{\ weighting}) + (Member\ gradient_{\ weighting}) + (Member\ flow\ velocity_{\ weighting}) + (Road\ type_{\ weighting}) + (Development_{\ weighting}) \quad (1)$$

Having now defined the blockage potential of existing drainage network members allows one to obtain a range of blockage potentials. This indicator is now used to define the maintenance priority as given in Table 4.

3. ALEXANDRA TOWNSHIP CASE STUDY

The above approach was applied and successfully used in a project undertaken in the Alexandra township within the Johannesburg City area. Details of the study and findings as well as recommendations are given below.

3.1 Study objective

The main objective of the study was to carry out a Stormwater Master Plan of the Alexandra township. This was required in order to analyse the existing drainage network as well as define required upgrading measures .As part of the Stormwater Master Plan the current blockage of the drainage network was investigated and planned future maintenance activities were identified . A further objective was to identify the cost implications relating to unblocking of the drainage network in relation to capital costs for having to replace the blocked and damaged drainage network.

3.2 Study area

The study area is situated within the Alexandra township as shown in Figure 2 below.

FIGURE 2: Study area locality

3.3 Existing drainage system details and condition

As part of the investigation a detailed survey and visual inspection of the existing drainage network was undertaken and an asset register developed. From this assessment it was established that about 80% of the drainage network was blocked with debris and silt.

The blocked drainage network could no longer be easily cleaned and would mostly have to be replaced.

Typical details of the existing drainage network members are shown in Table 5.

TABLE 5: Typical condition of existing drainage networks

3.4 Study approach and findings

Once the asset register was completed a hydrological model of the drainage catchments as well as a hydraulic model of the existing drainage network was compiled for the study area. From the modelling data the following information was abstracted for use in the blockage prioritisation algorithm:

i. Network member size, member gradient, member flow velocity, road and development details.

TABLE 4: Maintenance priority

Maintenance priority	Blockage potential
Very high (VH)	100 - 75
High (H)	74 - 60
Medium (M)	59 - 40
Low (L)	< 40

By now applying the indicator categories and weighting factors to each of the drainage network members the expected blockage potential has been determined. Once the blockage potential was determined the maintenance priority was established based on the ranges and categories given in Table 4.

The results are shown in Table 6.

The results of the prioritisation algorithm are shown graphically on Figure 3.

FIGURE 3: Map showing locality of prioritised maintenance requirements

3.5 Financial implications

It could be shown that there is a substantial financial implication if drainage networks are not regularly maintained. This is due to drainage networks becoming fully blocked which prohibits cleaning of the pipes both by mechanical and/or jetting operations. This in turn necessitates the removal of the drainage network which then needs to be replaced by a new network.

From the case study the following was established:

i. An annual operating cost of R400 000 would be required to regularly maintain the drainage network that was investigated;

ii. Due to the severe blockage the drainage network now has to be replaced at a capital cost of R60 million which is substantially more than the operating costs

4. CONCLUSIONS

The following is concluded:

i. Drainage network asset registers often do not have sufficient information;

ii. Existing drainage networks do not get maintained causing a significant decrease in hydraulic capacity;

TABLE 6: Drainage network blockage potential and maintenance priority

Conduit reference	Network characteristics						Blockage indicators					Maintenance prioritisation	
Conduit Name	Length (m)	Gradient (%)	Pipe Diam (mm)	Flow velocity (m/s)	Road type	Development	Weighting factors					Blockage potential rating	Maintenance category
							member size	member gradient	flow velocity	road type	Development		
C5-5	13,46	0,42%	375mm Class 75D	0,6	paved	formal residential	12,00	25,00	30,00	1,00	2,00	70,00	H
C5-10	57,314	0,41%	450mm Class 75D	0,55	paved	formal residential	10,00	25,00	30,00	1,00	2,00	68,00	H
C5-15	68,018	0,42%	450mm Class 75D	0,7	paved	formal residential	10,00	25,00	30,00	1,00	2,00	68,00	H
C5-20	34,723	11,43%	650mm Class 75D	3,5	gravel	formal residential	8,00	5,00	15,00	1,00	2,00	31,00	L
C5-20.1	31,143	6,22%	650mm Class 75D	2,8	gravel	semi-formal residential	8,00	5,00	20,00	10,00	5,00	48,00	M
C5-25	114,366	7,16%	700mm Class 75D	3,6	gravel	semi-formal residential	8,00	5,00	15,00	10,00	5,00	43,00	M
C5-30	57,904	5,54%	825mm Class 75D	2,6	paved	business	6,00	5,00	20,00	1,00	10,00	42,00	M
C5-35	52,514	6,06%	450mm Class 75D	2,6	paved	business	10,00	5,00	20,00	1,00	10,00	46,00	M
C5-05.1	45,78	0,62%	450mm Class 75D	0,76	gravel	business	10,00	25,00	30,00	10,00	10,00	85,00	VH
C5-50	14,799	3,05%	750mm Class 75D	1,8	gravel	formal residential	8,00	10,00	25,00	10,00	2,00	55,00	M
C5-50.1	38,241	1,63%	625mm Class 75D	1,3	gravel	informal	8,00	20,00	25,00	10,00	15,00	78,00	VH
C5-55	36,485	4,12%	900mm Class 75D	2,7	gravel	informal	6,00	5,00	20,00	10,00	15,00	56,00	M
C5-60	8,457	7,25%	1 050mm Class 75D	3,8	gravel	informal	4,00	5,00	15,00	10,00	15,00	49,00	M
C5-60.1	11,857	1,05%	1 200mm Class 75D	0,9	gravel	informal	4,00	20,00	30,00	10,00	15,00	79,00	VH
C5-65	44,255	4,56%	1 200mm Class 75D	3,1	paved	formal residential	4,00	5,00	15,00	1,00	2,00	27,00	L
C5-65.1	45,099	3,94%	1 500mm Class 75D	2,8	paved	formal residential	2,00	10,00	20,00	1,00	2,00	35,00	L
C5-70	27,616	3,79%	900mm Class 75D	2,5	paved	formal residential	6,00	10,00	20,00	1,00	2,00	39,00	L

iii. Non maintained drainage networks cause flood damage and liability claims against a municipality;
iv. Maintenance activities are performed reactively without proper forward planning;
v. Existing blocked drainage networks can no longer be cleaned and need to be replaced at a high capital cost;
vi. There is usually insufficient information and forward planning of maintenance activities due to the lack of As-build information;
vii. A proactive and prioritized drainage network maintenance system has been developed based on an algorithm taking into account the locality, slope and size of members to assist municipalities in carrying out required proactive maintenance in areas with a high risk of blockage.

5. RECOMMENDATIONS

The following is recommended:

i. Drainage pipes be placed at gradients higher than the minimum gradients to reduce the risk of blockage;
ii. Drainage pipes to not have a dimeter less than 450 mm;
iii. The stormwater drainage system asset register and As-build details be kept up to date;
iv. Regular maintenance be budgeted for and carried out to prevent drainage networks from being totally blocked and needing replacement at a high capital cost;
v. The developed prioritised stormwater maintenance system be used to guide a municipality to carry out pro-active maintenance activities in areas with a high risk of blockage.

6. ACNOWLEDGEMENTS

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