

PAPER 16

IMPROVED MUNICIPAL STORMWATER AND FLOOD MANAGEMENT IN CHANGING CLIMATIC CONDITIONS

¹M. Braune, ² Munya Rupende

¹Pr Eng. MIMESA, MSAICE, Director, Bio Engineering Africa (Pty) Ltd

¹Engineer, Bio Engineering Africa Consulting (Pty) Ltd

²Engineering Technologist, BMK Group

1. ABSTRACT

The current urban environment is rapidly changing due to more high-density developments within municipal areas. Additional climatic changes and sporadic, more intense storm events have caused widespread flooding, damage to property and loss of life both locally and internationally. Combined with financial constraints this increases the pressure on municipalities to be more proactive in both preventing and improving stormwater drainage systems to become more resilient to climatic changes.

Several urban flood management and Stormwater Master Plans have been completed for various municipalities over the past few years. The studies involved the hydraulic as well as condition assessment of existing urban drainage systems consisting of box culverts, pipe culverts, kerb inlets and grid inlets. On completion of the existing hydraulic and condition assessments, hydrological models were set up to determine required design flows. Based on the design flows in comparison to the hydraulic capacity. Stormwater upgrading measures were determined and designed. Due to budget constraints upgrading measures needed to be prioritised and phased budget programs set up. One of the main findings was that the several underground drainage networks are under capacity mainly because of higher expected peak flows due to Climate change.

More importantly it was found that kerb inlets and inlet structures are of the incorrect type and often incorrectly sized to drain the excess stormwater from roads thereby already causing flooding. A further observation was that a large percentage of stormwater control structures are either blocked or damaged thereby aggravating the situation.

This paper presents findings of the Master Plan studies and gives guidance on how better to manage and be more resilient regarding the control of stormwater, considering climatic changes by setting up proactive maintenance schedules as well as prioritisation algorithms for forward planning of required upgrading measures.

2. INTRODUCTION

It has been observed over the past few years and in particular the rainy season of 2021/22 that weather patterns have changed which cause 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 prevent flooding and damage to property.

A shortcoming often encountered when planning urban developments is the lack of attention given to the drainage of stormwater once the development has been completed. A further shortcoming is defining upstream future urbanisation which causes an increase in stormwater

runoff along both natural as well as artificial drainage systems. This in turn causes an increase in the flood levels and hence a higher flood risk.

3. INTERGRATED STORMWATER MASTER PLANNING

It is of utmost importance to first carry out an integrated stormwater master plan (SWMP).

This is essential and gives a municipality the following important information:

- An As-built inventory of the existing drainage network structures.
- Information of the status quo regarding broken, blocked and/or functional drainage network structures.
- Information on the hydraulic assessment and capacity of the existing drainage network structures.
- Expected drainage network peak flow rates during storm events.
- Required shortcoming and upgrading measures of the existing drainage network capacity.
- Required maintenance activities such as cleaning and/or repairs needed to the existing drainage studies.
- Additional required drainage networks needed in areas having insufficient and/or non-existing drainage network.
- Capital budget estimates for both maintenance and well as stormwater drainage networks upgrading requirements.

3.1 Typical Urban Municipal Stormwater Drainage Network Control Structures & Findings

A typical urban stormwater drainage network and layout is shown graphically in on Figure 1.

A brief description and functions of the various drainage network control structures as well as findings from field inspections is given below.



FIGURE 1: Typical example of an urban stormwater drainage network



FIGURE 2: Typical conditions of urban minor stormwater drainage systems



FIGURE 3: Typical type and conditions of urban mayor stormwater drainage systems

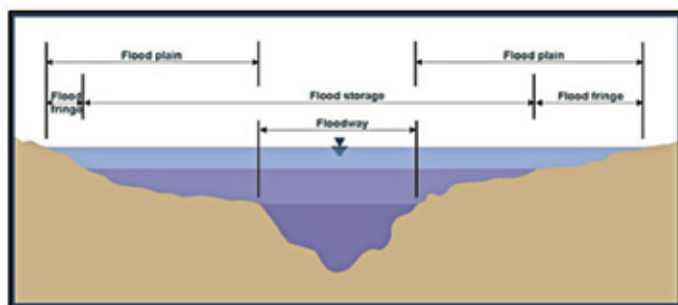


FIGURE 4: Typical profile of a natural river



FIGURE 5: Typical condition of our urban rivers

3.1.1 Minor Drainage System

The minor drainage system consists primarily of kerb inlets, grid inlets and artificial below and/or above ground drainage networks. The main function of this system is to drain the roads and runoff from adjacent properties from stormwater runoff emanating from usually a 2–5-year storm event. This drainage system is of upmost importance to prevent excessive road overflows which then cause both flooding of the road and adjacent developments as well as creates a safety hazard to road traffic.

Typical observed conditions of these structures are shown in Figure 2.

3.1.2 Major Drainage system

The major drainage system collects all the stormwater runoff from the minor

drainage system and discharges the combined runoff into either larger underground culvert structures and/or into natural urban watercourses

This drainage system usually caters for large storm events ranging from a 10-year to a 100-year storm event depending on the nature of the urban developments as well as size and predicted peak flow rates. Typical major drainage systems are shown in Figure 3.

3.1.3 Main rivers and flood ways

Urban major drainage systems typically drain into main rivers and their tributaries which now cater for the combined flows of all the major urban drainage systems including an entire river catchment. The main rivers consist of a floodway section catering for typical a 5-year to 10-year flood event and the floodplains section typically handling a 100-year or higher flood event. A profile of a typical river is shown on Figure 4.

Typical conditions of some of our urban rivers are shown in Figure 5.

3.1.4 Summary of findings and shortcoming

- On average 80% to 85% of the minor drainage systems are blocked and /or broken causing an excess flow on roads which then floods adjacent developments.
- Several major culverts and bridges are blocked due to debris significantly reducing the hydraulic capacity thereby causing road overflows and damages to the bridge and road infrastructure.
- Existing watercourses are often eroded causing bank instability and safety hazards.

4. CLIMATE CHANGE OVERVIEW AND IMPACT

Several climate change and impact studies have been carried out on a global basis. These studies are mostly based on historical rainfall records. The General Circulation Models (GCMs) are then used to do climate change predictions based on expected changes in temperate, cloud formation and pressure variations. At this stage is generally agreed that storm rainfall would increase on average by 15%.

In order to cater for this several Municipalities, require that the storm rainfall used in deterministic hydrological models be increase by 15% thereby obtained more conservative design flows.

5. PROACTIVE MAINTENANCE ACTIVITIES PLANNING FOR IMPROVED AND MORE RESILIENT STORMWATER CONTROL

Considering that 80% to 85% of mainly kerb inlets and manholes are blocked proactive and planned maintenance needs to be carried out. This however does not take place due to mainly budget and resource constraints at Municipal depots.

Considering this a proactive and prioritised maintenance approach using algorithms has been developed to assist a municipality in prioritising the locality of maintenance activities based on a drainage blockage potential and flood risk.

In this way limited funds and resources could be used to address high risk areas thereby reducing the potential of flooding. It has been established from previous projects and maintenance activities that between 15% to 20% of a roads and stormwater budget should be set aside for annual stormwater drainage networks maintenance activities.

A possibility to obtain assistance with maintenance funding could be to approach CoGTA and National Treasury to make available a grant funding mechanism to improve and assist with urgently needed maintenance activities. This could provide a long-term job creation as well as education benefits and opportunities for local residents to assist a municipality in proactive maintenance.

TABLE 1: Prioritisation 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
		1050-1200	4
		1350-1500	2
		>1500	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
		Urban (formal residential)	2

In addition to the above benefit this initiate would also significantly reduce the damage to infrastructure and potential liability claims against a Council emanating from flooding due to the lack of maintenance.

5.1 Prioritised stormwater maintenance program and budgeting

The prioritisation algorithm is based on input parameters as summarised in Table 1.

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).

Blockage potential member = (Member size weighting) + (Member gradient weighting) + (Member flow velocity weighting) + (Road type weighting) + (Development weighting) (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 2.

TABLE 2: Maintenance Priority

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



FIGURE 6: Map showing locality of prioritised maintenance activities

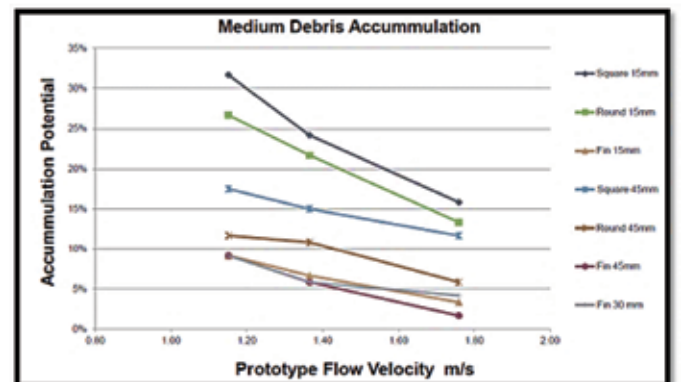


FIGURE 7: Reduction of blockage potential by debris fins

By applying the above approach, the locality and priority of require maintenance activities can be established as shown in Figure 6.

5.2 Major stormwater structures maintenance reduction

As is observed from the above field observation a large number of bridge and culvert crossings are blocked due to debris collecting at the entrance of the structure. Based on research by Stellenbosch University a significant reduction in the blockage potential can be achieved by construction debris fins. The debris fin enhances the flow lines to curve around the fin thereby letting the debris pass through.

It has been shown from Laboratory testing that the blockage potential can be reduced by as much as 25% as shown in the Figure 7.

A typical example of a debris fin is shown in Figure 8.

6. IMPROVED HYDRAULIC CAPACITY AND DESIGN OF MINOR DRAINAGE NETWORKS

A typical shortcoming observed from various stormwater drainage designs and field observations is the lack of sufficient kerb inlet hydraulic capacity



FIGURE 8: Typical example of debris fins



FIGURE 9: Typical example of kerb inlet and grid inlets

to drain the surface water into the underground pipe network. This caused excessive flows on roads which then cause flooding.

6.1 Selection of appropriate kerb inlets

A few typical types of kerb and grid inlets are shown below in Figure 9.

When selecting and designing kerb inlets the following factors must be considered:

- The gradient of the road (is it steep or shallow).
- Froude number (Fr).
- The length of kerb required.
- The number of kerbs required along a road section to ensure the design flow is drained into the underground network.
- Location of the kerb inlets at low points.

The above factors all have an impact on the efficiency and hydraulic capacity of the kerb inlet considering that the surface water needs to be guided into the kerb opening by mainly gutter flow as illustrated in Figure 10.

6.2 Hydraulic Design Aspects of Kerb Inlets

The correct hydraulic design of kerb inlets must allow for at least a 5-year flood event to be captured and discharged into the underground drainage network. This aspect is often overlooked, and not sufficient kerb inlets are

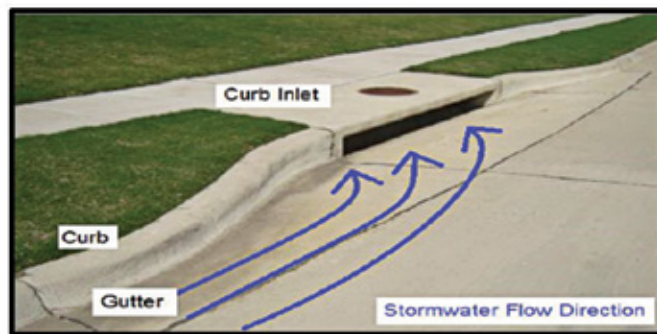


FIGURE 10: Stormwater flow guided into the kerb inlet

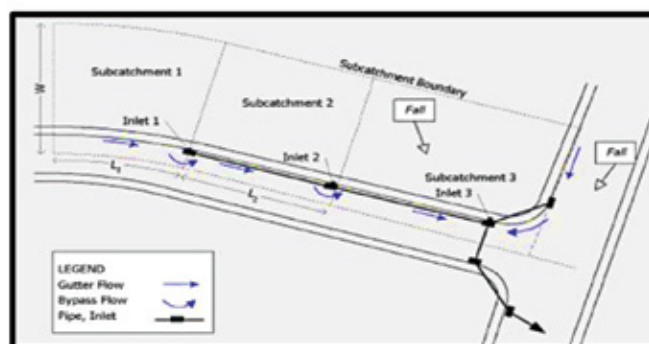


FIGURE 11: Existing drainage system capacity investigation



FIGURE 12: Existing kerb inlets without transition

installed leading to a stormwater network not flowing at full capacity. Herewith an example of a study carried out of a small urban drainage network as shown in Figure 11. The study involved the assessment of the current drainage network capacity and also to propose upgrading measures, if required.

6.2.1 Existing drainage system investigation

The existing kerb inlets consisted of the standard kerb inlet excluding any inlet transition as shown in Figure 12.

The existing drainage system details, current hydraulic capacity and design flows is summarised in Table 3.

TABLE 3: Existing drainage system details and capacity

Existing stormwater drainage network			5-year design flow (l/s)	Road slope (%)	Existing kerb inlet details				Excess road flow (l/s)
Reach	Pipe Size (mm)	Capacity (l/s)			Kerb inlet	Kerb inlet length (m)	Kerb transition	Capacity (l/s)	
Inlet 1-Inlet 2	750	500	400	0,5	1	4 m	none	60	340
Inlet 2-Inlet 3	825	700	650	2,0	2	4 m	none	35	615
Outlet		700	680	2,0	3	5m	none	45	635

TABLE 4: Upgraded and more efficient kerb inlet design

Existing stormwater drainage network			5-year design flow (l/s)	Road slope (%)	Optimised kerb inlet design				Excess road flow (l/s)
Reach	Pipe Size (mm)	Capacity (l/s)			No of kerb inlets	Total kerb inlet length (m)	Kerb upstream transition length (m)	capacity (l/s)	
Inlet 1-Inlet 2	750	500	400	0,5	2	2x4	6	400	100
Inlet 2-Inlet 3	825	700	650	2,0	2	3x4	6	640	60
Outlet		700	800	2,0	3	3x5	8	700	0
					Salberg Kerb Inlet Alternative				
					1	5	1	410	-10
					2	7	1	680	30
					3	9	1	750	-50

The following is observed:

- The pipe size capacity is sufficient to cater for the 5-year design flow.
- The kerb inlets can on average only handle about 5-8 % of the pipe capacity.
- There is a significant excess road flow which now causes potential flooding.

To have a hydraulically functional drainage system the following improved approach and design has been adopted:

- Use modified kerb inlets with an inlet transition.
- Allow for additional kerb inlets.
- In steep gradients allow for longer inlet transitions or alternatively use the Salberg type of kerb inlet or similar.
- Try and balance the total kerb inlet capacity with at least the existing pipe capacity.

The upgraded and more balanced kerb inlet design is summarised in Table 4.

The following is observed from the above Table 4:

- A marked increase in kerb inlet capacity is observed when using kerb inlets with an inlet transition.
- The standard kerb inlet becomes inefficient at steep road gradients usually more than 2%

- The total kerb inlet length becomes very long in steep gradients.
- Alternate more efficient type of kerb inlets should be used in steep gradients.
- The Salberg type of kerb inlet is significantly more efficient in gradients more than about 2% due to an additional traverse grid intake.
- The road excess flows are significantly reduced thereby also decreasing the risk of flooding for minor but more frequently occurring storm event up to about a 5–10-year event.

The type of kerb inlets proposed for the upgraded drainage system are shown in Figure 13 and Figure 14.

7. CONCLUSIONS

Extensive experience has been gained from various stormwater drainage system investigations and upgrading designs for various local authorities from which the following can be concluded:

- Minor drainage networks are generally not maintained hence causing significant road overflow and flooding.
- From previous studies it was observed that up to 80% of kerb inlets and manholes are blocked with debris.
- Insufficient detail is given to the selection and design of kerb inlets having a significant lower hydraulic capacity than the underground drainage network.
- Climate change has an impact of the storm rainfall intensity and should be considered for upgrading existing and designing new drainage systems.

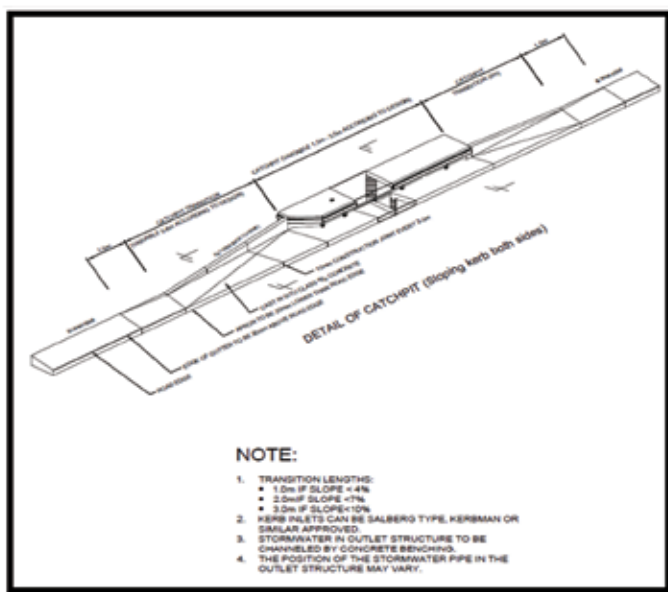


FIGURE 13: Proposed kerb inlet type with inlet transition suitable for road gradient up to about 2-3 %

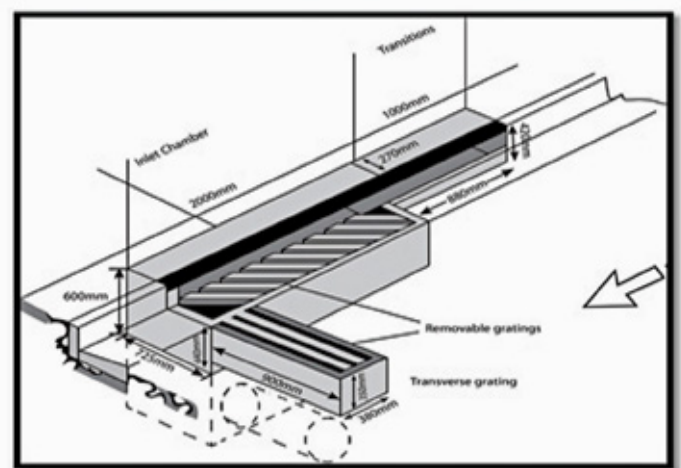


FIGURE 14: Typical Salberg kerb inlet for steep road gradient in excess of 2%

- Major drainage systems such as culvert and bridge crossings are often blocked with debris during storm conditions causing significant and flooding and damage to infrastructure.
- To be more proactive and resilient to climate change a local authority should make use of the maintenance prioritisation approach and algorithm to regularly at least carry out maintenance at high-risk areas, increase the kerb inlet capacity and reduce the risk of blockage at culvert and bridges by implementing debris fins.

8. ACKNOWLEDGEMENTS

The authors wish to acknowledge the opportunity given by several municipalities utilising our specialist stormwater management and hydraulic engineering expertise to improve the drainage of stormwater, reducing the flooding risk and potential liability claims against a municipality thereby having a safer and healthier environment

9. REFERENCES

The South African National Roads Agency SOC Limited, Drainage manual, 6th edition.