PAPER 10

SOLVING FLOODING PROBLEMS USING SUSTAINABLE URBAN DESIGN SYSTEMS (SUDS) IN A CHANGING WORLD

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1. ABSTRACT

The current urban environment is rapidly changing due to more high density developments within municipal areas. Additional climate change and sporadic, more intense storm events as South Africa has experienced during this recent rainy season has caused an increase in flooding problems and damage to property. This combined with financial constraints increases the pressure on municipalities as well as private urban developments to solve flooding problems in a more cost effective manner.

A recent project involving the remediation of flooding problems in a residential estate within the City of Tshwane has highlighted the benefits and cost savings achieved when considering the Sustainable Urban Design Systems (SUDS) approach. The project involved the remediation of frequently occurring flooding problems in the Zwavelkloof residential estate. This estate which was part of the Kungwini municipality was developed without considering the impact of natural watercourses and upstream development. This caused several private properties as well as roads to be flooded and damaged. A master plan study was subsequently carried out which determined that a budget of R 30 million would be required to solve the flooding problems. This budget was based on constructing an entirely new and larger underground drainage network consisting of pipes and culverts, which was unaffordable.

Due to budget constraints at the City of Tshwane and an urgent need to solve the flooding problems the Zwavelkloof body corporate assisted in obtaining their own funding by introducing a special levy. The maximum budget that they could afford was R 3,5 million that was only a fraction of the original budget estimation of R 30 million. In order to now assist the residential estate a new approach using SUDS was adopted. This approach included the use of an attenuation dam, diversion berms, as well as swales and natural floodplains thereby reducing the budget to R 3,5 million.

This paper presents a case study, which highlights the significant benefits of solving urban flooding problems using the SUDS principles. The paper also gives details on how the flood control measures were designed, constructed and how they performed during an extreme 1:100-year storm event that occurred during February 2022.

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.

The above shortcoming and lack of integrated stormwater management was the main cause of an increasing risk of flooding and flood damage within the Zwavelkloof estate. In order to now assist the Estate in reducing the flood risk an integrated stormwater master plan study was done to determine an economically viable and environmentally friendly solution. The approach adopted as well as the implementation of the flood control measures and operation thereof during recent extreme flood events is discussed and illustrated below.

3. INTERGRATED STORMWATER MASTER PLAN

It is of utmost importance to first carry out an integrated Stormwater Master Plan (SWMP). The main objective of a SWMP is to define the entire catchment draining into the study area, establishing the current and anticipated future development within the catchment and then quantifying the problem by compiling a hydrological model of the catchment. Once the hydrological modelling is completed peak flow rates were determined along the existing drainage network. A hydraulic study of the existing drainage network was then carried out to define the current capacity of the network. From the above information the extent of the problem as well as identification of remedial measures could be determined. Relevant information and results of the study are given below.

3.1. Study area locality and catchment definition

Zwavelkloof Private Estate is situated to the south of Saal Street, Olympus AH Gauteng as shown in Figure 1. The site is situated within a low naturally low lying area which forms a major flow path during storm events.

It was now important to define the entire upstream catchment as well as current and future planned land-use. This information was obtained from

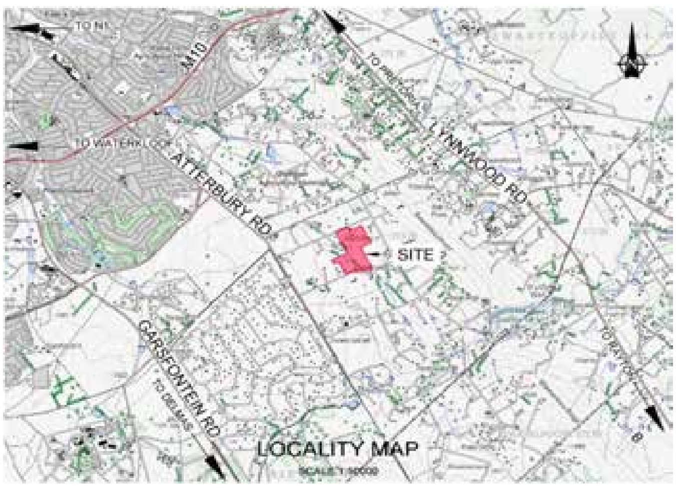

FIGURE 1: *Locality of the Zwavelkloof Private Estate*

FIGURE 2: *Catchment delineation and land-use*

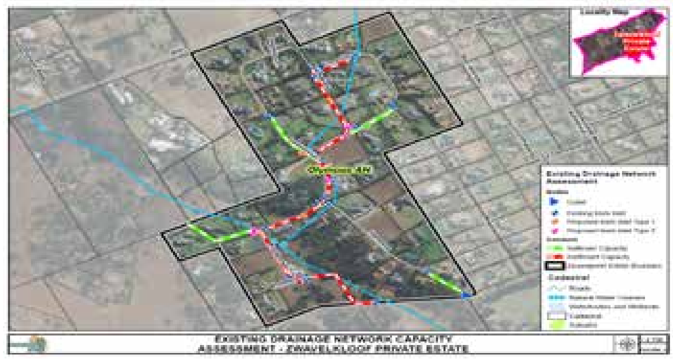

FIGURE 5: *Drainage pipe network capacity assessment*

the City of Tshwane planning department and is shown in Figure 2. It is observed from the above figure that an upstream catchment of about 1.4km^2 drains into the estate causing a significant stormwater runoff volume. It is also observed that about 65% of the catchment would still be developed causing and even higher impact on the stormwater runoff peak and volume.

3.2 Hydrological modelling

The PCSWMM Hydrological model was used for modelling of the catchment in order to obtain runoff peaks and volumes as selected node points. The schematic layout of a typical drainage network including road overflow and swale flows are shown on Figure 3 and a brief summary of the model input parameters is given below.

3.2.1 Storm rainfall

Relevant 24-hour storm rainfall for various return periods was obtained from the nearby South African Weather Bureau (SAWS) weather station. The 24-hour storm rainfall varied from 53mm to 135mm for a 1:2 year and 1:100 year storm event, respectively.

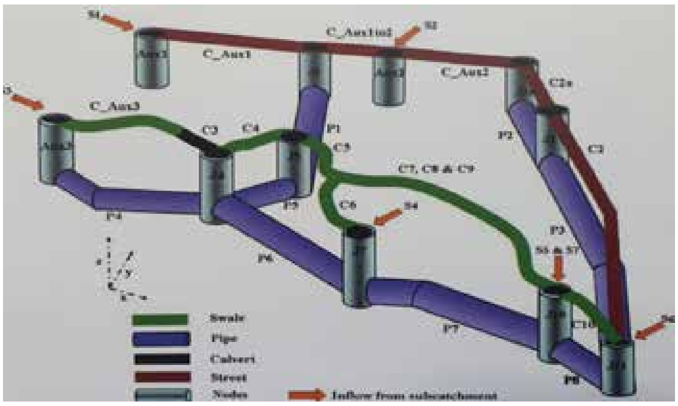

FIGURE 3: *Typical layout of stormwater drainage system for PCSWMM Model*

FIGURE 4: *Existing drainage network and sub-catchments*

3.2.2 Existing Drainage network and sub-catchment definition

A detailed site survey was carried out of the existing drainage network giving the size, type and locality of the drainage network members. Sub-catchments were now determined based on the layout of the existing developments as well as existing drainage network. The defined drainage network and associated sub-catchments are shown on Figure 4.

3.2.3 Determination of sub-catchment parameters

An important aspect of hydrological modelling is the determination of model input parameters for each of the defined sub-catchments. A summary of the determined model input parameters is given below.

- **Curve number (CN):** defines the potential runoff potential from an urban area
- **Imperviousness:** defines the percentage imperviousness of the catchment

3.2.4 Design peak flow determination

Before carrying out the hydrological modelling relevant design standards had to be determined. The design standards were based on the City of Tshwane guidelines for stormwater drainage systems as follows:

i. The minor system defined as the underground pipe network and kerb/grid inlets must cater for at least a 1:5 year storm event;
ii. The major system defined as the minor drainage stem plus road overflow must cater for at least a 1:25 year storm event.

Based on the above design standards the hydrological model was now used to determine relevant peak flow rates at each of the drainage network members.

3.2.5 Existing drainage network capacity

The hydraulic capacity of the existing drainage network was now determined by the PCSWMM model. The existing drainage network details were determined from a field survey and visual inspection giving the size and type of the drainage network members.

3.2.6 Existing drainage network assessment and compliance

An assessment of the existing drainage network compliance was now carried out by comparing the design flows with the hydraulic capacity of the drainage network. The compliance of the network is shown graphically on Figure 5.

3.2.7 Existing kerb inlet hydraulic assessment

A shortcoming often encountered in urban drainage systems is the undersized and/or incorrect type of kerb inlets. This causes a severe problem in draining stormwater runoff from the road surface causing a high excess flow not entering the pipe network. The exiting kerb inlet

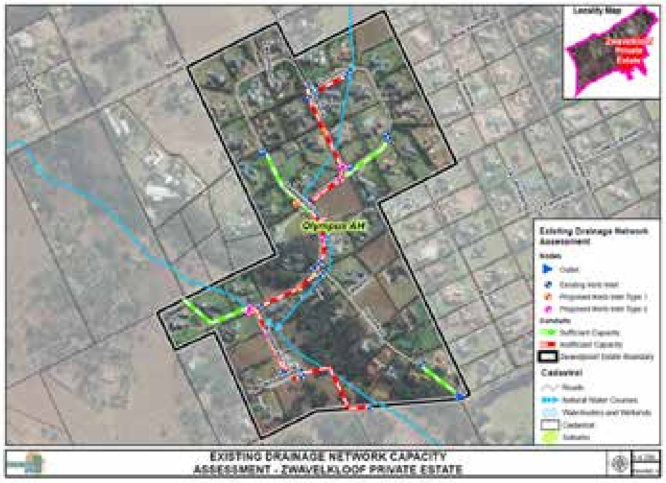

FIGURE 6: *Existing kerb inlet capacity assessment*

capacity assessment and shortfall are shown graphically on Figure 6.

4. FLOOD REMEDIATION MEASURES

Having now defined both the required design flows as well as shortcomings of the existing drainage network enables one to identify and design alternative remediation measures. The approach as well as selected remediation measures are discussed below.

4.1 Approach and alternative remediation measures

Due to budget constraints for the capital works several remediation measure options needed to be considered in order to obtain both a practical as well as afforded remediation alternative. In view of the above as well as to satisfy the City of Tshwane the following remediation measures were considered:

i. Alternative 1: Convectional upgrading of the existing pipe network by replacing the undersized pipes with larger dimeter pipes;
ii. Alternative 2: Implementing the SUDS approach consisting of a combination of attenuation facility and upgrading a portion of the drainage system to prevent further flooding of the development.

A description of each of the above alternatives is given below.

4.1.1 Alternative 1: Conventional approach

This approach includes a new design of all the undersized stormwater pipes and increasing the pipes to handle at least a 5-year storm event. Also included is upgrading of existing kerb inlets and implementing additional kerb inlets. This approach would have ungraded a total length 1038m of concrete stormwater pipes and implementing about 55.5m additional kerb inlets. The capital cost estimate was determined to be about R30 million.

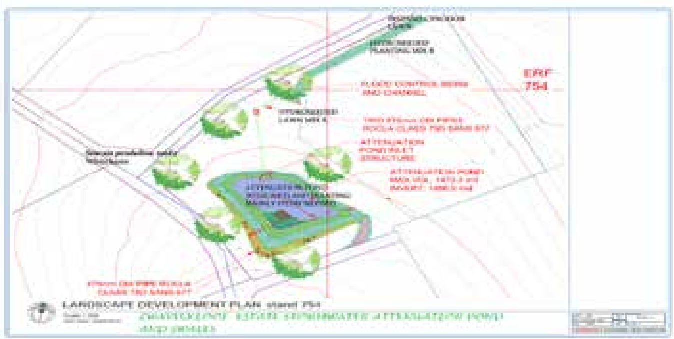

FIGURE 7: *SUDS approach attenuation dam*

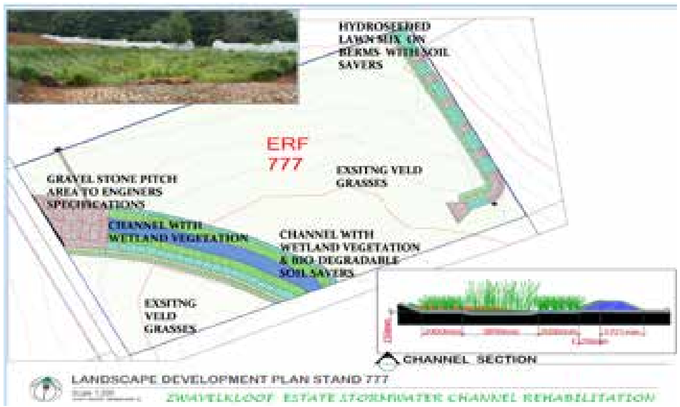

FIGURE 8: *Typical example of SUDS stormwater control*

4.1.2 Alternative 2: SUDS approach

This approach included the possibility of using on site flood attention to reduce the peak flows entering the downstream undersized drainage network. The dam has a controlled bottom outlet as well as an emergency spillway. The dam was sized to attenuate up to the 1:25-year flood event without overtopping. The dam has an earth embankment covered with natural indigenous vegetation. Based on the SWMM Hydrological model the 1:25-year peak flow is reduced by about 40% from 7m^3/s to 4m^3/s. The layout of the dam is shown on Figure 7.

4.1.3 SUDS approach and selected remedial measures

The SUDS approach is to minimise the directly connected impervious areas in an urban development and to implement natural and environmentally friendly control measures with the use of swales ,earth embankments, grassed waterways to reduce the energy of stormwater runoff. A typical example of the SUDS stormwater control channel is given on Figure 8.

It was established that even with the attenuation dam the excess stormwater on the roads would not route into the attenuation pond and would still cause flooding problems. In view of this additional control measures needed to be considered and designed using the SUDS approach. The following additional control measures were therefore considered:

i. Construction of diversion embankments routing additional excess road flow into the attenuation dam;
ii. Construction of additional special kerb inlets with a long entrance transition as well as the Salberg type kerb inlets at steep road gradients;
iii. Construction of side inflow diversion channels to route the stormwater into naturally low lying areas thereby reducing the risk of flooding developments.

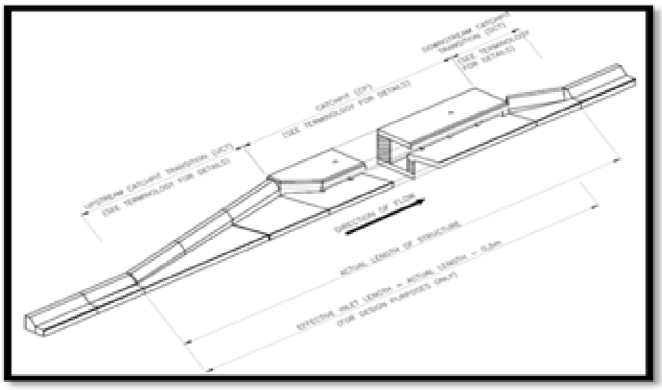

FIGURE 9: *Type 1- kerb inlet with upstream transition*

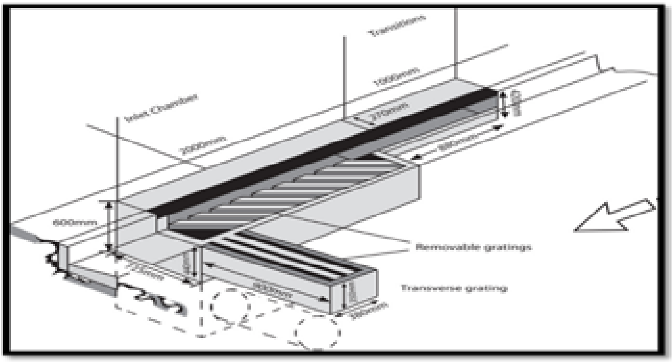

FIGURE 10: *Type 2-Salberg kerb inlet for steep gradients*

FIGURE 11: *Selected flood control measures using the SUDS Principle*

Two main types of kerb inlets have been considered for the upgrading measures as shown below. The Type 1 kerb inlet has been used for roads with a slope less than 7%. The Type 2 (Salberg) kerb inlets have been used for road gradients steeper that 7%. Typical details of the selected kerb inlets are shown in Figure 9 and Figure 10.

To enhance both the water quality as well as increase the aesthetic appeal of the control measures a landscape architect was commissioned to propose suitable vegetation such as Thypha capensis ,Vetiver grass that enhances both the water quality as well as reduces the erosion potential. This combination of engineering design as well as landscaping provided an environmentally friendly solution accepted by the local residents. The final selected flood control measures are shown on Figure 11.

4.1.4 Remediation measures cost-benefit assessment

A cost-benefit assessment was carried out for the client for each of the identified remedial measure alternatives prior to final implementation. From this assessment the following was established:

i. Alternative 1: This would require a substantial amount of construction and disruption of services and access to properties due to all existing drainage pipes needing to be removed and replaced by bigger pipes. The capital cost was estimate at R 30 million. The upgraded network would handle up to a 1:25 year event with potential flooding of properties during a 1:50 year storm event;

FIGURE 12: *Construction of the attenuation dam*

ii. Alternative 2: The combination of the attenuation dam and additional SUDS based control measures was found to be the most cost effective and environmentally friendly approach. The total capital cost was R 3,5 million with the upgraded drainage system being able to handle up to a 1:25 year flood event with no significant flooding during a 1:50 year storm event.

5. CONSTRUCTION OF THE FLOOD CONTROL MEASURES

Construction of the remedial measures was started in April 2021 and completed successfully by the end of end of September 2021. Typical details of the construction stages are shown on Figure 12 below.

6. OPERATION OF THE CONTROL MEASURES DURING EXTREME FLOOD EVENTS

In order to establish the operation of the flood control measures and in particular the attenuation dam a CCTV camera was installed at the dam site. This provided valuable footage during flood events. Since the dam was built major flood events occurred at the Zwavelkloof estate. The latest extreme flood event occurring during February 2022. This measured 145 mm in 24 hours, which is equivalent to a 1:100 year storm event. The dam outlet works as well as spillway was operational with no severe flood damage occurring within the estate. Flood event pictures taken on site as well as from the CCTV footage during the flood events are shown in Figure 13 below.

7. CONCLUSIONS

From this case study it can be concluded that making use of the SUDS approach can significantly reduce capital expenditure by implementing a combination of environmentally friendly solutions at a much lower costs and more acceptable to the community.

8. ACNOWLEDGEMENTS

The author wishes to acknowledge the opportunity given by the Zwavelkloof Homeowners association to assist in making the estate a safer place to live in during storm events as well as the support and approval of the City of Tshwane Roads and stormwater division.

9. REFERENCES

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CHI PCSWMM. 1 Guelph, Ontario, Canada, N1H 4E9.

FIGURE 13: *Flood events photographic records*