UNIVERSITY OF KWAZULU-NATAL

A Cost-Effectiveness Analysis of Stormwater Management Systems: Isipingo Prospection

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Declaration

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Abstract

Flood mitigation measures have become a contentious challenge due to the lack of infrastructure to prevent them after the 10 October 2017 flash floods, which impacted the Isipingo and Umlazi area the hardest within the eThekwini Municipality. The storm which caused the damage were measured as a 1 in 100 year recurrence interval storm or greater, however eThekwini Municipality only caters for 1 in 3 year storms and 1 in 10 year storms at critical points. A capital injection would thus be required to cater for a 1 in 100 year recurrence interval storm amidst a precarious economic climate. The purpose of this study is to determine a cost effectiveness analysis of conventional stormwater management systems, Sustainable Urban Drainage Systems (SUDS) and an attenuation facilities based stormwater management system as alternative configurations for the Isipingo Prospection area. A cost effectiveness analysis will be deduced by means of a multi-criteria decision matrix which enables a holistic incorporation of environmental and social effectiveness of the stormwater management systems proposed instead of costs in isolation. In addition, this approach allows for sustainability and an objective inclusion of preservation of biodiversity, social wellness and comparison of alternatives without compromising the functionality of the stormwater management system. The results show that Sustainable Urban Drainage Systems is the most cost-effective due to the utility of green infrastructure as opposed to a high reliance on grey infrastructure, with a final weighted score of 4.12 and Bill of Quantities (BOQ) estimate of R2 119 047.50, which is highly influenced by the excellent performance in the cost-effectiveness criteria. In addition, green infrastructure is able to incorporate environmental and social effectiveness and lower the costs required for mitigating a 1 in 100 year recurrence interval storm in the catchment studied. Conventional stormwater management systems received a final score of 2.22, which reflects the low cost and environmental effectiveness performance of 2.2 and 2 respectively. The BOQ estimate amounted to R5 188 921.33. Attenuation facilities based configuration was the least cost effective with a final score of 1.8, due mainly to the cost required for the underground concrete attenuation facility at a BOQ estimate value of R16 007 209.38. The utility of a multi-criteria decision matrix as a means of conducting a cost effectiveness analysis comes highly recommended by this study as an objective decision making tool for project managers. The alignment of existing strategies and policies requires the filtration to project managers to include green infrastructure to enable integration and sustainability.

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List of Abbreviations

BOQ- Bill of Quantities

CHI- Computational Hydraulics International

CSCM- Coastal, Stormwater and Catchment Management

DEM- Digital Elevation Maps

EIA- Environmental Impact Assessment

FV- Future Value

GDP- Gross Domestic Product

GI- Green Infrastructure

GIS- Geographical Information System

GSI- Green Stormwater Infrastructure

IDP- Integrated Development Plan

IWRM- Integrated Water Resources Management

JRA- Johannesburg Roads Agency

KPI- Key Performance Indicators

LID- Low Impact Design

LIDAR- Light Detection and Ranging

NDP- National Development Policy

NEMA- National Environmental Management Act

NPV- Net Present Value

PCSWMM- Personal Computer Storm Water Management Model

SDF- Spatial Development Framework

SU- Stormwater Utilities

SUDS- Sustainable Urban Drainage Systems

UDL- Urban Design Lab

UWC- Urban Water Cycle

VAT- Value Added Tax

1. Chapter One: Introduction

1.1 Background of Study

Subsequent to the severe storms which flooded eThekwini Municipality in June 2016 and October 2017 the Coastal, Stormwater and Catchment Management (CSCM) department within eThekwini Municipality was mandated to assist in flood mitigation measures. The Isipingo and neighbouring Umlazi area, in the Southern region of eThekwini was one of the areas which were heavily distressed by the storms which are estimated to be having been greater than or equal to 1 in 100 year recurrence interval storms. Stormwater infrastructure which is collapsed, damaged and/ or blocked due to the floods thus caused a negative externality on the community.

eThekwini Municipality caters for 1 in 3 year recurrence interval storms and 1 in 10 recurrence intervals at critical points such as low points and road crossings (Stormwater Guideline, 2012). The integrity of infrastructure is the responsibility of the government, thus municipalities are required to create an environment which is safe and conducive for productivity. Furthermore, prioritising infrastructure development is also aligned with eThekwini Municipality's vision "To become the most liveable city by 2030" (eThekwini Municipality, 2019).

The economic implications of upgrading the existing system to cater for a 1 in 100 year recurrence interval storm are high and some might say unrealistic. In addition, stormwater infrastructure is often overlooked financially relative to roads. Furthermore, South Africa is amidst a precarious economic climate thus budget constraints infiltrate down to expenditure proposed at Municipal level. Therefore, granting of funds to projects must be based on the level of priority and contribution to the socio-economic and environmental welfare of the community.

The mitigation of these heavy storms is significant in the Isipingo/ Umlazi area due to the location at highly flood prone low points. Numerous residential and commercial properties are located within the vicinity and were negatively impacted by the instantaneous floods. The consequence of being located at a low point is that as the sub-catchments accumulate and stormwater run-off increases, the stormwater system fails and thus floods the premises.

1.2 Location of the Study

The location of the study is in Southern region of eThekwini Municipality in the townships of Isipingo and Umlazi. A sub-catchment accumulating stormwater run-off from a portion of Umlazi kwa-V sections, the Isipingo commercial and industrial area will be the focal point of the study as seen in Figure 1.1. The area was chosen due to the devastating impact of the June 2016 and October 2017 1 in 100 plus recurrence interval storm which endangered the residential, commercial and industrial properties in the area.

The higher portion of the catchment is composed of commercial premises, open areas and informal settlements along Prince Mcwayizeni Drive. The Informal settlements do not have formal service provision thus waste is predominantly disposed of in the stormwater channels running adjacent. Jeena's supermarket is the low point of the catchment, thus during the flash floods the warehouse doors acted as dam gates for the stormwater to pass into the culvert behind the premises. Furthermore, a large amount of debris is washed into the stormwater network, thus blocking the system and escalating the problem.

Umlazi V-section is a predominantly mountainous area whereas, Isipingo is situated at lower elevations in flatter terrain. The average gradient across the catchment is 14 per cent, therefore allowing for faster run-off speed.

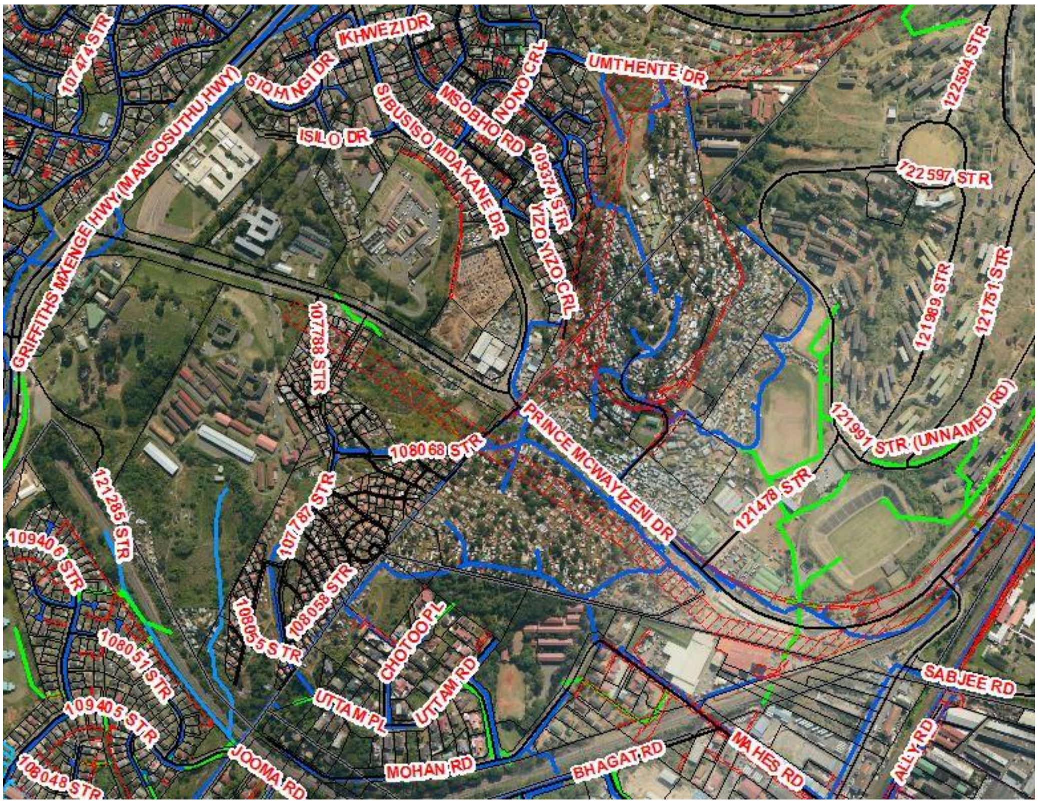

Figure 1.1: Locality Map of Site

Source: ArcGIS, 2018.

1.3 Focus of the Study

The focus of the study will be on performing a cost effectiveness analysis of upgrading a catchment in the Isipingo areas stormwater management system. A comparison of conventional stormwater management, sustainable urban drainage systems (SUDS) and attenuation facilities based system will be conducted. The contribution of the alternative stormwater management systems structures to the environmental and social effectiveness will also be integrated into the cost effectiveness analysis.

1.4 Problem Statement

The costs associated with constructing stormwater management systems can be exorbitant, however South Africa is a developing country with an ominous economic climate. Furthermore, the environmental and social consideration of stormwater management systems need to be incorporated into the decision making process to enable achieving sustainable objectives.

1.5 Significance of the Study

The study will assist in determining the cost-effectiveness of upgrading stormwater management systems. Due to drastic inclement weather and climate change, 1 in 100 year return period storms and greater will occur more often thus requiring adequate stormwater systems to manage the flows.

In addition, the cost of damage and repairs due to storms is high, thus necessary measures to avoid flood damage are required. Government organisations, municipalities and project managers in general, can adapt to conducting a cost-effectiveness analysis prior to applying conventional infrastructure designs in a slow growth economy.

The study further emphasizes the importance of prioritizing funding for stormwater management in mitigating against negative externalities caused by floods on infrastructure, business premises, private property and the community at large. Furthermore, the study can be used towards building a template for improving practice, decision making and efficient use of available capital.

1.6 Stormwater Management System Alternatives

1.6.1 Conventional Stormwater Management Systems

Conventional stormwater management systems utilize predominantly grey infrastructure such as concrete pipes, channels and manholes at connection points to build a network. Stormwater inlets are located along roads at low points and lead the stormwater to outfalls which are located at rivers, streams and ultimately the ocean.

1.6.2 Sustainable Urban Drainage Systems (SUDS)

Sustainable urban drainage systems use green infrastructure towards obtaining the same functionality as conventional stormwater management systems. The emphasis is on controlling the stormwater as close as possible to the source using structures such as water harvesting tanks, bio-retention basins, green roofs and dual functionality ponds.

1.6.3 Attenuation Facilities Based Stormwater Management Systems

Attenuation facilities incorporate the construction of stormwater storage ponds which enable the existing stormwater management system to not be inundated. Attenuation facilities act to simulate predevelopment flow rates slowing down the rate of flow in the system at a given period.

1.7 Purpose of the Study

The purpose of this quantitative study will be to use the Cost-Effectiveness Analysis theory that relates the cost of upgrading a stormwater management system to the outcomes of alternative stormwater management designs for the Municipality at the Isipingo prospection site. The stormwater management system will be defined as the conduits, culverts, junctions, canals and attenuation facilities required to manage the stormwater run-off. The outcomes will be defined as the mitigation of storm damage for a 1and related expenses avoided and retention of employment the intervening variable, will be defined as the provision of an economically viable and conducive environment to continue operating businesses, thus contributing to Gross Domestic Product (GDP).

1.8 Research Objectives

The research objectives are as follows:

1. To evaluate the cost effectiveness of three stormwater management systems, namely conventional pipe networks, sustainable urban drainage systems (SUDS) or incorporating attenuation facilities in stormwater management system designs;
2. To evaluate the social effectiveness of the three stormwater management systems;
3. To evaluate the environmental effectiveness of the three stormwater management systems.

1.9 Research Questions

1. What is the cost effectiveness of the three alternative stormwater mitigation systems?
2. What is the social effectiveness of the three alternate stormwater designs?
3. What is the environmental effectiveness of the three alternate stormwater management systems?

1.10 Overview of the Study

The study will investigate conventional pipe networks, Sustainable Urban Drainage Systems (SUDS) and incorporating attenuation facilities as possible stormwater management configurations. The study will not look at the extent of flood damage caused across the whole of eThekwini Municipality. Qualitative research methods were not utilized as the perspectives on the extent of damage would be subjective. Furthermore, the research will not look into engaging stakeholders affected by the floods in Isipingo.

1.11 Limitations

The study will not be able to quantify the residential damages that were affected by the floods within the vicinity of the area. In addition, due to time and data constraints not the residential and industrial members of the public will not be included in the study. Timeous investigations and designs are required to enable an adequate data analysis process. The catchment along Prince Mcwayizeni Drive from Umlazi to Isipingo will be analysed for the purpose of this study.

1.12 Conclusion

Chapter one sought to deliver an overview of the study conducted. The study is necessary due to the need for flood mitigation stormwater management systems which are cost effective for the Isipingo prospection area. The purpose of the study is to utilize the cost effectiveness analysis theory in comparing the costs associated with the construction of alternative stormwater management systems, namely conventional stormwater management systems, sustainable urban drainage systems and attenuation facilities based stormwater management systems. A quantitative approach was adapted to enable an objective outcome. Chapter two is next with the literature review on cost effectiveness and stormwater management systems.

2. Chapter Two: Literature Review

2.1 Introduction

The purpose of the second chapter is to review relevant and available literature on the cost effectiveness of stormwater management systems. It serves to provide a holistic reflection on stormwater management systems considered in this study and the cost effectiveness thereof. In addition, the social and environmental effectiveness of conventional stormwater management, SUDS and attenuation facilities as stormwater management systems will be explored.

2.2 Cost Effectiveness Analysis

Cost effectiveness analysis is an economic evaluation which compares the costs of alternative processes with the outcomes measured. Prior to the early 1980's, cost effectiveness analysis was the predominantly used form of economic evaluation. Cost effectiveness analysis are obligated to have effectiveness which is measured in appropriate natural units and ideally expressed in a single dimension (Boyle et al., 1983).

Cost effectiveness analysis is applied to planning and management of organized activity by project managers, senior managers and the likes. It enables competing designs to be compared not only on price but performance. For example, if a planner was assigned to procure medical waste disposal equipment, the performance may be equal or even slightly inferior to its opponent, but substantially less expensive and easier to procure. The planner may select it as the more cost effective alternative (Project Managers, 2018).

Effectiveness may be expressed in a single dimension thus allowing for direct comparison of outcomes such as marginal cost per unit of outcome. In contrast, in some studies multiple outcomes emerge from the alternatives. Robinson (1993) is of the notion that if one procedure emerges as less costly and of equal or greater effectiveness than all the other alternatives on each dimension of effectiveness, it is the most cost effective alternative. Using multiple dimensions to measure outcomes may permit informed decision making as opposed to trying to express outcomes in a singular form.

Culyer (1982) is of the perception that data on effectiveness should be collected in conjunction with a clinical trial so that relevant data costs and effectiveness can be collected simultaneously. However, conducting trials may be expensive and time consuming and epidemiological evidence may be non-existence, thus secondary data is utilized. This often results in a high dependency on assumptions on clinical evidence (Culyer, 1982).

Cost considerations dominate some scenarios, and so variations in effectiveness are unlikely to alter the preferred option. Therefore, the results must be subjected to a range of different assumptions about effectiveness, which is possible using a sensitivity analysis. Where there is uncertainty about the costs and effectiveness of procedures, sensitivity analysis can be used. The sensitivity analysis looks at alternative assumptions of the key variables and examines the sensitivity of the results (Briggs, et al., 1993). Applying a risk opposing strategy is relevant when comparing a new technology to an established one. Assumptions are thus drawn when uncertainty arises.

Other economic evaluation tools exist such as the cost benefit analysis (CBA) which places a monetary value to the measure of effect; cost utility analysis and distributional cost effectiveness analysis which incorporates concerns for the distribution of outcomes as well as their average level and make trade-offs between equity and efficiency (Hosking and du Preez, 2004).

2.3 Discounting Benefits

Robinson (1993) posed a strong argument that costs that are acquired at varying points in time need to be weighted or discounted to reflect the fact that those which occur in the immediate future are of more importance than those which accrue in the distant future. Thus economists questioned if the effects of substitute processes should not thus be discounted. Some economists believe it is inappropriate to discount benefits. The stance has recently been fuelled after two department of health economists agreed to the desirability of a zero discount rate for benefits with Treasury in New Zealand (Cairns, 1992).

The argument is that health is not an interchangeable resource that can be invested to produce health in the future, nor does it have a fiscal worth that can be expected to increase with income over time. Furthermore, there is no evidence to support opinion that people view future health status as lower priority than the current (Robinson, 1993). Other economists, are of the school of thought that activities that impact on health such as excessive smoking and heavy drinking implies that people discount the future consequences of their actions. Furthermore, biologically humans become frail as they age thus the expectation of lower health in the future relative to the present is apparent (Cairns, 1992).

2.4 The Economics of Infrastructure

It is apparent that public goods are not governed by rivalry and excludability in contrast to private goods. According to RSA (1996) municipalities have a constitutional obligation to provide a safe, healthy environment while ensuring economic development and extending the provision of services in a progressive and sustainable manner.

The government continues to play the role of ensuring the provision of traditional infrastructures. Furthermore, the often stringent regulations and coordination of infrastructure projects are also enforced by the government. Infrastructure is defined as physical resource systems which are prepared for the public to utilize and increase productivity for socio-economic development. Natural resources may also be classified as infrastructure due to their contribution to the capacity to serve communities (Hosking and du Preez, 2004). Traditional infrastructures are found in the form of governance systems such as courts of law; communication systems such as telephone networks and postal services; transportation systems such as roads, railways, ports and airlines; and basic public services such as sewers and water systems (Fisher-Jeffes and Armitage, 2012).

The provision of infrastructure is thus not intended only for profit gain, but to foster competitiveness for the sustainable service by all to participate in economic endeavours, which contribute to the growth of the GDP. The view is supported by Frischmann (2007) who argues that instead of worrying that too many people will engage in commerce, we should worry that too few will undertake the effort.

Infrastructure asset management in an openly accessible manner may be socially desirable when it facilitates positive externalities. The infrastructure is public and nonmarket related, thus no one can be discriminated from utilizing the resource. A market mechanism has an inherent bias which often infringes on the rights of those who cannot afford to purchase the goods or services (Frischmann, 2007).

Lessig (2001) explains that it would be inequitable to allow private ownership of public infrastructure as the value of the infrastructure would thus increase as the demand increased leading to barriers to entry. In addition, private control may be inefficient and the owner would capture social surplus that ought to be distributed among the consumers who contributed to the value creation.

Ceteris paribus, the demand for a product will decrease as the price increases, thus exhibiting an inverse relationship between price and quantity of product demanded. Therefore selling basic water services would result in poor communities living in inhumane conditions, thus violating basic human rights. Lessig (2001) poses a strong economic argument that resources should be managed in an openly accessible manner regardless of identity of the end-user. However access to infrastructure is not entirely free, due to payments such as tolls for highways, rates for water provision and stamps for posting letters.

Internationally, an increasing number of cities have set up separate stormwater utilities (SU) and begun charging the public directly for stormwater management services in order to secure the necessary funding (PWD, 2012). Fisher-Jeffes (2013) proposes that stormwater may be funded by provision of a separate stormwater utilities in order to secure funding instead of through general municipal rates. Municipalities across South Africa charge for the provision of portable water and sewerage whereas stormwater management funds come from general municipal rates (Fisher-Jeffes et al., 2012). Honchell (1986) states that, charging for stormwater is not a way out of financial problems, but it offers a means of ensuring adequate resources for effective management of stormwater.

Fees are most commonly levied on the basis of impervious area, which is the effective area draining to the stormwater system. Campbell (2010) argues that any stormwater charge must thus be seen as a reasonable payment for the provision and management of stormwater infrastructure. This suggests that any money raised from fees should be spent on those who paid for the service. The author further states that South Africa is behind the rest of the world with numerous other governments already having established the legal frameworks and institutional capacity to charge service fees for stormwater management (Campbell, 2010).

One problem with this approach is the level of income disparity in South Africa is the highest in the world. According to the latest “poverty trends in South Africa” report, poverty rose in 2015 to 55.5% from a series low of 53.2% in 2011(StatsSA, 2019). In addition, the unemployment rate is extremely high reaching 27.5% in the third quarter of 2018 (Trading Economics, 2019).

South Africa uses a subsidiary system where high rates are charged in urban areas to fund poverty stricken communities who cannot afford to pay rates (Fisher-Jeffes and Armitage, 2012). Ideally the stormwater management fee should be calculated based on the burden that stormwater run-off from each property is potentially placing on the environment and the consequential cost to the local authority to prevent damage. In addition, run-off is also generated from public spaces which cannot be assigned to individuals (Fisher-Jeffes and Armitage, 2012).

Adequate water management will require significant financial input in the short term, but the contribution to the ecosystem would yield positive results (TEEB, 2010). In contrast, Flynn et al., (2018) argues that irrespective of extensive investments in stormwater infrastructure, urban areas are still susceptible to water management problems thus the high capital injections are not justifiable.

2.4.1 Externalities on Infrastructure Development

The economics of traditional infrastructure are regarded to be complex due to the combined effect of positive externalities, which are not completely appreciated by the suppliers of goods and services within an economic system. It has been observed that from the extension of transportation and communication networks, the large capital injections were often accompanied by additional social benefits which may not have been premeditated or accounted for (Lessig, 2001).

Demsetz (1967) suggested that the costs of operating a communal property will not be stated by the owner or the community that may benefit, due to an unwillingness to pay for the operating and maintenance of the premises. This perspective is limited as Demsetz focused exclusively on negative externalities and thus failed to appreciate the positive externalities which can be gained from communal property.

Negative externalities are a result of producers shifting some of their costs onto the community, thus depicting less of costs for the production of goods on the supply curves (Janse Van Renburg et al., 2015). EThekwini Municipality stormwater regulations stipulate that any development in officially drained properties in excess of the allowable 40 percent coverage must be managed by the property holder, due to the excess stormwater run-off generated (Stormwater Guideline, 2012). Figure 2.1 depicts the effects of development on the amount of stormwater run-off which can infiltrate the ground and recharge the water table naturally at a reasonable rate.

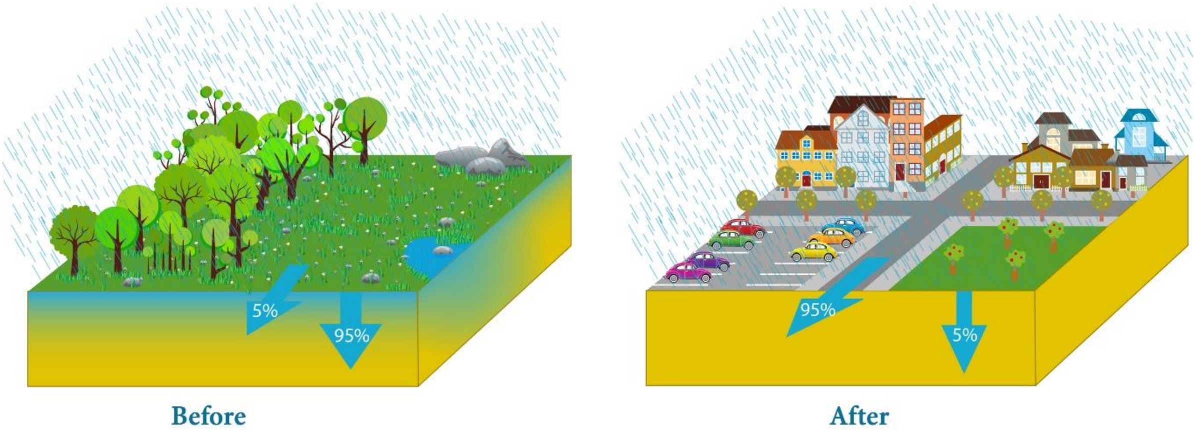

Figure 2.1: Stormwater Run-off Infiltration Before and After Development

Source: Author compiled from SUDS, 2018.

As seen in Figure 2.2, negative externalities accepted by society, supply curve S is generated by the producers is to the right of the full-cost curve St. Therefore, Qo, the optimal output is less than Qe, the equilibrium output (Janse Van Rensburg, 2015). The local government absorbs the negative externalities generated by developers who do not cater for the excess stormwater run-off, thus increasing the stormwater infrastructure budget required to mitigate storm damage.

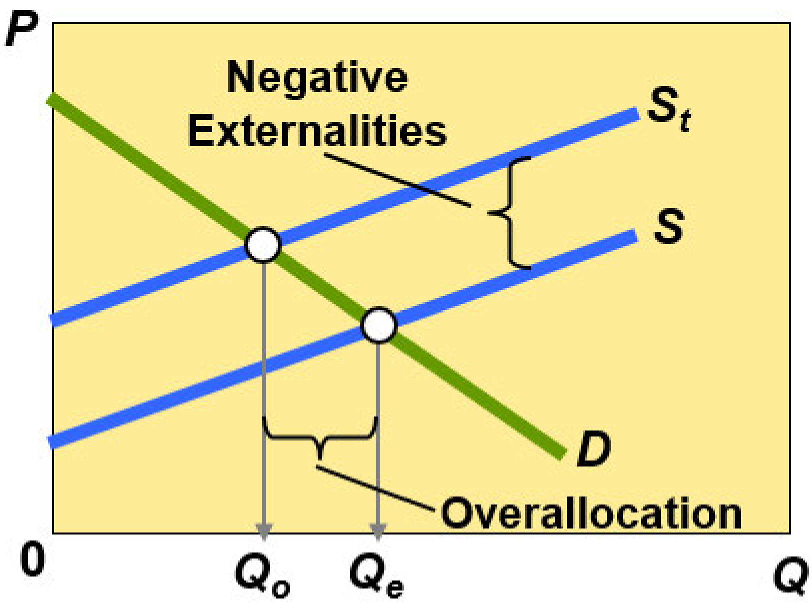

Figure 2.2: Negative Externalities

Source: Janse Van Rensburg, 2015: 399.

In contrast, Frischmann (2007) explains that due to a lack of adequate stormwater infrastructure, claims to the value of R300 million were submitted due to stormwater damage during the 10th October 2017 floods across eThekwini Municipality. Private property rights are well demarcated by the government through laws to protect against damage to private property, therefore allowing for parties suffering negative externalities to sue for compensation (Frischmann, 2007).

Tragedy of the commons is due to the abuse of resources with no monetary incentive to private establishments. It can be deduced that communities may lack incentives to incur the responsibility to dispose of waste responsibly when that responsibility may be transferred externally to society. Commonly used stormwater open channels are often polluted by dumping by upstream communities, thus decreasing the integrity of the system and amassing to the flooding problem. Therefore, it is imperative to pair investments infrastructure with the education of communities to enable an appreciation for resources provided. Furthermore, it is the governments mandate to correct the market failure caused by a third party on public shared resources such as the air, rivers, streams, oceans and parks (Janse Van Rensburg, 2015).

2.5 The Understated Importance of Stormwater Management Systems

Several studies have revealed that stormwater management receives significantly low funding within municipalities in South Africa (Fisher-Jeffes et al., 2013). This is due to institutional rationales, which relate income generation to infrastructure provision. Consequently, stormwater management is more often than not the responsibility of the roads department within Municipalities. The importance of stormwater management is lost in reactive measures which highlight, flood hazards and the rapid disposal thereof (Boshoff, 2009).

Stormwater management infrastructure is often inadequate due to insufficient budget allocation. However, stormwater management systems are imperative towards the preservation of private property value and, thus economic sustainability. Boshoff (2009), is of the thought that generally municipal infrastructure requires re-investment in maintenance and capital costs, with extrapolated results suggesting a current replacement cost of ZAR723 billion for all municipal infrastructure under the direct control of municipalities.

Leading from the Apartheid era when infrastructure development in Townships was not prioritized, thus a reactive approach is adopted rather than a proactive surge for development. Furthermore, townships were strategically positioned as labour hubs instead of economic hubs, thus this ideology is still perpetuated subconsciously by a lack of infrastructure which enables ease of trade and economic development and growth of property values.

A lack of integration of strategies within the Urban Water Cycle (UWC), which covers sanitation, stormwater, water supply and asset management results in an inadequate approach to water services (Fisher-Jeffes, 2012). In a water scarce developing country such as South Africa, the silo approach to solutions is out dated and requires a change in approach to fully utilize the water and finances at our disposal (Fisher-Jeffes, 2012).

2.6 Flooding and Climate Change Correlation

Alexander (2002) is of the notion that factoring climate change into flood design is unnecessary. The author poses the argument that rivers such as the Pienaar, Orange, Upington and Gamtoos have data which dates back to 1847 from flood level gauges, however the frequency and magnitude of the floods has not increased over the years (Alexander, 2002). The limitation in this study is that statistically the probability of a 100 year flood storm is every 100 years, thus one could argue that the data set is inadequate.

Similarly, the view on climate change is supported by Du Plesis and Burger (2015) who argue that the rainfall magnitude and frequency have not increased over time. The frequency analysis entailed measuring the frequency of rainfall events over a specified threshold. The results indicated predominantly inconsistent influence from the magnitude and frequency analysis on changing rainfall intensities, thus concluding climate change is not apparent (Du Plesis and Burger, 2015).

In contrast, Benhin (2006) argues that the magnitude and frequency of rainfall is expected to change due to climate change. Benhin (2006) states that an increase in extreme weather conditions such as droughts and floods are attributed to the accumulation of greenhouse gases in the atmosphere caused in part by the industrial revolution era. Shifting patterns of storm intensity and precipitation have been attributed to climate change thus exacerbating flood probability (Horton et al., 2014).

Brody et al., (2010) found an insignificant deliberation of climate adaptation in policy making and planning amongst local, provincial and national decision makers in the United States. Thus highlighting the lack of holistic strategies and compliance thereof.

Extreme rainfall events have caused significant damage to municipal infrastructure and private property over the past decade, particularly in the Western Cape (Holloway et al., 2010). The main limitation to most of these studies is the focus on 24 hour or daily rainfall instead of shorter rainfall periods. Design storm durations are often shorter than 24 hours, thus shorter duration measurements of rainfall are required.

2.7 Conventional Stormwater Management

Stormwater management is a longstanding environmental and societal challenge for communities and Municipalities who implement the infrastructure development. The type of system implemented is dependent on numerous factors such as the finances available, the spatial location and inclement weather conditions in the area (Flynn and Davidson, 2018).

Conventional stormwater management systems, as found in most developed countries utilize grey infrastructure such as deep storage tunnels, sewer separation projects and regional treatment facilities (Flynn and Davidson, 2018). The designs tend to favour centralized subsurface systems as a means to solving engineering problems. A typical stormwater management system would be composed of a manhole inlets at the edge of the road, which connects to a pipe network extending down through manholes towards a suitable outfall as seen in Figure 2.3 below.

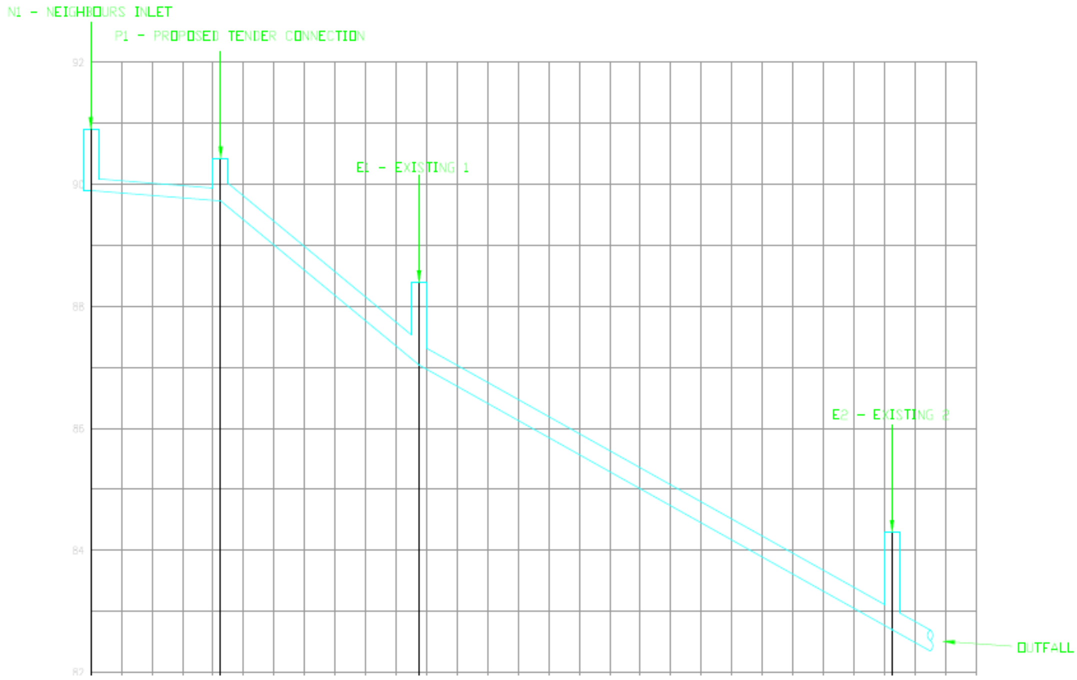

Figure 2.3: Typical Long Section

Source: eThekwini Municipality, 2018.

Stormwater pipe systems are predominantly composed of concrete pipes, which have a high durability and design life of approximately 50 years given the construction is adequate, thus very reliable. However maintenance is required at varying intervals due to structural defects and the removal of silt buildup within the system at entrance controls that may clog the structure and decrease the capacity.

2.8 The Utility of Attenuation Facilities for Stormwater Management Solutions

Stormwater attenuation utility is the incorporation of a pond and controlled outlet structure as a means of attenuating volumes of run-off which are equivalent to predevelopment conditions (Aldous and Buys, 2007). Therefore, the physical alteration of the discharge rate of run-off and timeframe from the catchment is stored temporarily in the attenuation pond in the post-development phase as seen in Figure 2.4 below.

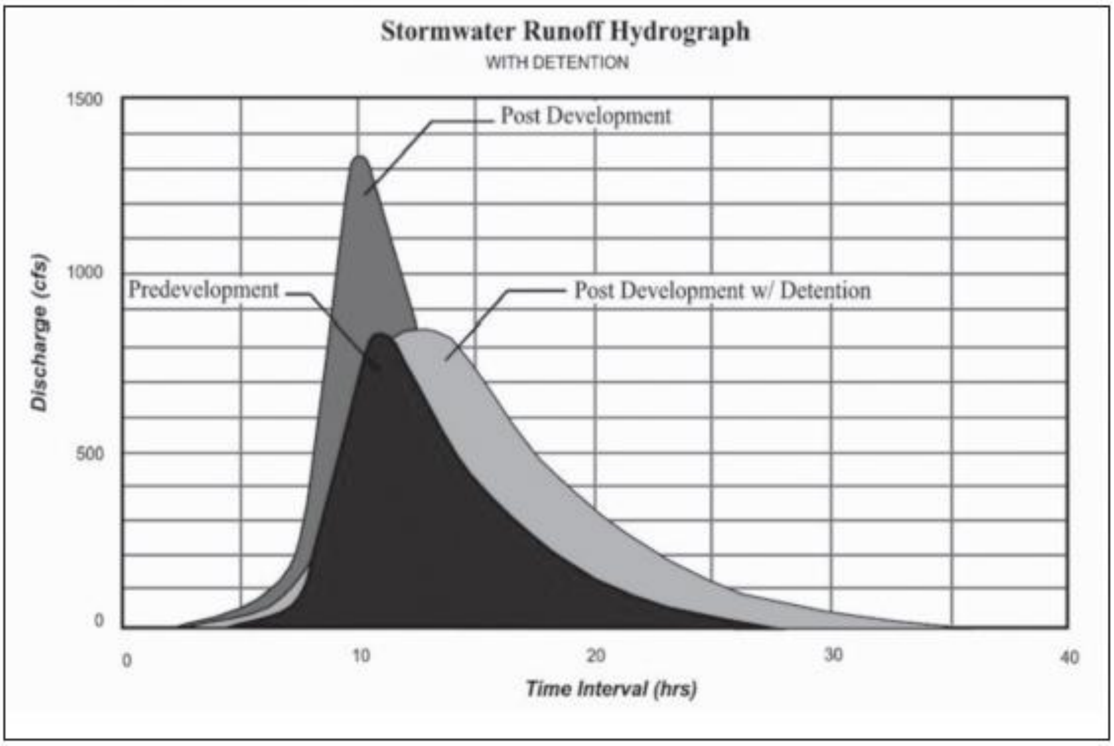

Figure 2.4: Typical Run-off Hydrograph for Pre and Post and Attenuated Storm Water Flows

Source: Buys and Aldous, 2007.

Attenuation structures may be constructed as 'dry' ponds which discharge completely over a delayed period after a storm event. The dry ponds may be open air ponds or constructed underground. The material utilized to construct the open air ponds varies as seen in Figure 2.5 and 2.6, where gabion walls and geosynthetic material were used respectively. Underground attenuation ponds are predominantly constructed using concrete and brickwork. Alternatively attenuation ponds may be constructed as 'wet' ponds which constantly have some water (Buys and Aldous, 2007).

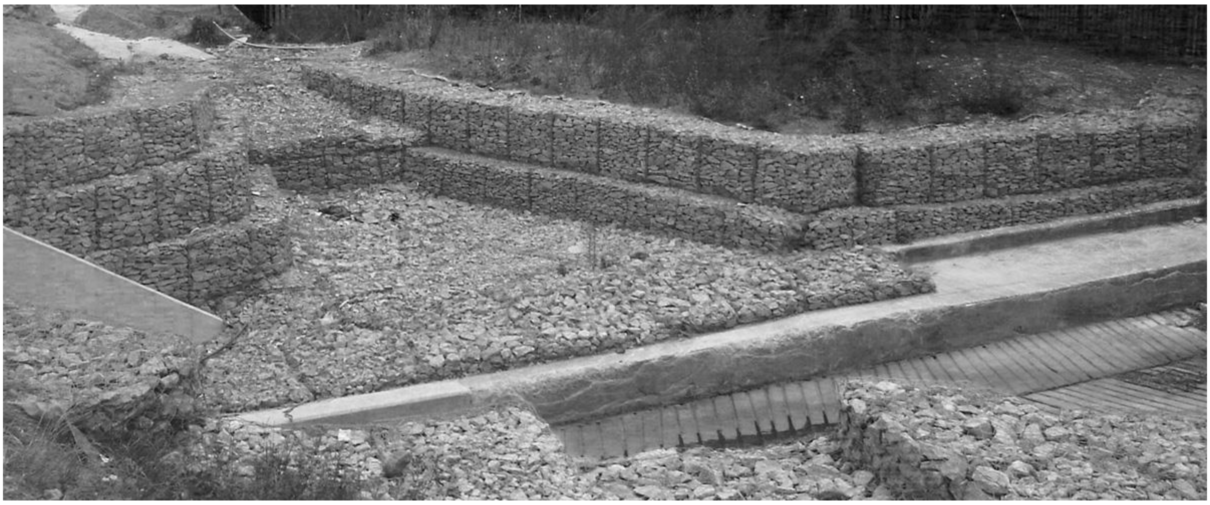

Figure 2.5: Typical Open-Air Stormwater Attenuation Pond in Johannesburg Area

Source: Buys and Aldous, 2007.

Figure 2.6: Construction of Attenuation Pond Using Geosynthetic Material

Source: Buys and Aldous, 2007.

The City of Johannesburg has created a stormwater management policy which mandates the use of attenuation ponds by private property developers to assist in controlling the volumes and speed of stormwater run-off entering the stormwater management system. In a constantly changing urban landscape burdened with urbanisation and increased population density, attenuation facilities improve the safety and protection against stormwater damage to properties (Buys and Aldous, 2007). The amount of impermeable surfaces in urban jungles significantly impacts on the time of concentration of stormwater run-off thus, increasing the risk of property value and loss of life during adverse weather conditions. Furthermore, Robson, Spence and Beech (2005) identified a correlation between a decline of biodiversity in natural watercourses and the increase in impermeable surface coverage.

Holistic integration of strategies is required to resolve the challenges facing infrastructure sustainability. The Johannesburg Metropolitan in alliance with the Integrated Development Plan (IDP) highlights the importance of an effective stormwater policy, however notes the current inadequacies of the on-site stormwater attenuation policy (City of Johannesburg, 2004). The 2007/2008 Spatial Development Framework (SDF) indicates an awareness of the stormwater infrastructure capacity being surpassed (City of Johannesburg, 2007). However, the Johannesburg

Roads Agency (JRA) are the authorized to implement and manage stormwater infrastructure (Johannesburg Roads Agency [Pty] Ltd, 2004).

The social and environmental impact of incorporating attenuating facilities provides a positive externality to the surrounding community by mitigating storm damage and biodiversity in ecosystems.

2.9 Sustainable Urban Drainage Systems

Due to volatile weather patterns and scarcity of resources, stormwater management methods seek to heighten the sustainability of urban water management by incorporating green infrastructure (GI). GI allows for stormwater management systems which are designed to restore or protect the natural hydrology, thus catering for flood control, water quality improvement or water harvesting (Flynn and Davidson, 2018).

Conventional stormwater management methods often require the destruction of ecosystems, high financial injections to construct extensive stormwater management networks, whereas GI offers an opportunity for transformational shifts in stormwater management, which are decentralized and offer multiple benefits to communities (Shuster and Garmestani, 2015).

Green infrastructure (GI), green stormwater infrastructure (GSI), low impact design (LID), best management practises (BMP) and sustainable urban drainage systems (SUDS) are all synonymous terms of reference to the new stormwater management technique which takes cognisance of the environment (Fletcher et al., 2014).

Sustainable urban drainage system (SUDS), propose the treatment of stormwater as close as possible to the source in as natural a manner as possible, which is an approach municipalities could look at in order to holistically gain multiple benefits that conventional systems do not offer. SUDS, is increasingly becoming the accepted best practice for managing stormwater internationally (Marsalek and Chocat, 2002). This is due to significant resource alleviation, biodiversity and socio-economic benefits which hold a compelling argument (Loos and Roger, 2016). As seen in Figure 2.7 below, stormwater may be collected from residential properties, through drain pipes and directed towards gardening systems or swales. Swales are a channel which allows for natural run-off infiltration and growth of vegetation. In addition, swales play a role of trapping pollutants and reduce the stormwater run-off velocity (U.S EPA, 1992).

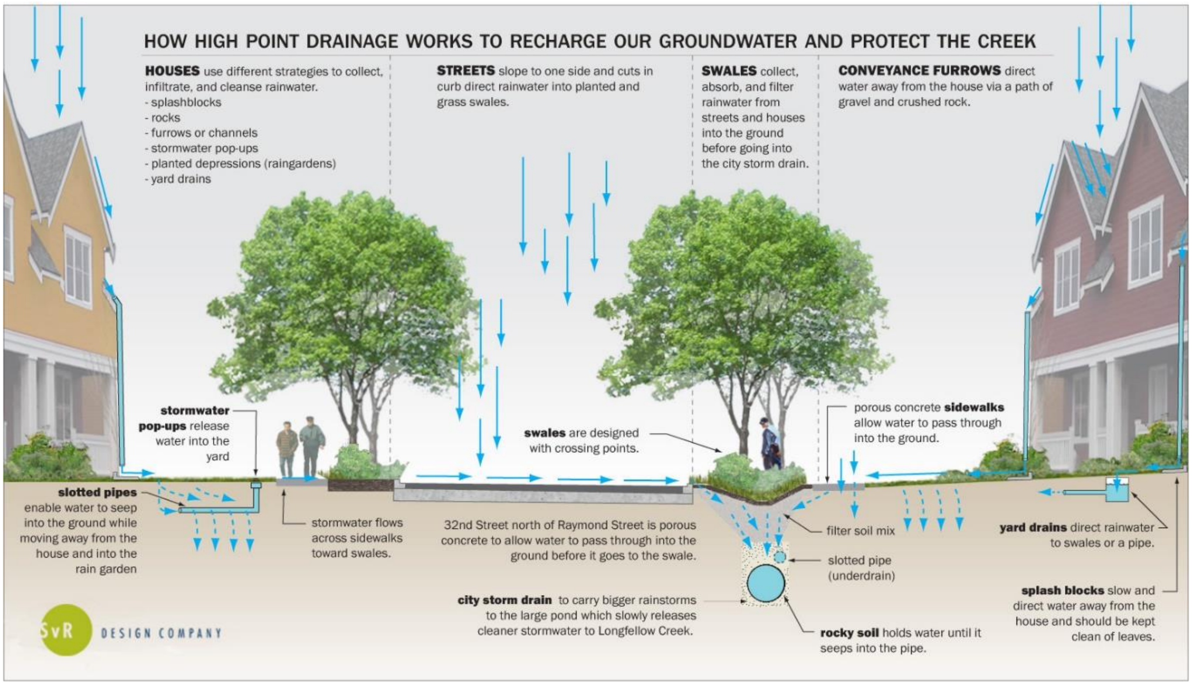

Figure 2.7: Sustainable Urban Drainage Example

Source: SUDS, 2018.

A notable challenge in working in built-up urban environments is the availability of suitable localities for SUDS. The spatial and progressive distribution of stormwater volumes in an urban location set clear boundaries on which technologies are applicable (Askarizadeh et al., 2015). Furthermore, soil characteristics and topography can hinder the process by being incompatible with the design (Shuster et al., 2014). For example clayey materials do not allow for water infiltration thus, the design of a swale on impermeable soil in the ideal location would be futile. Figure 2.8 depicts the use of dry wells as a stormwater detention, stormwater planter for natural infiltration, storm drain, permeable paving, rainwater harvesting cistern which stems from a green roof.

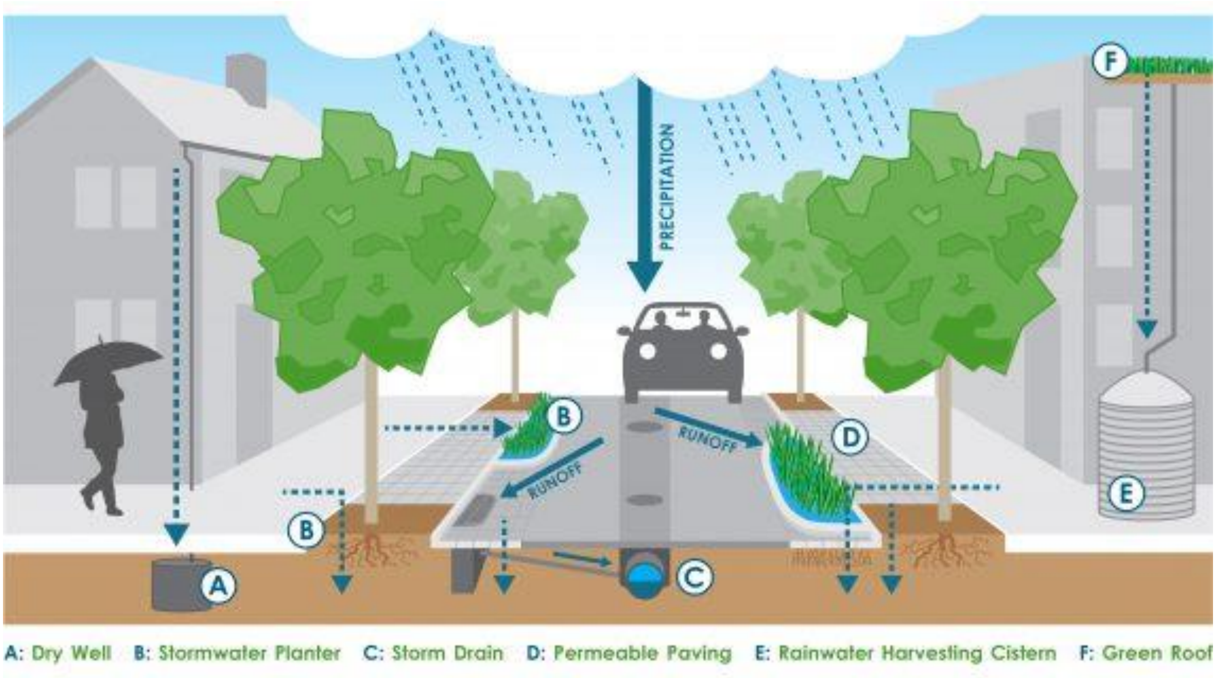

Figure 2.8: Example 2 of Sustainable Urban Drainage Systems

Source: SUDS, 2018.

Previous studies have found that the main limitations to SUDS are ordinances relating to water, environmental issues and the high funding requirements (Stockwell, 2009). A lack of alignment of enforcement officials funding expectations relative to financial authorities allowance may also be a barrier to implementation. It was found that calculating funding requirements based on the initial capital injection without including performance and maintenance costs, or if the community was not included in financial incentives it was divergent from the objectives (Parikh et al., 2005).

However, there is inconsistency with this study given the lack of information on the cost-effectiveness of SUDS. Nowacek et al., (2003) found that SUDS were enforced by government organizations with the objective to meet stormwater management outcomes in a cost-effective manner. In addition, GI technologies often exceed the benefits gained from environmental improvements and value-add to the community. For example, the utility of green roofs play a dual role of moderating stormwater and reducing urban heat islands.

Technological innovations are not tried and tested thus the legacy of GI infrastructure and the consequences thereof are unknown. The education of local communities on the purpose and functionality of SUDS contributes immensely to the success of stormwater management (Donovan et al., 2008). SUDS are often natural open stormwater systems, thus dumping by the community in the channel designated for swales defeats the purpose.

2.10 Social Effectiveness

It is essential for local government project managers and decision makers to understand the social consequences of projects. Social impact refers to actions which change the way in which people live, work and play. Furthermore, the cultural impact is included which highlights the changes to values, beliefs and rational and sense of self within society. Previously, it was a norm for infrastructure to be implemented based on economic autonomies in complete neglect of the social aspect. For example, the relocation of communities to new 'better' households due to the construction of a major road arterial would not include the social impact in the project. The change in distance relative to their workplaces and ancestral burial grounds of the community members would be completely ignored (U.S Department of Commerce, 1994).

The bias approach would reflect only the positive externalities reviewed. In addition, the impact of projects on vulnerable populations such as the poor, elderly, unemployed and culturally distinctive must be given attention. Therefore the consideration of the social equity and distribution amongst different stakeholders is just as important (U.S Department of Commerce, 1994).

Communities face the challenge of comprehending the impact of their vulnerability to floods due to the inability of stormwater infrastructure to cope with the demands (Loos and Rogers, 2016). Dumping in open areas and streams is commonly found in townships, specifically near informal settlements due to the lack of service delivery and ignorance amongst other factors. The dumping into open channels by informal settlement community members directly impacts on the probability to encounter flooding as seen in Figure 2.9 below.

Figure 2.9: Dumping in an open Channel along Cato Manor Township

The social constructs of reality are highlighted as affecting the human environment, thus consideration of both the government and communities perceptions and emotions are significant (U.S Department of Commerce, 1994).

The United States National Environmental Policy Act (NEPA) of 1969 appeals for the utility of social science in evaluating impacts on human environment to ensure integration of stakeholder requirements.

Shuster and Garmestani (2015) are of the sentiment that public participation is paramount to eradicating the misuse of public infrastructure. The education of the communities on the infrastructure that is meant to serve them, empowers them to better understand the functionality and actions which decrease the capacity thereof. This study explores the social effectiveness of the alternative stormwater management systems, however the lack of public participation poses as a research gap which can be done in future studies.

2.11 Environmental Effectiveness

The urbanisation and development of previously peripheral areas has become a double edged sword. An increase in economic emancipation in urban areas is directly related to an increase in environmental degradation (Flynn and Davidson, 2018). For example, the majority of Isipingo was once a Vlei onto which stormwater run-off from the Umlazi Township and surrounding areas would naturally infiltrate. In addition, Isipingo is positioned at a low point relative to Umlazi, thus it behaves like a basin. The residential and industrial development have occupied pre-development outfall and attenuation locations thus propagating the stormwater challenge in the area. The devastation caused by 1 in 100 year recurrence interval or greater storms in Isipingo along the N2 route is depicted in Figure 2.10 during the 10 October 2017 floods.

Figure 2.10: Devastating Floods in Isipingo Due to Adverse Storms on 10 October 2017

Source: Author Retrieved from WhatsApp, 2017.

According to RSA (1997) the Water Services Act, Act 108 of 1997 specifies that all government dominions are obligated to provide water supply services in an equitable, proficient and sustainable routine. One could argue that the provision of stormwater management is a right. However, eThekwini stormwater management systems are obligated to design for 1 in 3 year recurrence interval storms and 1 in 10 year recurrence interval storms at critical points such as low points and river crossings (Stormwater Guideline, 2012).

The re-vegetation and de-canalisation of natural water courses is an imperative operation towards the rehabilitation of streams towards achieving the objectives of the Integrated Water Resources Management (IWRM) strategy (Buys and Aldous, 2007). Environmental Impact Assessments (EIA) look at the threatened or endangers plants and wildlife species in the area (U.S Department of Commerce, 1994).

The incorporation of green infrastructure which encourage the conservation of natural ecosystems to provide benefits to communities is essential to achieve environmental, social and economic sustainability. Furthermore, the inclusion of green initiatives in land development and built infrastructure planning will produce holistic achievement of objectives, as highlighted in Spatial Development Frameworks (SDFs) (Benedict and McMahon, 2001).

In addition, National Environmental Management Act (NEMA) 1998, holds all persons accountable to avoid pollution, degradation of the environment and mitigate ecosystem disruption (South Africa, 1998b). However, a lack of integration of strategies and policies defeats the objectives as they tend to contrast on approach. Furthermore the implementation is a lack as local government enforcers are not privy to the strategies and policies in place.

Stormwater management systems which achieve the functionality required to cope with storms and promote biodiversity and preservation of ecosystems are imperative towards sustainability. This study aims to explore the utility of alternative stormwater management systems and to measure the environmental effectiveness.

2.12 Conclusion

The literature review seeks to make available understanding on the cost effectiveness of stormwater management systems considered namely conventional pipe networks, sustainable urban drainage systems and attenuation facilities based stormwater management. The utility of multiple dimension as a means to measure cost effectiveness enables informed decision making and comparison of design alternatives for project managers, although traditionally one dimension is considered.

Infrastructure distribution is the duty of the government to enable efficient trade and socio-economic growth for all members of the public. Stormwater infrastructure is mandated for all members of the public to occupy safe conducive environments however, only 1 in 3 and 1 in 10 year recurrence interval storms are designed for by EThekwini Municipality. Furthermore, 25 years into democracy basic infrastructure is still a lack in Townships.

There are positive externalities which are not appreciated with infrastructure development in only reviewing the economic consideration and negative externalities which the public impose onto government infrastructure which are also neglected which exacerbate infrastructure costs therefore, resulting in market failure and tragedy of the commons.

Conventional pipe networks as stormwater management systems are utilized due to their reliability and known stormwater functionality. Attenuation based facilities are a commanding structure for the purpose of temporarily storing stormwater run-off to allow for pre- development flow rates post development. SUDS are best practise internationally, however the implementation is slow locally.

The impact of climate change and the need for adaptation is contentious topic due to the increase in intensity and frequency in storms and floods over time, and the correlation thereof. Retrofitting stormwater management systems in urban developed environments is also a contentious challenge, due to a lack of space for the required infrastructure.

SUDS look at the holistic objectives of the infrastructure and the multiple benefits which could be possibly reaped from the design implemented. The resource alleviation, biodiversity and socio-economic benefits hold a compelling argument to the utility of green infrastructure as a sustainable means to stormwater management system implementation.

Comprehension of the social effectiveness of infrastructure is paramount to integrating the objectives of projects and strategies. Infrastructure serves a functionality, however the incorporation of social effectiveness strengthens the utility. Communities are vulnerable to economic consideration taking precedent, thus the exclusion of public participation process is a research gap. However, when public participation is necessary in a project, vulnerable communities are not privy to contribute to the design alternatives proposed for infrastructure development.

Infrastructure development is often at the expense of environmental consideration, which rescinds biodiversity and eco-systems. The inclusion of environmental effectiveness to stormwater management systems is paramount to achieving sustainability and compliance to existing water and environmental policies such as IRWM and NEMA.

Economic consideration is the predominant factor to infrastructure development, however the need for environmental and social effectiveness to be integrated is expressed by the strategies such as the Integrated Development Plan (IDP) and local government Spatial Development Frameworks (SDFs) which highlight holistic correlation of departmental objectives and regulations such as those set out by NEMA which is associated with environmental accountability. The lack of alignment of the above strategies and regulations with what is enforced at a local government level is apparent due to the lack of green infrastructure utility although it is best practise internationally. Chapter three will follow to present the research methodology used to conduct this study.

3. Chapter Three: Research Methodology

3.1 Introduction

The purpose of the third chapter is to make available understanding of the research methodology utilized in collecting data for this study. The objectives of this study are to conduct a cost effectiveness analysis of stormwater management system alternatives for a catchment in the Isipingo and neighbouring Umlazi area and evaluate three design alternatives as stormwater management systems. Chapter one provided comprehension to the need for the study due to recent devastating floods. In Chapter two, the literature review highlighted concerns relating to the understanding of the importance of stormwater management systems and the economic implications thereof.

The research methodology was designed to answer the research questions posed on cost effectiveness of stormwater management system alternatives. A scenario planning methodology was chosen to compare conventional pipe networks, SUDS and incorporating attenuation facilities in stormwater management system designs. The holistic contribution of infrastructure development to communities is important, therefore the environmental and social effectiveness of the stormwater management systems will also be incorporated into the cost effectiveness analysis by utilizing a multi-criteria decision matrix.

3.2 Aims and Objectives

The aim of this study is to establish the cost effectiveness of alternate stormwater management systems within eThekwini Municipality, specifically for a catchment which encompasses the Isipingo and Umlazi area.

The research objectives are as follows:

1) To evaluate the cost effectiveness of three stormwater management systems, namely conventional pipe networks, sustainable urban drainage systems (SUDS) or incorporating attenuation facilities in stormwater management system designs;
2) To evaluate the social effectiveness of the three stormwater management systems;
3) To evaluate the environmental effectiveness of the three stormwater management systems.

3.3 Research Strategy

The research strategy that will be used in this study is quantitative. Secondary data will be utilized to conduct a scenario based research methodology. A quantitative research strategy is appropriate in addressing the research question as it enables an objective analysis of the cost implications of design alternatives. Furthermore, a numerical method eliminates personal perceptions and subjective opinions to produce results which are highly dependable and can be easily duplicated (Saunders et al., 2012).

The purpose of scenario based research is to enable a comparison of design alternatives that best serve the objectives of all stakeholders. The primary objective is to design alternate stormwater management systems which mitigate 1 in 100 year recurrence interval storms and compare the cost effectiveness thereof. Economic consideration of the designs is of high importance in the current economic climate in South Africa. South Africa was in a recession in the first and second quarter of 2018 prior to a 2.2% growth in the third quarter (STATSSA, 2018). Furthermore, a multi-criteria decision matrix will incorporate the social and environmental effects of the alternate stormwater management systems. Cost, environment and social effectiveness will weigh 60, 30 and 10 percent respectively towards a holistic and sustainable solution.

Strategic design scenarios will be utilized to compare stormwater network design alternatives. Scenario planning enables the pros and cons of each alternative to be weighed against the set benefit. This tool enables the convergence of social and economic challenges which are often in conflict (Aldrich, 2018). The incorporation of a multiplicity of outcomes further strengthens the objectivity of the results.

Furthermore, collecting and comparing the Bill of Quantities (BOQ) using a set cost criteria for the stormwater design alternatives allows for a faster turnaround time as opposed to conducting interviews from project managers to gather their perspectives on the proposed stormwater management systems.

3.4 Research Paradigm and Approach

The positivist research paradigm and a deductive approach underpin the quantitative research design, thus reflecting positivist philosophical assumptions. The use of a multi-criteria strategy to arrive at a cost effective solution to the stormwater management systems presented, is appropriate for addressing the research questions as it takes into account the needs of different stakeholders, the residences, commercial property owners and the municipality. Moreover, a cost effective solution will be chosen to serve all stakeholders whilst including the environmental and social effectiveness.

3.5 Study Site

The location of the study is in the Southern region of eThekwini Municipality in the townships of Isipingo and Umlazi. A catchment accumulating stormwater run-off from a portion of Umlazi kwa-V sections, the Isipingo commercial and industrial area will be the focal point of the study as seen in Figure 3.1. The catchment area is highlighted in red and amounts to 56.05 hectares. The area was chosen due to the devastating impact of the June 2016 and October 2017 1 in 100 year recurrence interval storm which endangered the residential, commercial and industrial properties in the area.

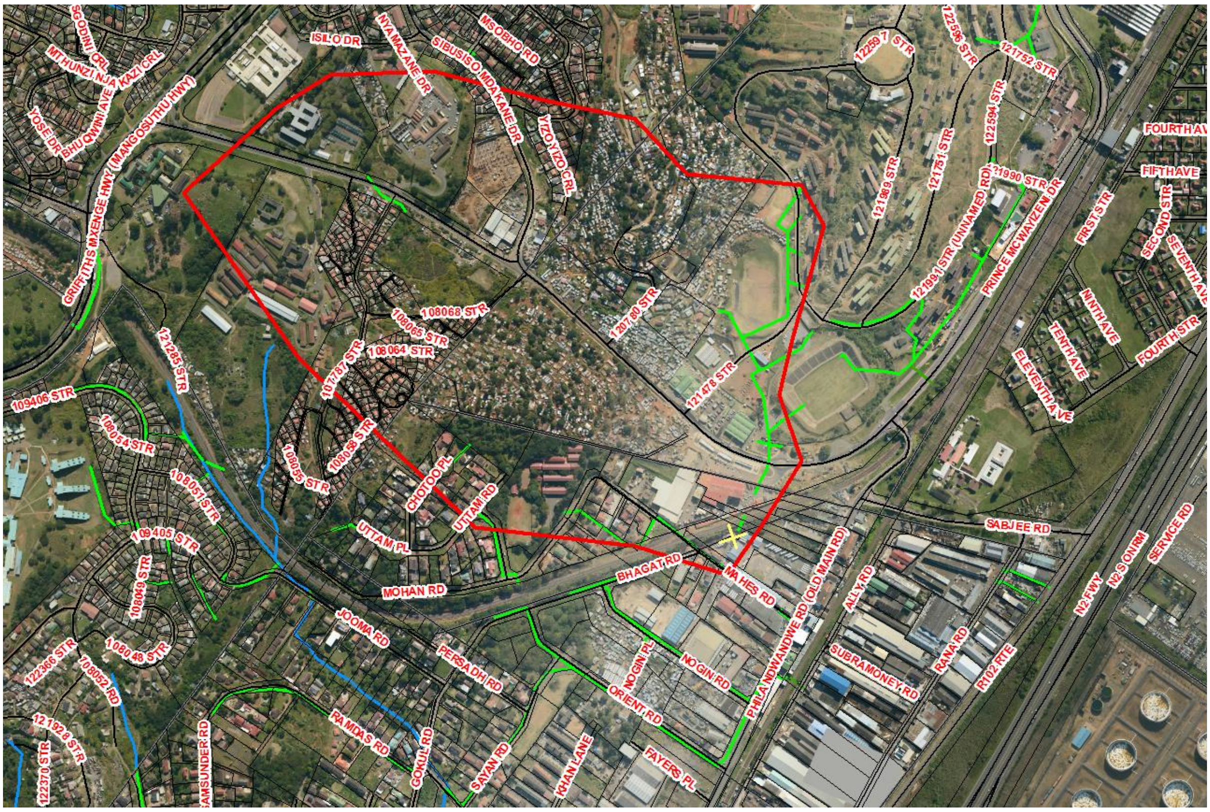

Figure 3.1: Locality Map of Catchment and Existing Stormwater Management System within Catchment Sourced: ArcGIS eThekwini Municipality

The higher portion of the catchment is composed of commercial premises, open areas and informal settlements along Prince Mcwayizeni Drive. The Informal settlements do not have formal service provision thus waste is predominantly disposed of in the stormwater channels running adjacent. Jeena’s Supermarket is the low point of the catchment, thus during the flash floods the warehouse doors acted as dam gates for the stormwater to pass into the culvert behind the premises. Furthermore, a large amount of debris is washed into the stormwater network, thus blocking the system and escalating the problem.

Umlazi V-section is a predominantly mountainous area whereas, Isipingo is situated at lower elevations in flatter terrain. The average gradient across the catchment is 14 per cent, therefore allowing for high stormwater run-off velocity.

There are two existing formal stormwater systems which drain the catchment, as demarcated in green in Figure 3.1 above. The systems combine at Jeena's Supermarket and drain to a culvert passing under the railway line. The culvert further connects into another culvert which flows through the bus depot and towards a canal system, which discharges into a Vlei between the N2 highway and the R102. Water collecting in the Vlei drains via a canal system through Isipingo and into the Indian Ocean, through an outfall.

3.6 Stakeholders in the Study

Stakeholders are defined as individuals, groups or organizations that have a vested interest in the outcome of a project (Project Manager, 2018). The stakeholders relevant to this study will be members whom are affected by the stormwater within the selected catchment area, thus eThekwini Municipality, the residential community of Umlazi V-section, and the commercial property owners within Isipingo and Umlazi are the stakeholders for this study.

eThekwini Municipality, will supply the resources required to conduct the research. Furthermore, the study will contribute towards the development of cost effective consideration when project managers within the Municipality consider design alternatives.

The residential community of Umlazi V-section are directly affected by the impact of the severe storms, thus the mitigation thereof grants a safe and conducive environment for residing.

The commercial property owners on the downstream of the catchment were negatively affected by storms in previous years, which lead to insurance claims in the millions of ZARs and loss of business. The mitigation of the storms would enable the prevention of damage to property, preservation of property value, jobs and contribution to the GDP.

3.7 Research Instruments

The primary research instruments utilized in this study are Personal Computer Storm Water Management Model (PCSWMM) and Microsoft excel. PCSWMM was used to model the stormwater management plans whilst Microsoft excel was used to analyse the data collated. The secondary research instrument utilized was the eThekwini Municipality Geographic Information System (GIS), where attribute data is stored and analysed in spatial maps (ArcGIS, 2018).

In 1978, Computational Hydraulics International (CHI) established themselves as software developers, thus introducing PCSWMM. PCSWMM is a stormwater management modelling software, with the latest upgrade, version 7.1.2480, being introduced in 2017. A licence was purchased by eThekwini Municipality for the purpose of modelling stormwater management solutions.

PCSWMM was chosen due to its ability to model the stormwater management design alternatives which can be analysed from an economics perspective. The procedure for recording data fits the research as an in-built scenario planning tool exists within the software. Furthermore, it addresses the research question number one which is “To evaluate the cost effectiveness of three stormwater management systems, namely conventional pipe networks, SUDS or incorporating attenuation facilities in stormwater management system designs”. Attendance of the PCSWMM course from 11 to 14 September 2018 was completed to gain understanding of the abilities of the software, which was conducted in Cape Town by the developers of the software, CHI water.

Microsoft Excel was used for its ability to calculate, tabulate and statistically analyse data; therefore enabling data entry, analysis and visualisation of results. The production of the multi-criteria scenario matrix to weigh the economic, social and environmental effectiveness of the stormwater management systems was also prepared in Excel.

PCSWMM allows for the input of accurate data from Digital Elevation Maps (DEM), which is retrieved from verified sources such as Light Detection and Ranging (LIDAR) surveys (Survey, 2016). Furthermore, PCSWMM allows for the importing of known attributes such as soil properties and rainfall data, which are appropriate to the location.

Well renowned reviews of PCSWMM as a research instrument proved difficult as no review panels from accredited bodies were found, thus being a shortcoming of this study.

The data collection method is scenario based research. The rationale is that it enables an objective analysis and comparison of design alternatives. Furthermore, a numerical method eliminates personal perceptions and subjective opinions to produce results which are highly dependable and can be easily duplicated.

3.8 Study Procedure

The research design called for the use of secondary data to conduct a scenario based research methodology. A quantitative research strategy was appropriate in addressing the research question as it enables an objective analysis of the stormwater management system design alternatives.

The purpose of scenario based research was to enable a comparison of design alternatives that best serve the objectives of all stakeholders. The primary objective was to design alternate stormwater management systems which mitigate 1 in 100 year recurrence interval storms and to compare the cost effectiveness thereof. The inclusion of social and environmental effectiveness produced a multi-criteria research, which strengthened the objectivity.

The literature review provided insight into the material using secondary data to emphasize challenges which include economic, social, environmental and legislative concerns.

The methodology procedure was conducted as seen in the following flowchart, Figure 3.2:

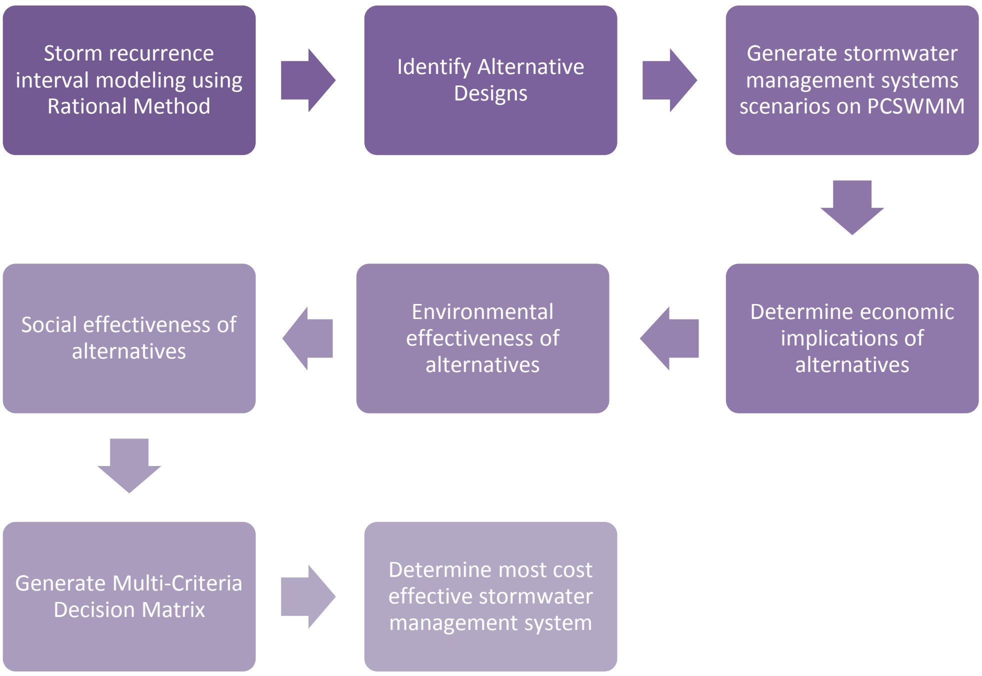

Figure 3.2: Methodology Procedure Flowchart

3.8.1 Stormwater Run-off Calculations

A stormwater design was required to be conducted to understand the 1 in 100 year recurrence interval storms run-off flow rate. The Rational Method, as seen in Equation 3.1 was employed to calculate the run-off flow rate using an excel spread sheet which required catchment specific inputs as seen in Table 3.1 below.

Equation 3.1: Rational Method Equation

Source: eThekwini Guideline, 2012.

Rational Method Equation	**Q= ft*C*I*A/360 (m3/s)**

Where:

Q = design run-off flow rate (m^3/s)

F_t = Recurrence interval factor

C = Run-off coefficient

I = Rainfall Intensity (mm/hr)

A = Area of overland run-off (Ha)

Table 3.1: Input Characteristics of Catchment

Source: ArcGIS, 2018.

Characteristic	Value	Units
Catchment Size	56.05	Ha
Slope	14.6	%
Run-off Length	1232	m

The appropriate pipe size required to cope with the catchment run-off flow rate was then calculated using the Nomograph and Manning's equation. The slope of the outlet pipe (12%) and the calculated run-off flow rate was used to determine the required diameter on the Nomograph. Manning's equation is found in Equation 3.2 and the Nomograph is presented in chapter four Table 4.2.

Equation 3.2: Manning's Equation

Source: eThekwini Guideline, 2012.

Manning's Equation	Q=(1/n)*(D/4)^2/3*(S1/100)^1/2*(Π*(D^2/4))

Where:

Q = Capacity of pipe required (m^3/s)

n = Roughness coefficient

D = Diameter of pipe required (m)

S_1 = slope of pipe used (%)

3.8.2 PCSWMM Modelling

The conventional stormwater management system was modelled first using PCSWMM. The design was composed of standard concrete pipes and stormwater manholes which are composed of brickwork, mortar and concrete. Pipes are referred to as conduits whilst manholes are junctions on PCSWMM. A LIDAR survey clip was imported into PCSWMM to transfer geographic information from ArcGIS. The model was then created by placing conduits and junctions appropriately along the flow path with an outfall at the end, as seen in Appendix 7, a long section of the conventional stormwater management system (PCSWMM, 2016). Watershed delineation was used to accurately split the catchment into sub-catchments. The characteristics of the catchment such as infiltration, imperviousness and rainfall gauge are required to be setup prior to running the simulation. Pressing run on the PCSWMM software enabled the model to simulate and see the profile and behaviour of the stormwater run-off through the system. The results indicated a flow rate along the flow path.

In the event of surcharging or flooding of the stormwater management system, the model depicts the junctions that are not managing in red at a specific time as seen in Appendix 8 below.

The design can thus be altered and run again to ensure the surcharging and flooding points are removed from the system. The status tab shows the flow rates and checks required to validate the design.

Design alternative two considered the use of SUDS to alleviate for a 1 in 100 year recurrence interval storm. A new file was established on PCSWMM using the scenario planning manager to duplicate the file and rename it accordingly. Scenario two uses swales along the stormwater run-off path and a communal sports field which acted as run-off storage during storms. The model was simulated to determine the stormwater run-off behaviour within the SUDS. The long section of the SUDS profile is seen in Appendix 9 below.

Scenario three was created to model the simulation of the attenuation facilities based stormwater management system. Attenuation one was composed of gabion walls and the natural ground as base, whilst attenuation two was composed of concrete. The flow path was setup with pipes connecting the two attenuation facilities, one at the top in an open field and the other at the bottom of the catchment underground beneath Jeena's Supermarket parking area. The model was run to simulate the flow behaviour as seen in Appendix 10 below. The flow rate was thus checked for any inconsistencies (PCSWMM, 2016).

The PCSWMM modelling step by step guideline is found in Appendix 2 or further help can be obtain via the PCSWMM help link as follows:

http://www.chiwater.com/Software/PCSWMM.NET/Help/

Due to the lack of clarity of the long sections from the PCSWMM modelling, drawings were done on Civil Designer-3D to better illustrate the long sections of the stormwater management alternatives as found in Appendix 4 to 6.

3.8.3 Cost Effectiveness Analysis

Upon completion of the stormwater alternative designs, the cost implications of constructing the conventional stormwater system, SUDS and the attenuation based stormwater system was determined by gathering quotation from suppliers for the bill of quantities (BOQ) and collated on an excel spreadsheet.

15% of the total BOQ value will be added to the sub-total of each stormwater management system as the contractor's labour and profit margin. Furthermore, 15% Value Added Tax (VAT) will be included to attain an ultimate total.

Table 3.2 depicts the criteria utilized to determine the cost effectiveness of the stormwater management design. The scoring ranges from 1-5, with 1 reflecting high construction costs that are greater than R10million and 5 reflecting low construction costs which are less than R1million. The score and set criteria thus exhibit an inverse relationship. The cost effectiveness analysis will contribute 60 percent to the multi-criteria decision matrix.

Table 3.2: Cost Effectiveness Analysis

Score	Criteria	Scenario 1: Conventional Pipe Network	Scenario 2: Sustainable Urban Drainage Systems	Scenario 3: Attenuation Facilities
5	< R1 million			
4	R1million < Design > R2 million			
3	R2 million < Design> R5 million			
2	R5 million < Design > R10 million			
1	Design > R10 million			
Economic Score				

3.8.4 Environmental Effectiveness Analysis

The environmental performance of each stormwater design alternative will be determined relative to the set criteria. A measure of how environmentally friendly the project will be deduced by evaluating the structures used for the stormwater management systems and overall contribution to the socio-ecology of the area. Environmental consideration is paramount to the preservation of ecologies, thus the scoring will range from 1 to 5, with 1 being poor and 5 being excellent contribution to the environmental effectiveness as seen in Table 3.3 below. A stormwater management design which deteriorates the environment will be scored very poorly with a score of 1 as opposed to a design which contributes positively to the eco system which will be scored excellent with a score of 5.

Table 3.3: Environmental Effectiveness Score Range

1	2	3	4	5
Very Poor	**Poor**	**Good**	**Very Good**	**Excellent**

Environmental consideration will be weighted 30 percentage contribution to the overall multi-criteria design matrix, as seen in Table 3.4. The designs will thus be evaluated and scored according to the following Table 3.4.

Table 3.4: Environmental Effectiveness Analysis

No.	**Criteria**	**Scenario 1: Conventional Pipe Network**	**Scenario 2: Sustainable Urban Drainage Systems**	**Scenario 3: Attenuation Facilities**
1.	Are the materials for the construction of the design natural?			
2.	Was an ecosystem degraded for the construction?			
3.	Does the design restore biodiversity?			
4.	Does the design promote sustainable objectives?			
5.	Does the design serve the community's needs?			
Score Calculation				
Environmental Score				

3.8.5 Social Effectiveness Analysis

The social performance of the stormwater management systems alternatives will be determined using the set criteria. A measure of how the stormwater management system structure contributes to the social ability of the community was explored. The scoring will range from 1 to 5; stormwater management systems which do not integrate a social effectiveness will be scored 1, which indicates very poorly relative to designs which fully integrate social consideration which will receive an excellent score of 5, as seen in Table 3.5 below.

Table 3.5: Social Effectiveness Score Range

1	2	3	4	5
Very Poor	**Poor**	**Good**	**Very Good**	**Excellent**

The social effectiveness analysis will be weighted 10 percent contribution in the multi-criteria matrix as seen in Table 3.7. Table 3.6 was used to deduce the social impact of the stormwater management alternatives.

Table 3.6: Social Effectiveness Analysis

No.	**Criteria**	**Scenario 1: Conventional Pipe Network**	**Scenario 2: Sustainable Urban Drainage Systems**	**Scenario 3: Attenuation Facilities**
1.	Does the structure contribute to the way people, live, work and play directly?			
2.	Was a social area removed for the construction of the design?			
3.	Does the design facilitate socializing?			
4.	Does the design contribute to improving social constructs?			
5.	Will the design improve the culture in the community?			
Score Calculation				
Social Score				

3.8.6 Multi-Criteria Decision Matrix

A multi-criteria decision matrix was generated to weigh the economics, environmental and social performance of each stormwater management design relative to the criteria. The weighting was 60, 30 and 10 respectively as seen in Table 3.7 below. The scoring was therefore utilized to determine the most cost effective stormwater management system.

The multi-criteria decision matrix is key to the integration of different strategies which are often in contention. For example, the contemplation to construct infrastructure in a wetland which would obliterate the ecology or expropriate private property and uproot a community socially. The implementation of stormwater management systems by local government enforcers is challenging due to retrofitting in an established urban background, therefore the multi-criteria decision matrix enables an objective sustainable approach which encompasses different aspects to be incorporated.

Table 3.7: Multi-Criteria Decision Matrix

Description	**Weighting (%)**	**Scenario 1: Conventional Pipe Network Score (1-5)**		**Scenario 2: Sustainable Urban Drainage Systems Score (1-5)**		**Scenario 3: Attenuation Facilities Score (1-5)**	
		Score	Weighted Score	Score	Weighted Score	Score	Weighted Score
Cost Effectiveness	60						
Environmental Effectiveness	30						
Social Effectiveness	10						
Final Score (out of 5)							

3.9 Data Analysis

The PCSWMM model will be able to deduce for a 1 in 100 year recurrence interval storm, the capacity required for each design alternative to mitigate flooding. Furthermore, the models will be able to stipulate the sizes of the conduits and medians required to prevent flooding. PCSWMM will convey the efficiency of each design alternative by displaying the flow rate, head and conduits sizes required to cope with a 1 in 100 year recurrence interval storm. The data will be organized in tables and long sections from the research instruments.

The resulting BOQs for the conventional stormwater system, SUDS and attenuation based system will contribute to the cost effectiveness analysis utilising the set criteria. A score will be given to the stormwater management system based on the associated costs. The environmental effectiveness will be analysed using the set criteria to deduce the environmental consideration of each stormwater management system. The social effectiveness will be deduced using the set criteria to establish the social consideration of the structural components of the stormwater management systems.

The multi-criteria decision matrix will be employed to incorporate the cost, environmental and social effectiveness of the alternative stormwater management systems by weighting the score 60, 30 and 10 respectively to achieve sustainable, holistic objectives. Furthermore, the multi-criteria decision matrix enables an objective comparisons of the alternative stormwater management systems.

3.10 Ethical Consideration

Participation of people was not utilized in this study, thus consent agreements were not drafted. A gatekeepers letter was retrieved from eThekwini Municipality as a means of getting approval to conduct the research and utilize the available data and tools as seen in Appendix . The ethical clearance is also attached in Appendix in compliance with the institution's ethical procedures.

3.11 Conclusion

The purpose of the third chapter was to explain the research methodology used for this study. Cost effectiveness is a contentious issue, in a developing country where infrastructure is required however, the costs may be inflated.

The PCSWMM modelling was conducted compare the alternative stormwater management designs considered and determine the components required to construct a system which mitigates a 1 in 100 year recurrence interval storm. The cost effectiveness analysis was conducted by compiling BOQs for the conventional, SUDS and attenuation based stormwater management system. Modelling is an iterative process which requires trying different combinations of components to try and resolve the problem at hand.

Considering the cost alone in the implementation of projects is bias and perpetuates a silo approach which is not sustainable thus, the inclusion of environmental and social effectiveness criteria were implemented. The criteria was set out to evaluate each stormwater management system and the scoring thereof.

The utility of a multi-criteria decision matrix was employed to integrate the cost, environmental and social effectiveness in aligning with existing strategic policies and the sustainability thereof. Furthermore, to arrive at a weighted cost-effectiveness analysis which approaches the project objectively and holistically. The results and discussion of the stormwater management systems will be further discussed in chapter four.

4. Chapter Four: Results and Discussion

4.1 Introduction

The purpose of the fourth chapter is to present and analyse the information collected from the stormwater run-off calculations, PCSWMM modelling, environmental and social effectiveness assessments of the alternative stormwater management systems and the cost effectiveness analysis which utilizes the multi-criteria scenario matrix as a decision making instrument. The discussion of the results will follow accordingly.

4.2 Stormwater Run-off Calculations

The input of the catchment characteristics resulted in a Time of Concentration (Tc) of 9.8 minutes which is below the allowable 15 minutes, therefore 15 minutes was used to deduce a run-off flow rate of 38.10 m^3/s using the rational method as seen in Table 4.1 below.

Table 4.1: Stormwater Run-off Calculation

Source: Author calculated using EThekwini Municipality Stormwater Guidelines (2012).

Stormwater Design Spreadsheet			
Location: Isipingo/ Umlazi	**KwaJeena Outfall**	**Catchment 1**	
Input	**Equations**	**Amount**	**Unit**
Rational Method			
Overland Flow			
Area, A	A=(L*B)/10000	56.05	Ha
Catchment Average Slope, S_1	$S_{1=}Y_2$-Y_1/X_2-X_1	0.146	
Run-Off Length	L_1=sqrt(L^2+B^2)	1232	m
Actual Time of Concentration, Tc_1	Urban min Tc	15	min
Kerby Time of Concentration, TC_{k1}	$TC_{k1}= 36(r_1L_1/1000/S_1^{0.5})^{0.467}$	40.19	min
Kerby Factor r_1	Roughness Factor Table	0.30	
where runoff L, >200m			
Streamflow Bransby-Williams Tc	$Tc=60(0.87*L^2/10^9/S)^{0.385}$	**9.80**	min
Combined Area	Sum(A)=A1	56.05	Ha
Recurrence Interval, RI		100	years
RI Reduction Factor, f_{t1}	Recurrence Interval Table	1	
Run-Off Coefficient, C_1	$C=(Cs+Cp+Cv)xf_{t1}$	0.95	
Rainfall Intensity, i_1	Rainfall Gauge, interpolate on Tc used	257.6	mm/hr
Runoff Flow Rate, Q_1	$Q= f_t*C*I*A/360$	38.10	m^3/s

Using the 38.10 m^3/s flow rate and the slope of the pipe of 12%, a required diameter of 1.68m was deduced using the Nomograph as seen in Appendix 1. Manning's equation therefore generated a required flow rate based on the required diameter. Due to the fact that the pipe diameter sizes are determined by manufacturers, an appropriate size that is slightly greater than the required diameter was thus chosen as the actual pipe diameter. A pipe diameter of 1.8m was ultimately chosen, which has a capacity to handle a stormwater run-off flow rate of 43.12 m^3/s as seen in Table 4.2 below. Therefore a 1.8m diameter pipe will utilize 66.7% of its capacity to withstand a 1 in 100 year recurrence interval storm.

The 66.7% utility allows for contingencies where a storm, which is greater than the one designed for occurs, thus allowing for an additional 5.02 m^3/s can be catered for. This safety factor is imperative to overall flood mitigation, in cognisance of the probability of stormwater management systems being polluted and blocked by debris, specifically during flood events which decrease the capacity. Furthermore, taking climate change into account, the intensity of storms is likely to increase, thus additional capacity decreases the risk of flooding. The costs of construction increase annually due to escalation, therefore it is always better to implement infrastructure, which will not require extensions in the foreseeable future.

Table 4.2: Outlet Pipe Sizing Calculation

Source: Author generated from EThekwini Municipality Stormwater Guideline, 2012.

Outlet Pipe Sizing			
Roughness Coefficient, n	Smooth	0.012	
Diameter of Pipe Required, D_{req}	From Nomograph	1.68	m
	Mannings Equation		
Capacity of Pipe Required, Q_{req}	$Q_{req}=(1/n)*(D/4)^{2/3}*(S_1/100)^{1/2}*\prod*D^2/4$	35.870	m^3/s
Diameter of Pipe Used, D_{u1}		**1.8**	m
Survey Slope of Pipe Used, S_1		12.00	%
Length of Pipe Used, L_{u1}		980	m
Capacity of Pipe Used, Q_{u1}	$Q=(1/n)*(D/4)^{2/3}*(S_1/100)^{1/2}*\prod*D^2/4$	**43.12**	m^3/s
Max. Flow Velocity in Pipe Used, V_{max1}	$V=Q/\prod D^2/4$	16.952	m/s
Flow Time in Pipe Used, T	T=L/V/60	0.964	min
Time of Concentration at CP	Sum(Tc)	15.964	min

4.3 PCSWMM Modelling

4.3.1 Conventional Stormwater Management

Arriving to the final configuration for the conventional stormwater management system was an iterative process. The system indicated significant surcharging at junctions when using 1.2 diameter pipes as seen in Figure 4.1 below. Ultimately using 1.8 diameter pipes and a sports field as a storage pond assisted the conventional stormwater management system to cope with the 1 in 100 year recurrence interval storm as seen in Figure 4.2 of the profile and the layout in Figure 4.3. The components of the stormwater management system is captured in Table 4.3 and 4.4 below.

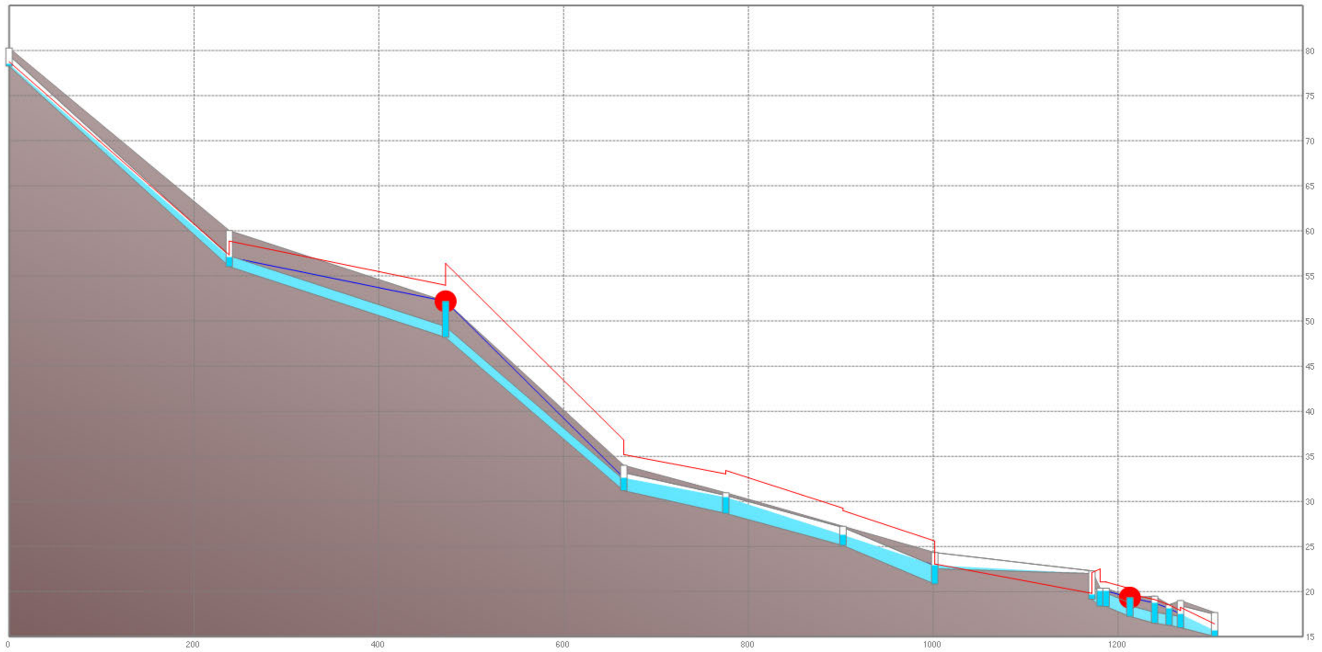

Figure 4.1: Conventional Configuration with Surcharging

Source: PCSWMM, 2018.

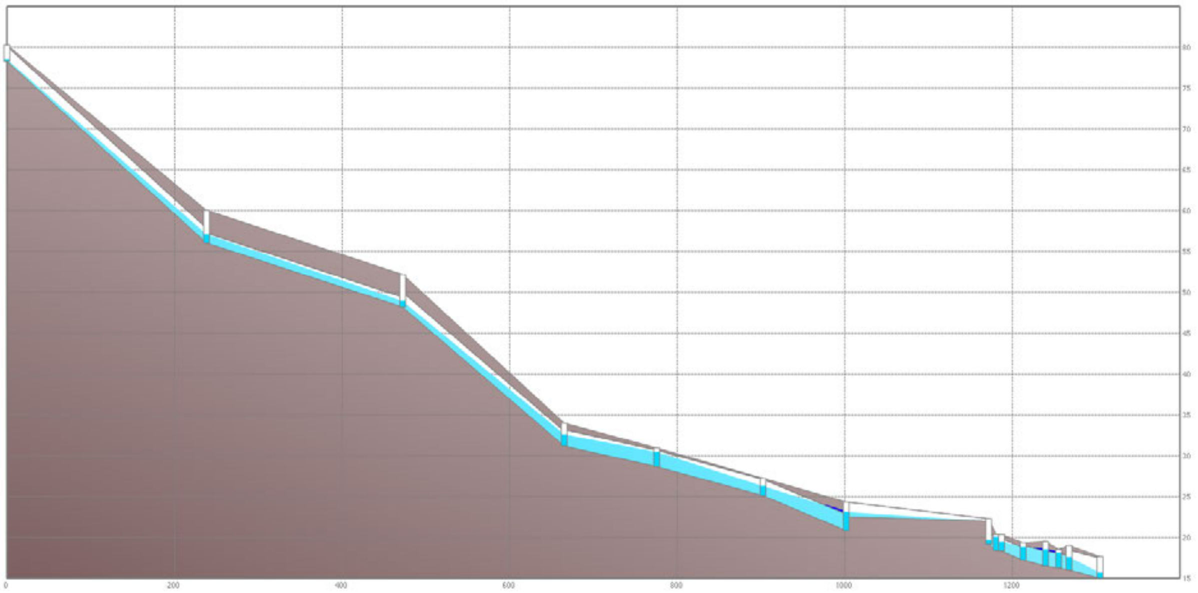

Figure 4.2: Conventional System Corrected Profile

Source: PCSWMM, 2018.

Figure 4.3: Layout of Conventional Network

Source: PCSWMM, 2018.

Table 4.3: Configuration for Conventional Stormwater Management system

Name	Size (m)	Length (m)	Type
C1	1.8	238.16	Concrete Pipe
C5	1.8	234.07	Concrete Pipe
C6	1.8	192.92	Concrete Pipe
C3	2	110.36	Concrete Pipe
C2	2	126.84	Concrete Pipe
C7	2	99.27	Concrete Pipe

Table 4.4: Attenuation Required for Conventional Stormwater Management system

Name	Location	Depth	Volume (m3)
SU2	Glibb Lands Sports field	2.5	17086

4.3.2 Sustainable Urban Drainage Systems

The SUDS model was simulated by changing the conduits along the same alignment into trapezoidal shaped swales with a roughness coefficient of 0.4 instead of 0.013 for concrete pipes. Running the simulation resulted in numerous surcharges and flooding along the path as seen in Figure 4.4, thus additional several simulations were done to correct the model with the profile displayed in Figure 4.5.

Figure 4.4: SUDS Surcharging Model

Source: PCSWMM, 2018.

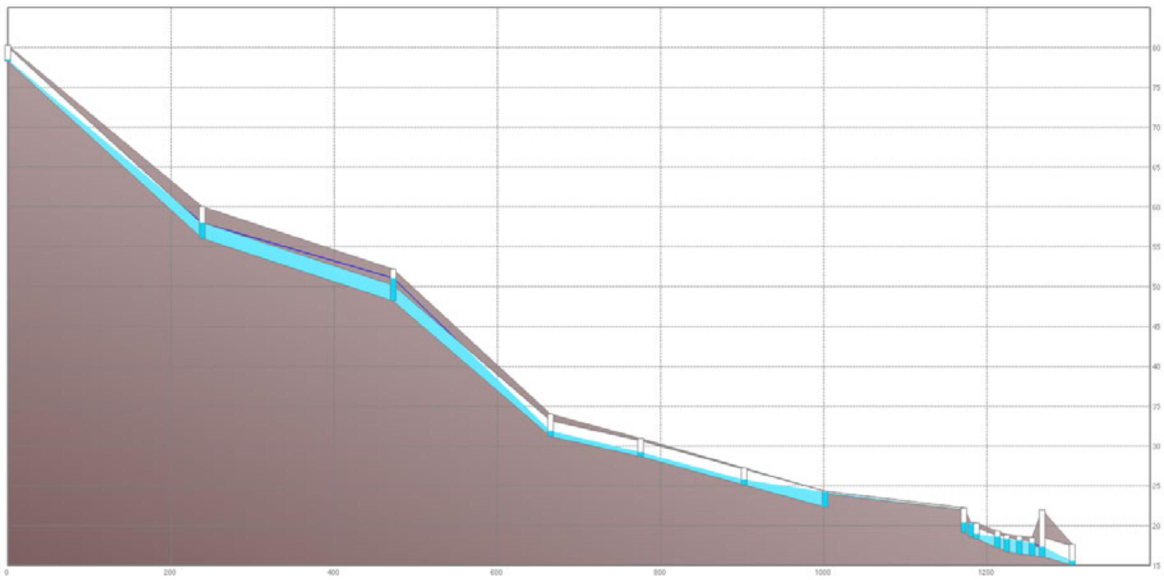

Figure 4.5: SUDS Corrected Model

Source: PCSWMM, 2018.

The configuration of the model which coped with the 1 in 100 year recurrence interval flood is depicted in Figure 4.6 and 4.7 below, which included the utility of 2 storage ponds along the configuration. The need for the attenuation facilities is due to the extremely steep gradients in the Umlazi region accompanied by flat grades in the Isipingo region. The velocity of the stormwater run-off is highly dependent on the grade which thus impacts on the rate of accumulation. The configuration of the SUDS model is captured in Table 4.5 and 4.6 below.

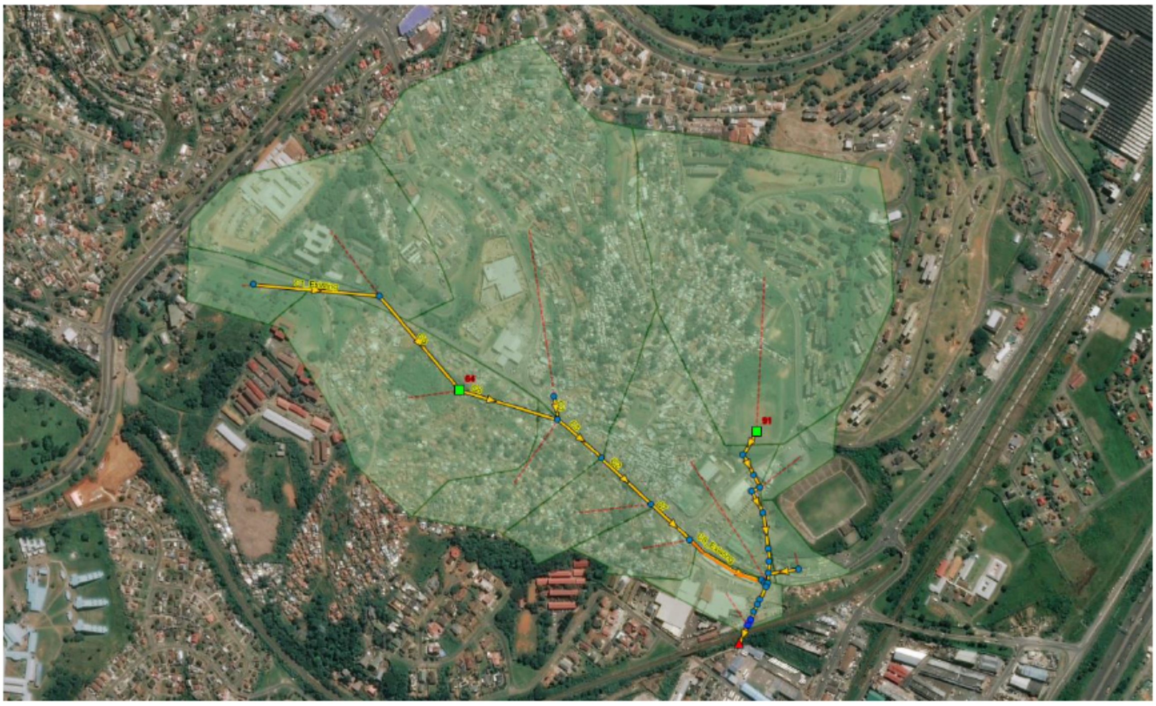

Figure 4.6: Layout of Sustainable Urban Drainage System

Source: PCSWMM, 2018.

Table 4.5: Configuration for Sustainable Urban Drainage System

Name	Size (m)	Length (m)	Type
C1	2x2 slope 2%	238.16	Trapezoidal Swale
C5	2x2 slope 2%	234.07	Trapezoidal Swale
C6	2x2 slope 2%	192.92	Trapezoidal Swale
C3	2x2 slope 2%	110.36	Trapezoidal Swale
C2	2x2 slope 2%	126.84	Trapezoidal Swale
C7	2x2 slope 2%	99.27	Trapezoidal Swale

Table 4.6: Attenuation Required for Sustainable Urban Drainage System

Name	Location	Depth (m)	Volume (m3)
SU1	Vacant Land, Prince Mcwayizeni	3	8000
SU2	Glibb Lands Sports field	2.5	17086

4.3.3 Attenuation Facilities Management System

The attenuation based facilities design prioritized the utility of attenuations as a means to flood mitigation above and beyond reliance on a pipe network. The model showed flooding due to the use of smaller 1.2 diameter pipes as seen in Figure 4.7. An underground attenuation facility below the Jeena's Supermarket, a vacant land attenuation along Prince Mcwayizeni Drive and the sports field behind Glibb Lands are required to mitigate the 1 in 100 year recurrence interval storms as seen in Figure 4.8 and 4.9. The components of the system are tabulated in Table 4.7 and 4.8 below.

Figure 4.7: Attenuation Model with Surcharging

Source: PCSWMM, 2018.

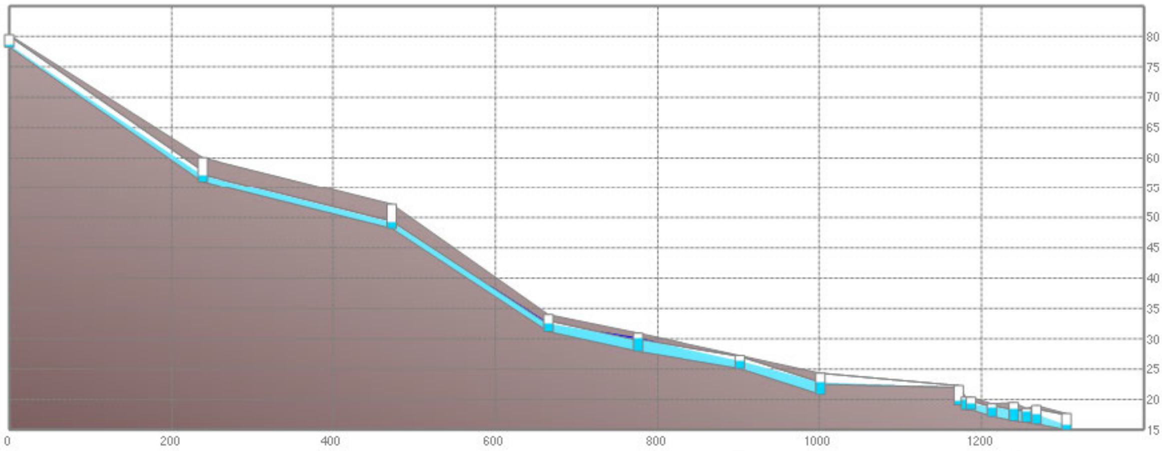

Figure 4.8: Attenuation Based Corrected Model

Source: PCSWMM, 2018.

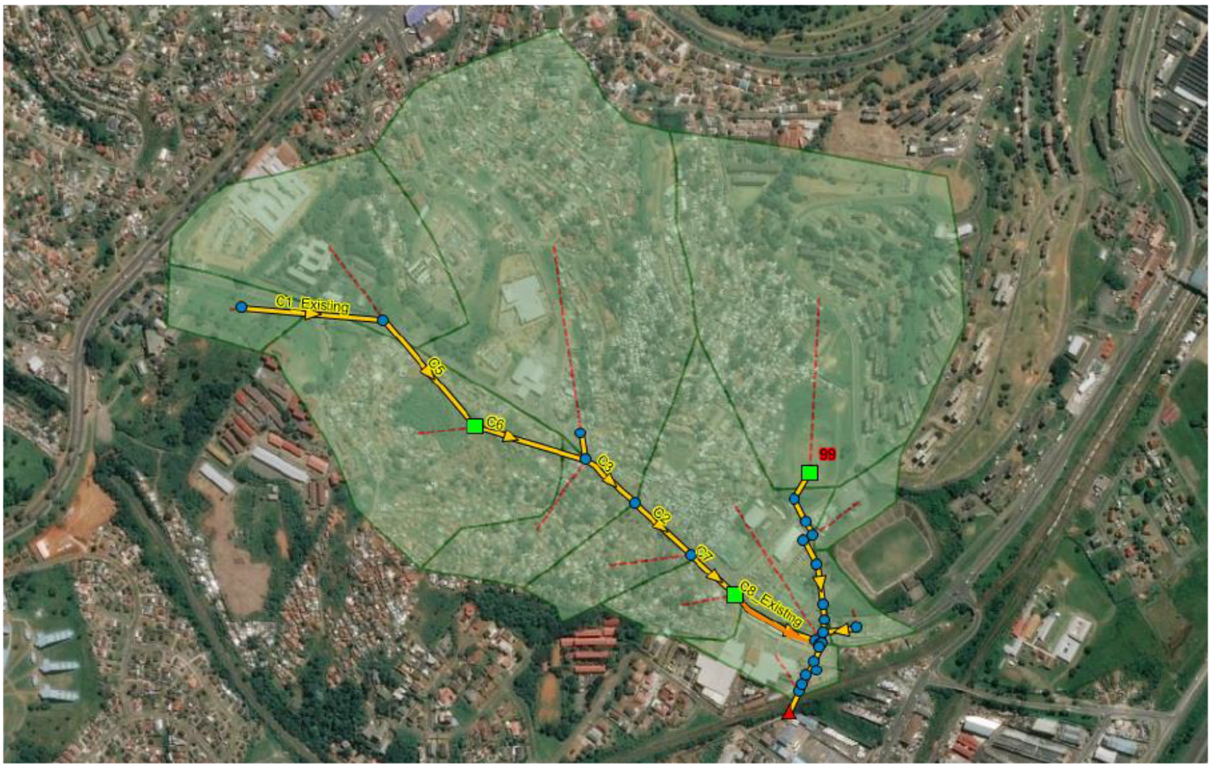

Figure 4.9: Attenuation Based Facilities Layout

Source: PCSWMM, 2018.

Table 4.7: Configuration for Attenuation Based Facilities

Name	Size (m)	Length (m)	Type
C1	1.8	238.16	Concrete Circular Pipe

C5	1.2	234.07	Concrete Circular Pipe
C6	1.2	192.92	Concrete Circular Pipe
C3	1.8	110.36	Concrete Circular Pipe
C2	2	126.84	Concrete Circular Pipe
C7	2	99.27	Concrete Circular Pipe

Table 4.8: Attenuation Required for Attenuation Based Facilities

Name	Location	Depth (m)	Volume (m3)
SU1	Vacant Land, Prince Mcwayizeni	3	8000
SU2	Glibb Lands Sports field	2.5	17086
SU3	Jeena Underground Parking	1.5	4650

4.4 Cost Effectiveness Analysis

The Bill of Quantities (BOQ) for the conventional stormwater management systems, SUDS and attenuation based were collated in excel spreadsheets, which resulted in cost estimates of R5 188 921.33, R2 119 047.50 and R16 007 209.38, respectively as seen in Tables 4.10 to 4.12. According to the set cost effectiveness criteria, conventional stormwater management scored a 2, whilst SUDS scored a 3 and attenuation facilities scored a 1 as seen in Table 4.13.

The conventional stormwater management alternative has a high pipe supply installation cost of R2 450 000.00 due to the size of the pipe. The equipment required to install the pipe is expensive and also requires a specialized skillset and experience.

The SUDS alternative also requires botanic or environmental specialists whom can specify suitable vegetation for the required functionality of slowing down stormwater run-off and enabling infiltration whilst also rooting the system and mitigating embankment collapse.

The attenuation facilities design is the most overpriced however, it serves the functionality equally well. The gabion basket based attenuation structure is not expensive, however the underground concrete structure is at R6 200 000.00 for a 6000m^3 retention facility. The professional services required for the construction of the underground facility warrant the inflated costs. The underground attenuation must be considered due to the space constraints of providing infrastructure in urban areas.

The utility of green infrastructure is more cost effective relative to conventional and attenuation based stormwater management systems. The SUDS design requires 40.84 percent of the conventional stormwater management design budget and 13.24 percentage of the attenuation facilities design budget to be executed. Consequently 2.45 SUDS based designs can be implemented on the conventional stormwater management systems budget requirement and 7.55 SUDS based designs may be implemented on the attenuation budget.

Table 4.2: Conventional Stormwater Management System Bill of Quantities

Conventional Stormwater Management System Bill of Quantities				
Item description	**Rate (ZAR)**	**Quantity**	**Unit**	**Value (ZAR)**
Preliminaries and General	511 770.00	1	PC Sum	511 770.00
Supply and installation of 2m diameter concrete HDPE pipes	3500	700	m	2 450 000.00
Standard Type B Manholes at 1-3m depths	1500	10		15 000.00
Excavation of existing unsuitable material	100	6300	m^3	630 000.00
Importing suitable fill material	150	2000	m^3	300 000.00
Reinstatement of site	80	210	m^3	16 800.00
Sub-Total				**3 923 570.00**
15% Profit and Labour				**588 535.50**
Sub-Total				**4 512 105.50**
VAT		15%		**676 815.83**
TOTAL				**5 188 921.33**

Table 4.3: Sustainable Urban Drainage System Bill of Quantities

Sustainable Urban Drainage System Bill of Quantities				
Item description	**Rate (ZAR)**	**Quantity**	**Unit**	**Value (ZAR)**
Preliminaries and General	205 500.00	1	PC Sum	205 500.00
Excavation of existing unsuitable material	100	4000	m^3	400 000.00
Importing suitable fill material	150	360	m^3	54 000.00
Supply and planting of suitable swale vegetation	200	3200	m^2	640 000.00
Construction of earth berms around sports field	120	800	m^3	96 000.00
Grass sodding	50	3600		180 000.00
Sub-Total				**1 575 500.00**
15% Profit and Labour				**236 325.00**
Sub-Total				**35 448.75**
VAT		15%		**271 773.75**
TOTAL				**2 119 047.50**

Table 4.4: Attenuation Facilities Stormwater Management System Bill of Quantities

Attenuation Facilities Stormwater Management System Bill of Quantities				
Item description	**Rate (ZAR)**	**Quantity**	**Unit**	**Value (ZAR)**
Preliminaries and General	1 578 750.00	1	PC Sum	1 578 750.00
Gabion walls for attenuation 1	1000	1000	m^3	1 000 000.00
Underground concrete attenuation structure	1 033.33	6000		6 200 000.00
Supply and installation of 2m diameter concrete HDPE pipes	3500	600	m	2 100 000.00
Excavation of existing unsuitable material	100	6000	m^3	600 000.00
Reinstatement of Jeena's parking area	250	2500	m^2	625 000.00
Sub-Total				**12 103 750.00**
15% Profit and Labour				**1 815 562.50**
Sub-Total				**13 919 312.50**
VAT		15%		**2 087 896.88**
TOTAL				**16 007 209.38**

Table 4.5: Cost Effectiveness Analysis Results

Score	**Criteria**	**Scenario 1: Conventional Pipe Network**	**Scenario 2: Sustainable Urban Drainage Systems**	**Scenario 3: Attenuation Facilities**
5	< R1 million			
4	R1million < Design > R2 million			
3	R2 million < Design> R5 million		3	
2	R5 million < Design > R10 million	2		
1	Design > R10 million			1
Economic Score				

4.5 Environmental Effectiveness Analysis of Stormwater Management Systems

By means of the criteria, the environmental effectiveness resulted in the conventional pipe network, SUDS and the attenuation facilities based design with scores of 2.2, 4.4 and 2.8 respectively as seen in Table 4.14. The question posed in criteria one explored the use of materials in the construction of the stormwater management designs. The utility of concrete as the base material resulted in the conventional system receiving a 2 for the first criteria, relative to a 5 for SUDS which utilizes soil material to construct berms for storage and vegetation in a swale to manage the stormwater run-off velocity and infiltration. The attenuation facilities scored a 3 due to the use of gabion baskets and concrete for attenuation facilities. Gabion basket walls are composed of dump rock and mesh wire, thus are quite environmentally friendly.

Criteria two measured the degrading of any ecosystems for the construction of the stormwater management system. The three design alternatives received a scoring of 3 due to the fact that no known or earmarked ecosystem was disturbed however, the area was vacant thus a possible natural habitat for some wild fauna and flora.

SUDS received a 5 for criteria three due to the creation of biodiversity within the swales as opposed to the attenuation facilities which received a 3. The fourth criteria evaluated the sustainability of the design which found the conventional system to score 2 relative to 5 and 3 for SUDS and attenuation facilities respectively. Sustainability was measured by the overall alignment of the stormwater management system with environmental policies and strategies which are in place. The utility of green infrastructure was found to be most environmentally effective.

The question posed in criteria 5 was to determine if the stormwater management system achieves the needs of the community. From an environmental perspective, SUDS attained a scoring of 5 relative to 3 for both the conventional stormwater management system and attenuation facilities due to the designs ability to harness natural resources.

Table 4.6: Environmental Effectiveness Analysis Results

No.	Criteria	Scenario 1: Conventional Pipe Network	Scenario 2: Sustainable Urban Drainage	Scenario 3: Attenuation Facilities

		Score (1-5)	Systems Score (1-5)	Score (1-5)
1.	Are the materials used for the construction of the design natural?	2	5	3
2.	Was an ecosystem degraded for the construction?	3	3	3
3.	Does the design restore biodiversity?	1	5	3
4.	Does the design promote sustainable objectives?	2	5	3
5.	Does the design serve the community's needs?	3	4	3
Score Calculation		=(2+2+1+2+4)/5	=(5+2+5+5+5)/5	=(2+2+3+3+4)/5
Environmental Score		2.2	4.4	2.8

4.6 Social Effectiveness Analysis of Stormwater Management Systems

The social effectiveness analysis of the stormwater management alternatives resulted in the conventional, SUDS and attenuation facilities scoring 3.8, 4 and 3.8 respectively as seen in Table 4.15. All of the design alternatives scored 4 for the first criteria due to the fact that they would all alleviate the worry and tension regarding stormwater flooding to the communities within the catchment irrespective of the different designs. The manner in which people live, work and play would be positively impacted by the installation of the stormwater management system.

The second criteria was posed to assess if the design alternatives would disturb the socializing in the community. Due to the fact that no social area was demarcated in the flow path of the stormwater, no social area would be disturbed therefore meriting a score of 4 for all the design alternatives.

The third criteria looked at the facilitation of social effectiveness of the designs. The SUDS attained a score of 4 for criteria three whilst the attenuation facilities attained a 2, due to the fact that the SUDS system creates a sports and recreation field which can also be used for socializing when there are no storms. The attenuation facilities do not make any allowance for socializing on the stormwater management structure, due to the gabion baskets on the ground surface.

The question posed by criteria four addresses the improving of social constructs by the construction of stormwater management system in this area. The implementation of a formal stormwater management system in a Township which has informal settlements within close proximity, contributes immensely to removing social constructs due to the general lack of service delivery in these areas. Therefore the fourth criteria saw conventional and attenuation facilities designs scoring 5 whilst SUDS scored 3. SUDS may not be understood by the communities thus, they pose a risk of perpetuating the social constructs the designs are attempting to remove. The open system is prone to pollution thus a probable safety hazard if the community is not engaged in public participation workshops regarding the purpose of the SUDS.

Criteria five posed a question addressing the culture change the stormwater management system may bring to the community. All three of the designs were found to positively change the culture of the community, due shift in perception and dogmas of the communities sense of identity, thus the scoring for all three designs is 4.

Table 4.7: Social Effectiveness Analysis Results

No.	Criteria	Scenario 1: Conventional Pipe Network	Scenario 2: Sustainable Urban	Scenario 3: Attenuation Facilities

		Score (1-5)	Drainage Systems Score (1-5)	Score (1-5)
1.	Does the structure contribute to the way people, live, work and play directly?	4	4	4
2.	Was a social area removed for the construction of the design?	4	4	4
3.	Does the design facilitate socializing?	2	4	2
4.	Does the design contribute to improving social constructs?	5	3	5
5.	Will the design change the culture in the community?	4	4	4
Score Calculation		=(4+4+2+5+4)/5	=(4+4+4+3+5)/5	=(4+4+2+5+4)/5
Social Score		**3.8**	**4**	**3.8**

4.7 Multi-Criteria Decision Matrix

The multi-criteria decision matrix was employed to objectively evaluate the cost effectiveness of the stormwater management alternatives, whilst taking into account the sustainability. Therefore environmental and social effectiveness of the stormwater management alternatives was taken into account to ensure sustainable implementation.

The utility of the multi-criteria decision matrix resulted in the conventional stormwater management system, SUDS and attenuation facilities receiving overall scores of 2.22, 4.12 and 1.8 respectively as seen in Table 4.16 below. SUDS alternative was found to be the most cost effective stormwater management system for this catchment.

The SUDS performance was strong due to the relatively low costs and high environmentally effectiveness of the design. The 60 percentage weighting of the costs contributed 2.4 to the weighted score thus producing a gap between SUDS and the other designs. The 30, 10, 60 weighting of the environmental, social and costs correspondingly further perpetuated the SUDS alternative being the most cost effective due to the positive performance in the environmental and cost effectiveness analysis.

Table 4.8: Multi-Criteria Decision Matrix

Description	**Weighting (%)**	**Scenario 1: Conventional Pipe Network Score (1-5)**		**Scenario 2: Sustainable Urban Drainage Systems Score (1-5)**		**Scenario 3: Attenuation Facilities Score (1-5)**	
		Score	Weighted Score	Score	Weighted Score	Score	Weighted Score
Environmental Effectiveness	30	2.2	0.66	4.4	1.32	2.8	0.84
Social Effectiveness	10	3.6	0.36	4	0.4	3.6	0.36
Cost Effectiveness	60	2	1.2	4	2.4	1	0.6
Final Score (out of 5)		**2.22**		**4.12**		**1.8**	

4.8 Discussion

Green infrastructure is a relatively new concept which has not been tried and tested in South Africa. Consequently, the reliability of SUDS are unfamiliar as opposed to international best practice (Marsalek and Chocat, 2002). The maintenance requirements associated with a SUDS design are also unknown, which could significantly impact on the costs over the design life, for example due to excess levels of silt build up where the SUDS connects with a conventional pipe network system. In contrast, the benefits one reaps from green infrastructure projects such as reduction of heat islands, reduction of carbon emissions and replenishment of ground water levels are also not computed (Loos and Roger, 2016).

The inclusion of maintenance costs in the economic analysis may change the result considering the varying frequencies of maintenance required for each stormwater management system. In the event of debris blocking the systems, the attenuation facility may be the most expensive to maintain due to its vulnerability to the gabion baskets being torn which may require reconstruction as the integrity of the structure would be compromised.

Green infrastructure is currently misunderstood by most project managers due to a lack of exposure to the innovation. The implementation thereof is at a slow rate relative to international practices However, the extent of knowledge held by project manager's on green infrastructure was not measured in this study.

The use of green infrastructure such as water harvesting, green roofs and SUDS are best practice internationally (Marsalek and Chocat, 2002). Environmental legislation and policies are enforced by stakeholders such as EDTEA, however the implementation and compliance by project managers is indefinite.

The conventional management systems are highly dependable and well renowned due to the majority of concrete pipes being operated over decades without failure. However, ogee joint pipes were enforced prior to spigot and socket joint pipes which fail predominantly at the joints and create sinkholes along road pavements, therefore the reliability on pipe networks is not absolute.

Attenuation facilities based designs assists with the storing stormwater temporarily, thus reducing the flow rate and velocity at which the run-off enters the system. The benefit gained in the additional storage is important to a flood prone location. Finding solutions to a built up environment includes the consideration of unconventional underground storage facilities which may have high capital investments with long term effectiveness (Buys and Aldous, 2007).

The combination of design configuration is inevitable as conventional pipe networks are predominantly utilised. The Isipingo and Umlazi catchment in question is characterised by a steep average gradient thus the stormwater run-off is prone to high speeds. These characteristics in essence necessitate the utility of a storage facility to assist in mimicking predevelopment stormwater run-off behaviour (Buys and Aldous, 2007).

The multi-criteria decision matrix is utilized as a scenario planning tool thus an objective quantitative approach may seem sufficient at this point. However, the social consideration was difficult to score due to a lack of engagement with the community to include their opinions on the infrastructure which may not be suitable for their daily circumstances. An objective non-community consultative approach does not fully capture the needs of the community (Shuster and Garmestini, 2015). In contrast, the community may not be in a position to contribute on what they require due to a lack of expertise on the overall function of stormwater management systems.

The use of the multi-criteria decision matrix as an essential part of the cost effectiveness analysis shows a willingness to integrate and align strategies which promote both infrastructure development and the preservation of environmental and social cognisance in achieving sustainable service delivery. Furthermore, it is imperative for the dismantling of silo departmental objectives within a holistic representation of government objectives.

The implementation of infrastructure without public engagement in South Africa, often leads to protest action by neighbouring impoverished communities whom feel excluded from the opportunity to acquire skills or generate income. Therefore public participation is crucial to the successful implementation of any stormwater management system of this magnitude (Shuster and Garmestini, 2015). The appropriate time to engage the public and practical extent of their contribution is unknown.

Consequently, eThekwini Municipality project managers are required to engage the community via the assistance of the Ward Councillor regarding works to be implemented within their jurisdiction. The Councillor often acts as a liaison between the social needs of the community and the economic resources of the project manager, thus assisting in tailoring the design to incorporate social benefits.

The SUDS design being the most cost effective alternative in this catchment does not mean that the same would apply for other catchments, due to the varying characteristics of catchments in different locations.

4.9 Conclusion

The purpose of this chapter was to consolidate the cost effectiveness of the conventional, SUDS and attenuation facilities based stormwater management systems. The contribution of the economic, social and environmental effectiveness were given opportune consideration in reaching a holistic conclusion on the cost effectiveness of the stormwater management systems proposed. The strengths and shortfalls of the proposed stormwater management systems were analysed.

The conclusion drawn from the multi-design criteria matrix indicate that SUDS are the most cost effective with a score of 4.12 in comparison to attenuation facilities and conventional pipe networks in this study. In contrast, SUDS were found to be unreliable due to the fact that they are a relatively new approach to solving stormwater management challenges in South Africa. Green infrastructure takes cognisance of the environment and the social aspects of solutions thus, adaptation to this internationally recognised best practise is pertinent for sustainability and alignment with set regulations.

Conventional stormwater management systems scored 2.22 when weighted using the multi-decision matrix in measuring its cost effectiveness. Conventional stormwater management systems are the normal practice and are highly dependable from an engineering perspective, however the environmental effectiveness does not meet best practice standards due to a low performance of 2.2.

Attenuation based stormwater management facilities scored an overall score of 1.8 on the multi-criteria decision matrix due to the low performance in the cost effectiveness with a score of 1.The major contribution to the low score is the estimated BOQ exceeding R10 million. Retro-fitting solutions in a developed urban environment is a huge challenge for engineers and project managers whom are solving inherited problems, thus the underground concrete attenuation facility is a valid design alternative.

The 30, 10 and 60 percent weighting of the environmental, social and cost effectiveness respectively, plays a pivotal role in the results of this study. The next chapter entails the conclusions and recommendations found in this study.

5. Chapter Five: Conclusion and Recommendations

5.1 Introduction

The purpose of the fifth chapter is to provide the conclusion and recommendations from this study and areas of research for the future. The purpose of this study was to determine the cost effectiveness of stormwater management systems and incorporate the environmental and social contribution of the stormwater management systems on the community. The stormwater design alternatives considered are the use of conventional stormwater management systems, SUDS and attenuation facilities based stormwater management.

5.2 Summary of Findings

The study contributed to the set objectives in the following manner.

5.2.1 The Cost Implications of Stormwater Management Systems

The first objective was to evaluate the cost effectiveness of three stormwater management alternatives namely, conventional stormwater management systems, Sustainable Urban Drainage Systems and attenuation facilities based stormwater management systems. The study revealed that SUDS was the most cost effective stormwater management design alternative. The utility of SUDS as a stormwater management system in South Africa is currently clouded by a lack of understanding of the benefits one could yield, although it is best practise internationally to implement green infrastructure instead of conventional stormwater management systems. The cost savings in providing green infrastructure which serves the same functionality yet uses less costs is an imperative highlight of the findings of this study.

The multi-criteria decision matrix is a powerful instrument for the integration of varying dynamics. The operation of the multi-criteria decision matrix to weigh economic, environmental and social effectiveness objectively may be implemented by other project managers in the planning and decision making process.

5.2.2 Unchartered Benefits of Environmental Consideration

The second objective was to determine the environmental influence of each of the stormwater management systems. The most environmentally responsive design was the SUDS with a score of 4.4. The study found that SUDS utilized natural materials for construction such as soil for berms and vegetation within swales. Furthermore, SUDS contributed the restoration of biodiversity within the system as opposed to destroying natural habitats for ecosystems to flourish. However, the awareness of the positive externalities gained from green infrastructure as a means to sustainability is not apparent to local government enforcers. The alignment of designs to sustainable objectives and therefore policies and strategies which are in place are not implemented in the decision process used by project managers.

Conventional stormwater management systems scored 2.2 when measuring the environmental effectiveness. The study found that the use of concrete as a predominant material did not impact positively on the environment. Furthermore, the system does not create an ecosystem nor restore it, thus it was deemed to not be aligned with the sustainable intentions.

Conventional stormwater management are currently being implemented irrespective of the lack of environmental effectiveness due to the functionality and reputation. Pipe networks have been tried and tested thus the reliability is high. The incorporation of green infrastructure to existing conventional pipe networks is a step towards the right direction.

Attenuation based stormwater management systems scored 2.8. The environmental effectiveness of the attenuation based design was low due to the underground concrete storage, however it was balanced by the use of a gabion baskets attenuation facility. The preservation of biodiversity may be apparent in the gabion attenuation, thus the environmental performance was more sustainable than conventional systems. The study also established that the integration of attenuation facilities which also serve environmental requirements is of paramount importance towards reaching environmental policy goals and objectives.

5.2.3 The Social Contribution of Stormwater Management Systems

The final objective of the study was to determine the social contribution that the stormwater management systems would provide to the communities within the catchment. SUDS was the most responsive stormwater design with a scoring of 4 from a social perspective. The inclusion of a sports field which acts as a storage basin during floods allows for social activities to take place on the design premises. SUDS would contribute positively to the community, however to be certain of the improvement to social constructs would require public participation.

The conventional stormwater management system was found to contribute positively to the manner in which people live and further contributed to removing social barriers. Although, the implementation of the conventional system as a part of service delivery would subconsciously improve the community’s sense of self due to years of neglect, proving of the removal of social constructs was deemed difficult.

The attenuation facilities design scored a 3.8 for social effectiveness. Attenuation facilities was deemed to positively impact on the culture and values of the community and would further remove social constructs such as deserving less service delivery due to the geographic location of being within a township.

5.3 Recommendations

The utility of a cost effectiveness analysis as a standard government project management tool would assist in alleviating budget constraints in a precarious economic climate. It is recommended that cost effectiveness analysis is employed as an objective means of making decisions on design alternatives. In addition, green infrastructure options must be mandatory to the alternatives considered in designs due to the provision of service delivery at a more cost effective rate.

The utility of a multi-criteria decision matrix as a decision making technique and cost effectiveness incorporates the environmental and social effects of projects, therefore it is recommended that project managers and planners within local government institutions use it to assist in achieving more objective decisions on sustainable project implementation.

The enforcement of green infrastructure projects has not gained moment within eThekwini Municipality, which is highly due to a lack of knowledge on the advantages and positive externalities retrieved from their implementation. Therefore it is recommended that project managers and designers of infrastructure attend courses to advance their understanding on green infrastructure.

The utility of green infrastructure as a means to compliance with environmental policies aligns with the strategic objectives of the IDP (2017) and NEMA (1998), therefore the mandate must be cascaded down to project managers within local government spheres to ensure implementation. Consequently, it is recommended that a policy which stipulates that a percentage of the infrastructure development must be green would assist in reaching alignment with policies and strategies which are in place. Furthermore, the inclusion of the above objective in the Key Performance Indicators (KPI) of project managers would ensure a consequence for not complying with the strategic objectives set. In addition, the enforcement of Maintenance Management Plans (MMP) which govern the construction methodology in cognisance of the environment are paramount to the successful implementation of environmental legislation and compliance by local government officials.

The conclusion on social effectiveness was difficult to obtain without the engagement of the affected community. Therefore public participation and knowledge sharing of the functionality and potential impact of infrastructure developments is recommended prior to constructing infrastructure.

5.4 Recommendations for Future Studies

Future research should consider the inclusion of maintenance costs over the design life of the stormwater management systems as such costs may influence the cost effectiveness significantly. The frequency of the maintenance is dependent on the amount of pollution and blockages experienced by the system and the contingencies incorporated into the design, for example placing a net across the upstream to mitigate against the accumulation of debris entering the stormwater management system. This in turn is dependent on the education and public participation engagements with the communities within the catchment. SUDS are the most vulnerable to aesthetically displeasing visuals in the event of pollution of the stormwater management system.

Isipingo Regeneration is a project within the EThekwini Municipality which incorporates the objectives of different departments towards a holistic design strategy and implementation thereof. Departments such as Town Planning, Stormwater, Transport, Disaster Management and Environment have established a committee under the Development Planning and Environmental Management unit, Deputy Head, Mr Musa Mbhele to mitigate the challenges faced by the Isipingo community. The project is inspired by the 10 October 2017 floods which devastated the Isipingo community. A climate change adaptation approach is being utilised using the Urban Design Lab (UDL) model and workshops, which took place from the 18^{th} to 20^{th} February 2019 across the city towards mitigating the contemporary challenges plaguing the area. Stormwater flood mitigation plans were thus integrated into the Town planning plans. Future research into the outcomes of the Isipingo Regeneration Project is recommended.

An investigation into the amount of understanding project managers and designers have on green infrastructure and its importance towards reaching sustainable environment and climate change objectives is recommended. Furthermore, the filtration of environmental policies and the level of compliance and awareness by project managers may be researched.

Water harvesting structures enable the reuse of water, which would contribute to the alleviation of droughts and promote sustainability within South Africa as a water scarce country. Further research is recommended for the possible applications of this green infrastructure to change the paradigm of treating stormwater as a nuisance but rather a valuable resource.

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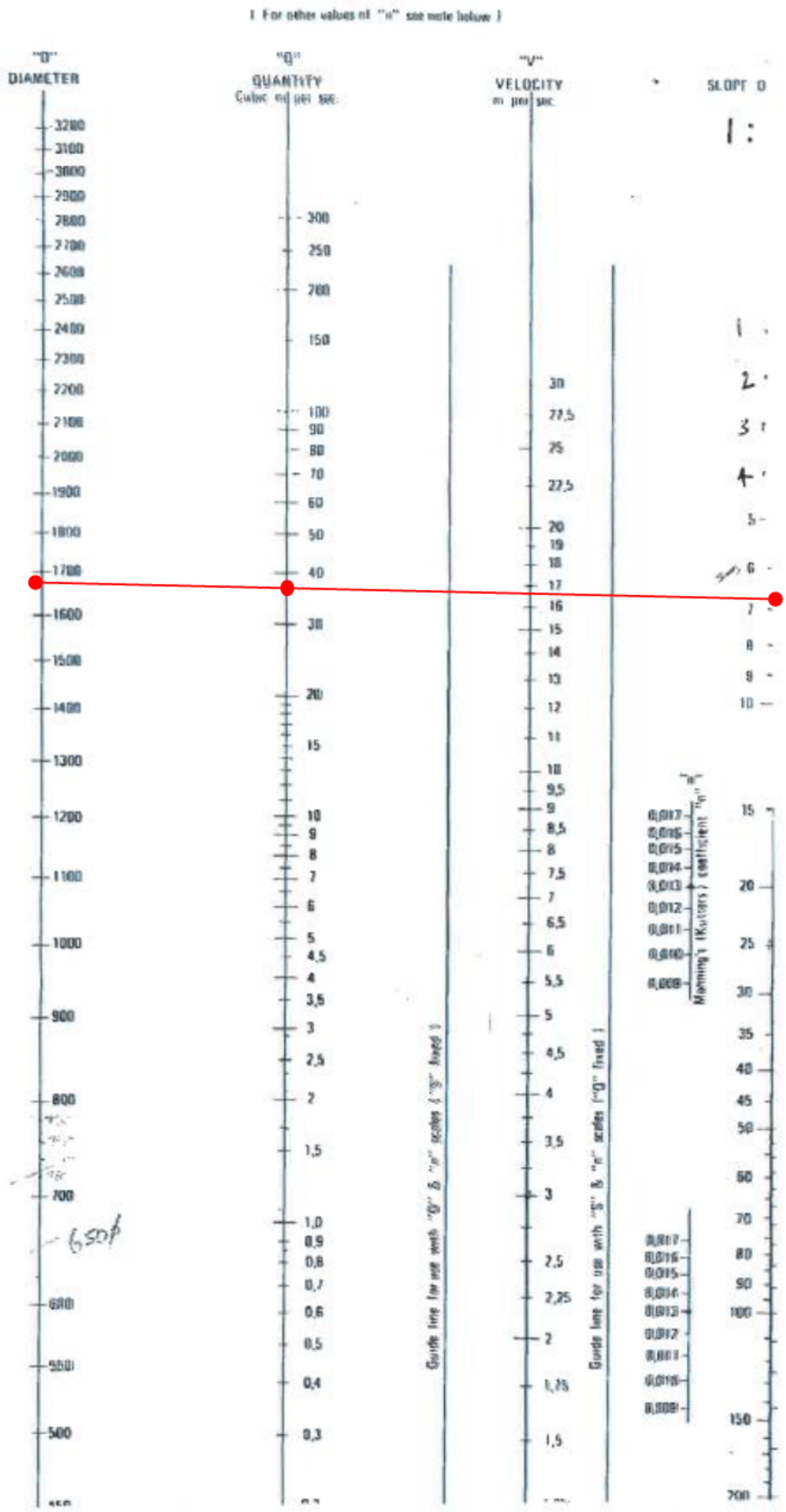
Appendix 1: Nomograph used to Find Pipe Diameter Required

Source: eThekwini Stormwater Design Manual, 2012.



Appendix 2: Run-off Flow Calculation Rules

Table 1: Time of Concentration, Tc, Stormwater Guideline, 2012.

Time of Concentration Tc	
	Min Tc
Urban	15
Rural	15
Commercial	10
industrial	10

Table 2: Roughness Coefficient Value, Stormwater Guideline, 2012.

Type of Surface Roughness Value	
Description	**r Factor**
Smooth Paving	0.02
Clean Soil	0.10
Sparse Grass	0.30
Moderate Grass	0.40
Thick Bush/Grass	0.80

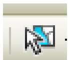
Table 3: Absolute Minimum Allowable Gradients, Stormwater Guideline, 2012.

Note		
Absolute minimum gradients		
Dia. (mm)	**Grade 1/**	**Grade %**
300	80	1.25
375	110	0.91
450	140	0.71
525	170	0.59
600	200	0.50
675	240	0.42
750	280	0.36
825	320	0.31
900	350	0.29
1050	440	0.23
1200	520	0.19

Appendix 3: PCSWMM Modelling Step by Step Guideline

1. Capturing your Input Files for the Model

The first step is to attend the PCSWMM workshop to introduce one to the software and the extent of its abilities, just as the author did from 11 to 13 September 2018 in Cape Town, at Radisson Blu Hotel conference room. The catchment area must then be delineated on ArcGIS to retrieve geographical information from the full extent of the project area and the services within it (PCSWMM, 2018).

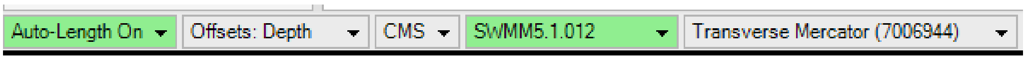
1. Open ArcGIS Map > Locate site by searching for the road name> delineate by switching on contours in the table of contents and following the extent of the catchment accordingly.
2. Activate all layers which require consideration such as stormwater pipes, stormwater manholes, flood planes and sewer pipes.
3. Right click feature from the table of contents on the Stormwater Manholes layer and make this the only selectable layer.
4. Click on Select Features 
5. Click and drag on map to select desired extent of the feature
6. Right click on feature from table of contents > Data > Export Data
7. In the Export Data window select 'Selected Features' from drop down menu and select 'This layers source data' for the co-ordinate system. Browse to save file in project folder > OK > No
8. Click  to Clear Selected Features.
9. Repeat steps 3 to 7 to export layers which are relevant to the projects for PCSWMM modelling (PCSWMM, 2018).

2. Starting a New PCSWMM Project

1. Start PCSWMM and click New Project menu under the File menu.
2. In the New Project dialog, enter the name of your project (Conventional Stormwater System)
3. Select Simulations Options and check the following under General & Dynamic Wave:
   - Infiltration model: Green-Ampt
   - Routing Method: Dynamic Wave

- Flow Units: CMS
- Inertial Terms: Dampen
- Normal Flow criterion: both
- Force main equation: Hazen-Williams

4. Edit the bottom left tabs of the screen as shown (PCSWMM, 2018).



3. Importing Layers into PCSWMM

1. Import the polygon layers exported from ArcGIS by opening PCSWMM and click Open Layer 

 > Browse > required files and import accordingly.
2. Repeat for other polygon layers
3. Click on File > Import > GIS/ CAD file formats
4. Select layer in which to add specific features by clicking on the tabs in the Import data window

** Manholes are referred to as Junctions and Pipes are referred to as Conduits on the software.

5. Select the options under the Import Data window before browsing for the desired shapefile – browse for file (Stormwater_Manholes.shp) by clicking on the folder icon > open
6. Match project attributes to imported shapefile attributes > Finish > No
   - Repeat for conduits
   - Turn on the street map or Bing map satellite on the bottom left to see where you are geographically (PCSWMM, 2018).

4. Preparing Shapefile Extents

The extent of the shapefiles imported from ArcGIS may contain additional features on the layer which are not required for the purpose of the simulation, thus one may delete them using the following step below:

1. Click on the junctions feature first in the layers panel
2. Make sure you are in select mode – hold down ctrl and left click on the mouse to draw a square over the area within which you wish to keep/delete items – notice they highlight in blue
3. Alternatively, if the area you wish to delete is smaller than what you wish to keep then

simply press delete on the keyboard. If the area you wish to delete is bigger, then at this stage click on the 'Find' icon > Invert selection > delete

4. Repeat for conduits and other shapefiles accordingly (PCSWMM, 2018).

5. Connectivity and Error Checking – Stage 1

Now that you have all of the required network shapefiles, you want to check that there is connectivity between the junctions and conduits. You also want to inspect that the information within the shapefiles is realistic.

1. Cross check that there are no missing data in the network. Do a visual inspection and comparison. With the information available on ArcGIS.
2. The first thing to check is that the dimensions of the imported shapefiles are correct. Select Conduits on the project panel and change the view to Table on the top of the screen. These columns represent the attributes allocated to conduits. Notice the Geom1 column is set at meters. Therefore the values in that column are incorrect. To change the values to pipe diameters represented in m, use the following tip:
   - Open an excel sheet on the side. In PCSWMM click on Geom1 to highlight the column. Right click copy and paste into excel so that you can manipulate the data
   - Copy and paste it over the old data in PCSWMM
3. Change to Map view. Each service line requires an outfall. Find the last junction along each line and convert it to an outfall by right clicking on the junction > Convert > Outfall. Notice the blue dot changed to a red triangle. (Repeat for each line)
4. To check that all conduits and junctions are connected to allow flow through them, click on any junction + hold down shift and click an upstream or downstream junction. If the line is not interconnected an error message similar to the one below will appear – If so, move in smaller line lengths to find the error.
5. You may also use the connectivity tool to find missing info
6. To connect them, while still in the map view, click on Tools > Connectivity > Auto-Connect. A Click Analyze > Apply > Close
7. Repeat step 4 to check that it has connected successfully.
8. If there are unconnected nodes (junctions, outlets, outfalls) which we call 'orphans' the model won't run

9. Change to Map view. Click on Junctions
10. Select Tools > Nodes > Select Orphans
11. Select Current Layer only (Junctions) > Select (N.B if you want to apply to all you can however it is more thorough to go through each individually).
12. Repeat step 4 to check (PCSWMM, 2018).

6. Adding Items to the Model

This section will teach you how to add/delete items. Before moving on, let's create a duplicate of the model by using the scenario tool.

1. Click on the Scenario Manager icon Plan > Add > Duplicate current project

2. Rename the copy as Conventional 2 and change description. Browse to save the model in the same folder and click Create.

3. You have now created the copy in the scenario manager window. Double click Conventional 2 in the scenario manager to open the model (close reports that pop up) (PCSWMM, 2018).

7. Add an Outfall Node

The next step is to add physical model entities to the project in the **Map** view. First it's useful to start by adding an outfall node:

1. As a general rule return to the **Map** view by clicking the **Map** view tab at the top of the screen.
2. Click the **Outfalls** item in the **Project** panel and click **Add** in the map panel. Click on the map where you would like to place the outfall.
3. Change to **Select** mode to stop the add mode. Attributes can be changed in the **Attributes** panel on the right hand side (PCSWMM, 2018).

- To move nodes select item on the map > click **Move** > drag arrow to new position > double click > change to **Select** mode to exit

8. Adding Conduits

After the nodes are placed in the correct locations, the conduits can be inserted in a similar manner remembering to start from upstream to downstream:

1. Click the **Conduits** item in the **Project** panel and click **Add** 
2. Click on upstream junction and then on the downstream junction to finish creating the conduit. The attributes can be changed in the **Attributes** panel on the right hand side.
3. Change to **Select** mode to exit **Add** mode

- Manhole spacing should be approximately every 50m and where there is a change in direction to allow for gradual bends (PCSWMM, 2018)

9. Adding Sub-Catchments

Now let's delineate our sub-catchments (keep in mind that PCSWMM considers an average slope for the catchment area. Therefore if it includes vast differences in slope then further divide the catchment to get a refined answer for significant catchment areas):

1. Click the **Sub-catchment** item in the **Project** panel and click **Add** 
2. Place vertices on the map (by clicking the desired location) to define the polygon shape for the sub-catchment.
3. Click **Select** or press Enter to commit to sub-catchment created.
4. Refer to **Attributes** panel for sub-catchment characteristics
5. The area and width are usually set at default values. Click on **Tools**  > Sub-catchments > Set area/length > close (PCSWMM, 2018).

10. Delineating Sub-Catchments Using LIDAR

This section will explain the use of LIDAR and how to read the data from the .flt files.

1. Firstly, save your work in Conventional 2. Open the

Conventional_Stormwater_Management System.inp model from the PCSWMM Prelim Course 2019> Conventional_Stormwater_Management System.inp. (be sure to activate your Bing map on the bottom left).

2. Click Open> Browse the PCSWMM dissertation folder.
3. Select and open LIDAR.FLT.
4. If you hover your mouse over the grey area, you will notice a z-value appear on the bottom of the screen. Refer to the back of your manual for extra notes on LIDAR.
5. To delineate sub-catchments, click on Tools > Sub-catchments > Watershed Delineation.
6. Make sure the DEM layer is set to the correct file. Change the Target discretization level to 5 ha.
7. Click Delineate watershed. The program will now create sub-catchments as close to 5 ha as it can using the point elevations available in the DEM layer. Text editor reports will pop up at the end giving you a summary of the action, click close.
8. Notice there are flow paths that have been created in blue that are looking for valleys and carrying the flow to the nearest outlet. In some cases the program would have created junctions to accept the flow. This is where your engineering judgment comes in.
9. We will assume you understand the site and the intricacies of the buildings etc. The aim is to analyze the capacity of the stormwater network. You need to identify which watersheds are flowing into which inlets in the network.
10. If the sub-catchments are too large or too small you may use edit it by joining, splitting or simply editing the vertices. To do this click on a sub-catchment and then right click > Edit > select the action you want. For joining 2 or more sub-catchments, first highlight them by holding down control and right click > Edit > Join. For this exercise you are welcome to try any action – we will be using another model to proceed.
11. Once you are happy with the size and shape of your sub-catchments, you will have to edit the sub-catchment attributes for each by editing the properties in the attributes panel on the right of the screen.
12. Make sure to set an outlet for each sub-catchment (it can be a node / another sub-catchment).
13. If you are working with a large network and this process is too tedious then a quicker way is to use the Set Outlet tool (Tools> Sub-catchments > Set Outlet (PCSWMM, 2018).

11. Rendering

This Section will show you the functionalities of the Render 

tool. This allows you to manipulate the map and table views. The Properties tool in the Graph and Profile views have similar functions.

1. Rendering Network : Select the layer to be rendered and click Render
2. You will notice a window pop up (see below-Layer Properties). This window allows you to change the shape color and labels you see on the display. You may also play around with the opacity (transparency). Apply changes and close.
3. Rendering LIDAR: You may edit the LIDAR to show different ranges of elevations by color. While still in the Render tool > select LIDAR from the layer options.
4. Notice that the window looks different. Click on Levels. This will open a Level Creator.
5. Specify a min and max elevation depending the terrain data (you can find the min and max by hovering over the LIDAR
6. The Levels indicate the no. of ranges created within the min and max values.
7. You may change the color scale by changing the ‘Ramp’ simply by dropping down the arrow and clicking select > Create levels to apply changes.

12. Checking your Model Setup – Stage 2

The next step is to check the model entities and ensure there are no invalid data points. This is an iterative process as you will initially find the obvious missing information, correct it, and then when running a simulation, you may find more, and then correct again and so on until you are happy with the set-up.

Here is an overview of some of the most common problems that occur when importing data from the GIS system:

- Missing or incorrect junction inverts

Now that the lines are connected and can allow a flow through it, we need to check that the grades within the system are realistic – if it an existing system, scrutinize the reliability of the data and if t is a new system you are lucky enough to dictate your own slopes.

1. Start with the Render plot, and select junction, then invert, make the font large, apply and do a visual inspection.
2. Select all the junctions, and then switch to the Table view and inspect.
3. Use the invert correction Tool correct. If you are uncertain, you can manually enter the invert and depth. Use the contours and junctions upstream and downstream to assume an invert.
4. Highlight the line as you did in Step 4 – you may start from upstream-down or vice versa.
5. Select Profile view at the top of the screen to view that lines profile. Does the profile look ok to you? You are looking for sudden spikes or dips in the profile.
6. Repeat for all lines.

- Conduits are linking in the wrong direction (upstream)

1. Not a major problem. Flows may be shown as negative. Use the render plot to plot Junction total flooding. Or use the Simulation output file and find unusual flooding junctions. Re-enter the junction in and out in the attribute table once the conduit is selected.
2. Use the analysis Tool function to check the system continuity.

- Sub-catchments link to the incorrect junction.

1. Use the Assign Junction to Sub-catchment Tool make sure every Sub-catchment has a link out.
2. Use the lowest, middle function.
3. If you are worried about this, you have to go through each Sub-catchment and check. where the little red flow line links up

- Sub-catchment widths are incorrect and require individual inspection.

14. Simulating a Rainfall Data

Now that we have a network setup, we need to introduce a flow to the network for the simulation to work. To do this we need to create a Rain Gauge:

1. On the top left of the GUI under Climatology there is a drop down. Click this to collapse more options.
2. Select Rain Gauges from the options to open the Rain gauge Editor.
3. Click Add > Name your rain gauge. Make sure to set the rain format to INTENSITY; Time Interval as 0:05 (minutes).
4. Click Design Storm Creator > South Africa SCS (South Africa's rainfall trends are similar to a Type 2 distribution so we usually use Type 2. Change the name to match the rain gauge name. Set the rain format as desired but keep this in mind when reading simulation results).
5. The total rainfall is found using the same method you would have used to find your rainfall intensity for the Rational Method. The only difference is you will be reading off values from the 1440 column.
6. Select Create Rain Gauge.
7. Check to see that all the information is correct before clicking OK.
8. In the Map view, select a sub-catchment and Ctrl + A to select all sub-catchment
9. In the Attributes panel go to Rain Gauge and click on the *. Notice there is an option to select the new rain gauge you just created. Selecting the rain gage will apply the same rainfall across all catchments > Save.

15. Creating Rainfall Gauges for the Simulations

- Real data for actual storms.

It is very useful to run simulations with actual rainfall data. It provides an indirect way of calibrating the model by comparing outputs with observational data.

6. Obtain a text file of the rainfall recorded in the region.
7. Use Excel to create a continuous time series. The recorded data will only have a time

series for when it rains, you need to fill in the missing times steps using Excel tools like Vlookup etc.

8. Create a new rain gauge in the PCSWMM rain gauge setup. Then add a new time series and copy and paste your actual rainfall into the time series. (Follow the steps explained in the previous section).

16. Setting up and Running Simulations

Once your rain gauges are set up, you will have to tell the program how you want it to run the data you have inputted.

1. Click on the **Simulation Options** tab in the **Project** panel and ensure the general information is correct.
2. Select the **Dates** tab and only input date for **Start analysis on** and **duration.**
3. The rest of the information will change automatically.
4. Now select **Time Steps** tab and input Reporting time. (Reporting time should be the same as the time series interval) > OK.
   - For real rainfall data: Be careful to ensure the simulation period matches that of the input time series (if dates are supplied in the time series). If rainfall or climate data are read from external files, then the simulation dates should be set to coincide with the dates recorded in these files.
5. Click on Run  to run the simulation. The bottom right hand corner will report on the status of the run.
6. If the simulation does not run successfully, look into the Status report section on Warnings to identify why.

To see the profile and behaviour of the stormwater run-off through the system a profile was projected by pressing the profile tab as seen in Figure 1 below (PCSWMM, 2016).

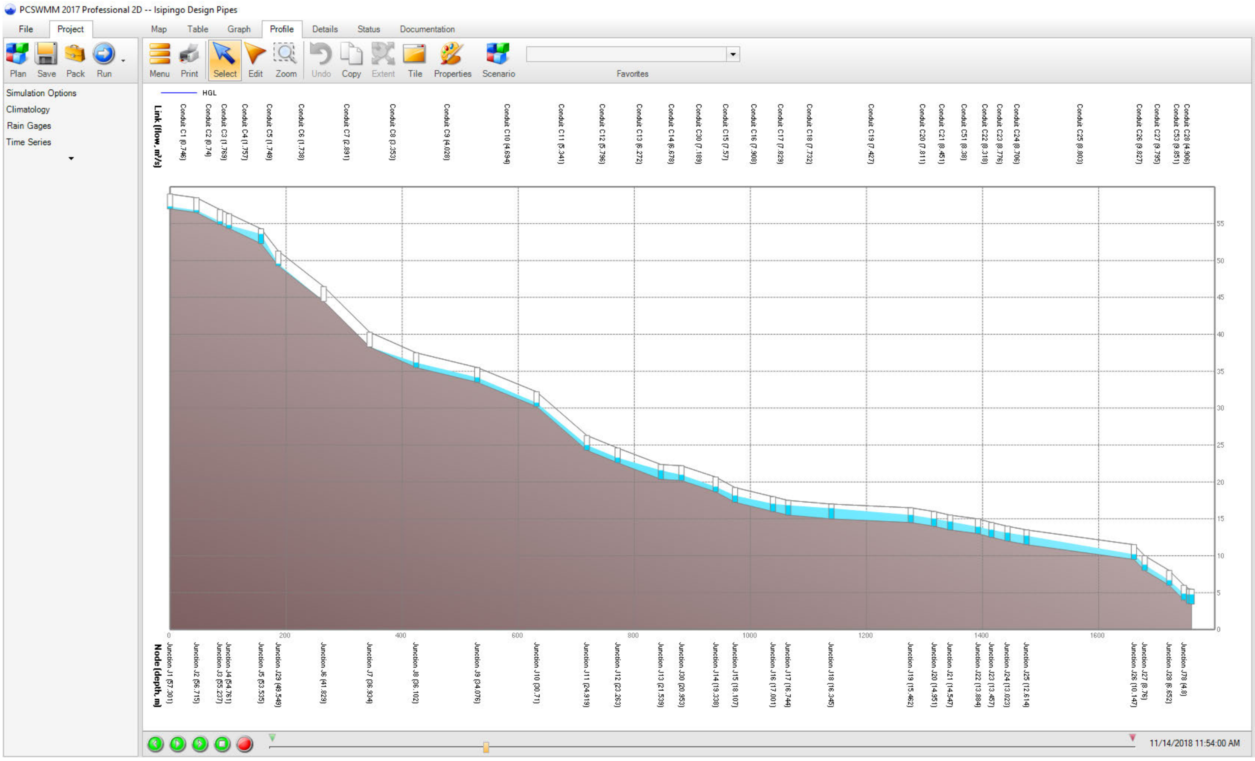


Figure 1: Long Section of Conventional Stormwater System

Source: PCSWMM, 2018.

In the event of an error or overflowing of the stormwater management system, the model depicts the junctions that are not managing at a specific time as seen in Figure 2 below.

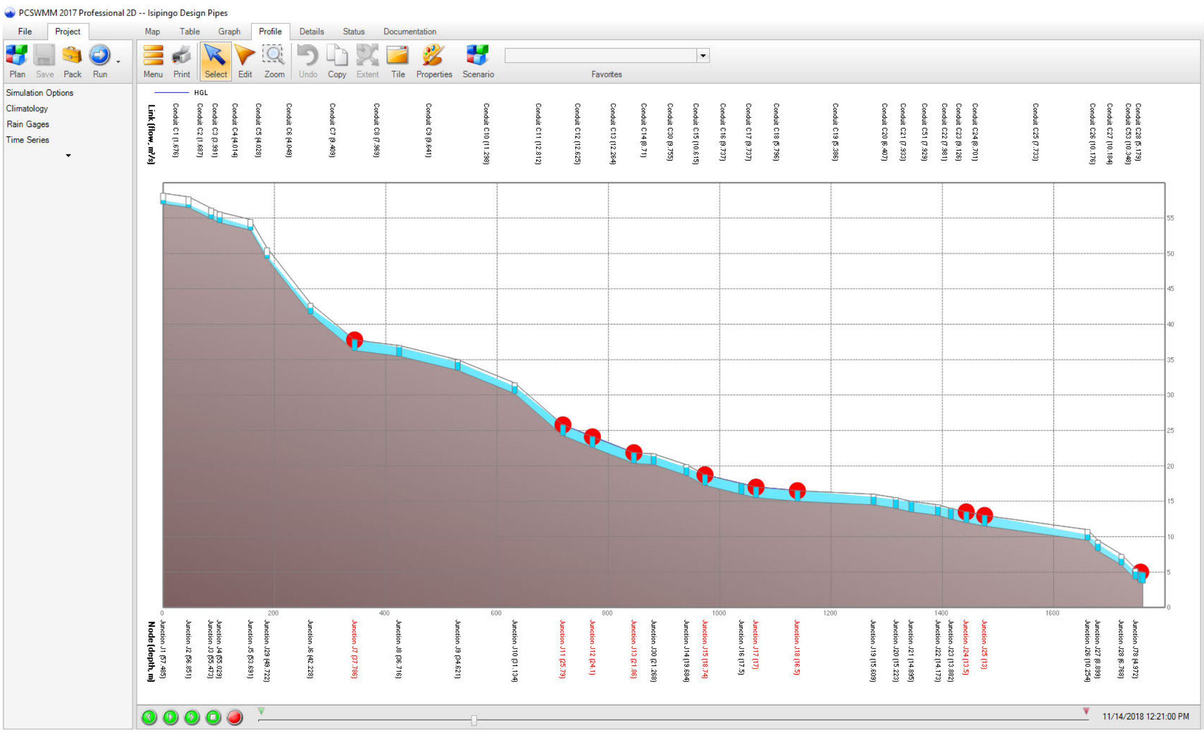


Figure 2: Depiction of Flooding and Surcharge

Source: PCSWMM Model, 2018.

The design can thus be altered and run again to ensure the surcharging and flooding points are removed from the system. The status tab shows the flow rates and checks required to validate the design.

17. SUDS PCSWMM Model

1. Click on the Scenario Manager icon 

 > Add > Duplicate current project.

2. Rename the copy as SUDS and change description. Browse to save the model in the same folder and click Create.

3. You have now created the copy in the scenario manager window. Double click SUDS in the scenario manager to open the model (close reports that pop up) (PCSWMM, 2018).

4. Click on the conduits layer in PCSWMM and open the table to view all conduits and properties.

5. Change the size and roughness coefficient to suit the properties of a swale instead of a concrete pipe. The swales are trapezoidal in shape with a 0.4 roughness coefficient.

6. Run the simulation to see flow rates. Figure 3 shows the long section profile generated by PCSWMM.

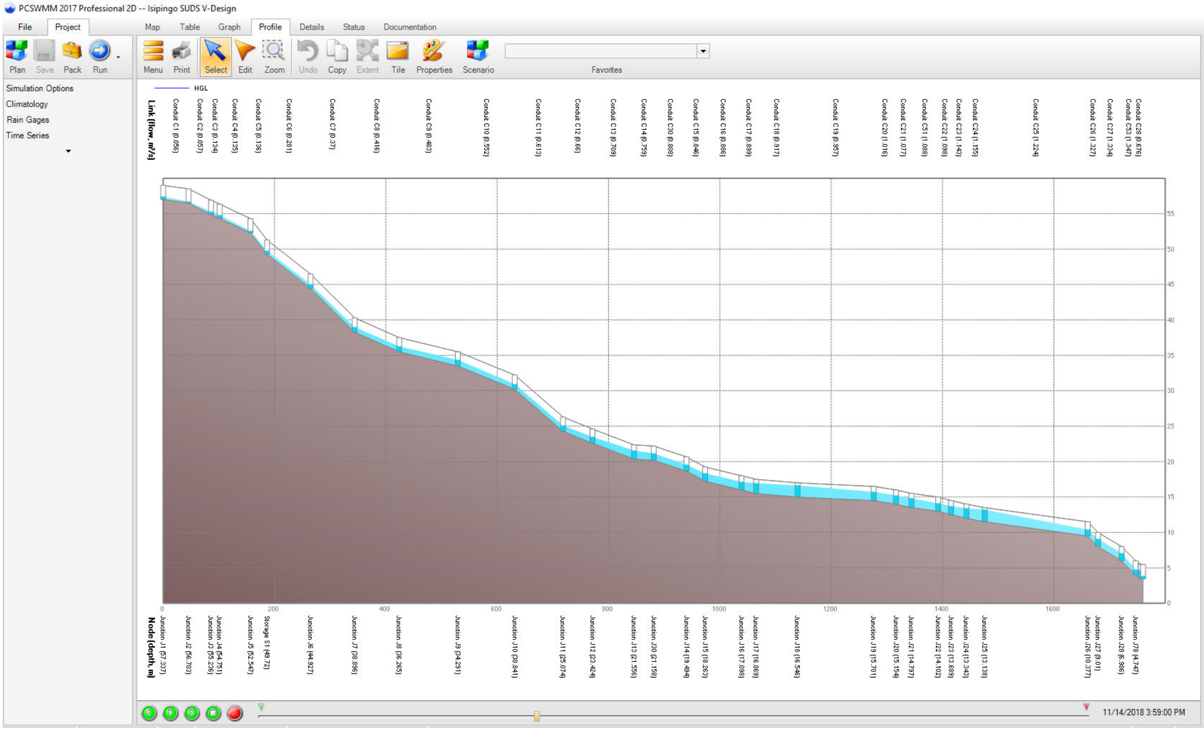


Figure 3: SUDS Model on PCSWMM

Source: generated from PCSWMM, 2018.

18. Attenuation Based Facilities PCSWMM Model

1. Click on the Scenario Manager icon 

 > Add > Duplicate Conventional 2.
2. Rename the copy as Attenuation Based and change description. Browse to save the model in the same folder and click Create.
3. You have now created the copy in the scenario manager window. Double click Attenuation Based in the scenario manager to open the model (close reports that pop up) (PCSWMM, 2018).
4. Click on the storage layer on PCSWMM and add accordingly onto your network.
5. Alternatively, you could convert an existing junction into a storage unit by clicking on convert> storage.

6. A rating curve is required to demarcate the size of the attenuation by pressing on the storage curve drop down and clicking on tabular.

7. Press on curve name below and add the curve according to the depths and area to simulate the storage volume of your attenuation facility.

8. Repeat steps 4 to 7 to add another attenuation where appropriate.

9. Run the simulation to see the outcome. The profile shows attenuation ponds the same way it does manholes as seen in Figure 4.

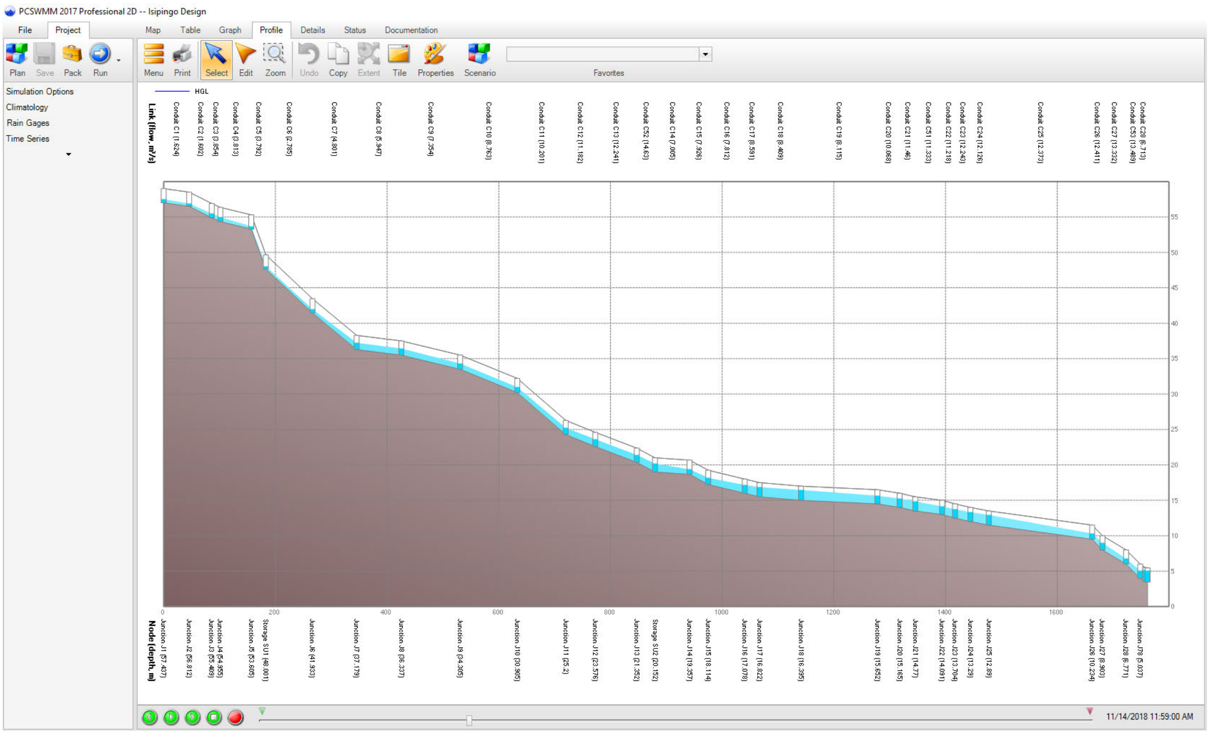
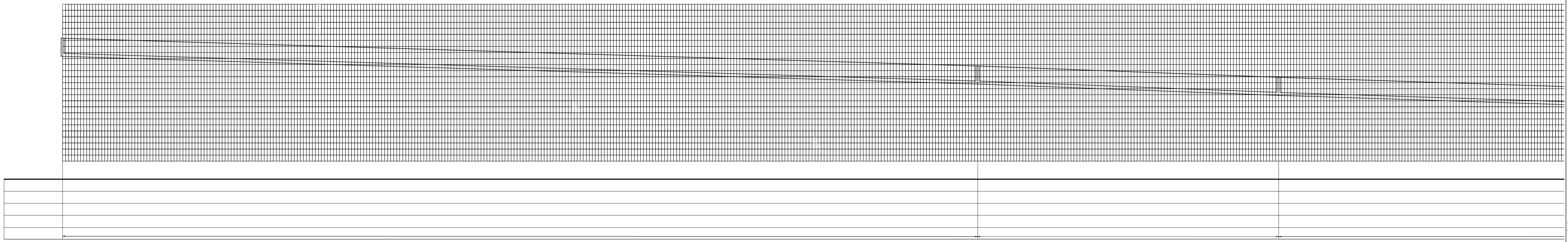


Figure 4: Attenuation Facilities PCSWMM Model

Source: Author generated from PCSWMM 2018.

Appendix 4: Long section of Conventional Stormwater Management System



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REDUCED PLAN USE SCALE BELOW

0 10 20 30 40 50 60 70

70mm ON ORIGINAL PLAN

LEGEND

EXISTING UNDERGROUND SERVICES
ARE AS SHOWN BELOW

SEWERS AND M.H.'S

STORM WATER DRAIN AND M.H.'S

WATER MAINS AND VALVES

ELECTRICITY CABLES

G.P.O. TELEPHONE CABLES

Revision	Date	Description

NOTE: No construction work to commence until land and servitude acquisitions have been completed

Acquisitions completed: –

Date Engineer

UNDERGROUND SERVICES CHECKED

SERVICE	DATE	SIGNATURE
S.W DRAINS	00000	
SEWERS	00000	
WATER MAINS	00000	
G.P.O CABLES	00000	
ELECTRIC CABLES	00000	
S.A.R. CABLES		
E.S.C. CABLES		
OIL PIPE LINE		

NOTE: Only underground services affected by new constuction work are shown.
Care must be taken during excavations for road foundations, trenches etc, to avoid damage to underground services such as sewers, drains, cables, water mains and connections. Wherever possible these must be located before work proceeds.

Contract No. 0 0 0

Project Title

Drawing Title

S S S
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SCALES	AS SHOWN	Date	JAN 2019
Designed	B.VELLA	Checked	
Drawn	N.NGIDI	Surveyed	

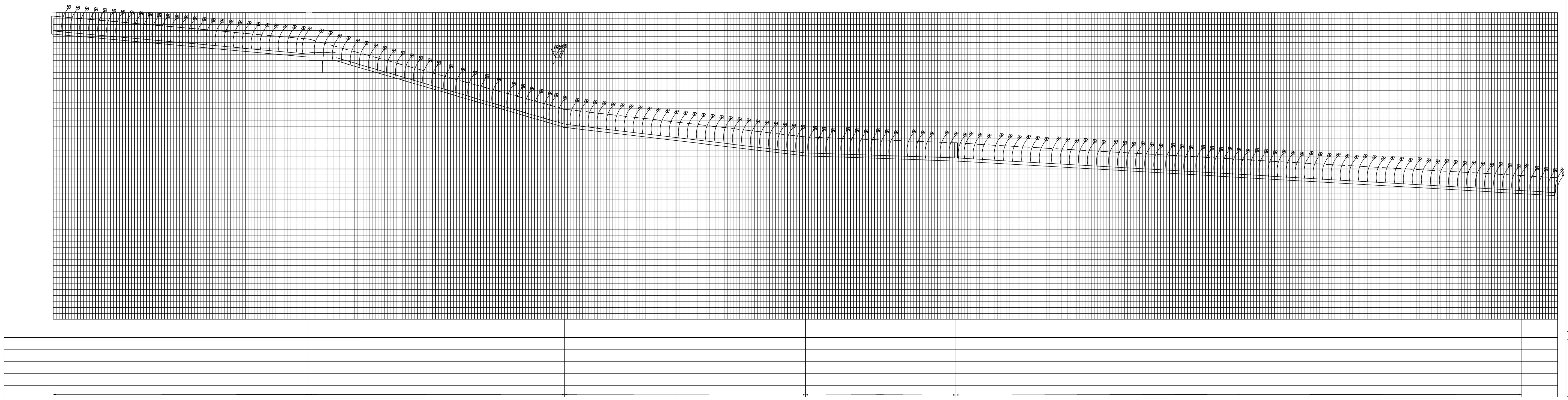
Manager (Stormwater Eng.)

Deputy Head

G.S. EVANS HEAD : ENGINEERING

Drawing No. 0 00	Sheet of	Rev.

Appendix 5: Long Section of Sustainable Urban Drainage System



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REDUCED PLAN USE SCALE BELOW

0 10 20 30 40 50 60 70

70mm ON ORIGINAL PLAN

LEGEND

EXISTING UNDERGROUND SERVICES ARE AS SHOWN BELOW

SEWERS AND M.H.'S

STORM WATER DRAIN AND M.H.'S

WATER MAINS AND VALVES

ELECTRICITY CABLES

G.P.O. TELEPHONE CABLES

Revision	Date	Description

NOTE: No construction work to commence until land and servitude acquisitions have been completed

Acquisitions completed: –

Date Engineer

UNDERGROUND SERVICES CHECKED

SERVICE	DATE	SIGNATURE
S.W DRAINS	00000	
SEWERS	00000	
WATER MAINS	00000	
G.P.O CABLES	00000	
ELECTRIC CABLES	00000	
S.A.R. CABLES		
E.S.C. CABLES		
OIL PIPE LINE		

NOTE: Only underground services affected by new constuction work are shown.
Care must be taken during excavations for road foundations, trenches etc, to avoid damage to underground services such as sewers, drains, cables, water mains and connections. Wherever possible these must be located before work proceeds.

Contract No. 0 0 0

Project Title

Drawing Title

S S S
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S S

SCALES	AS SHOWN	Date	JAN 2019
Designed	B.VELLA	Checked	
Drawn	N.NGIDI	Surveyed	

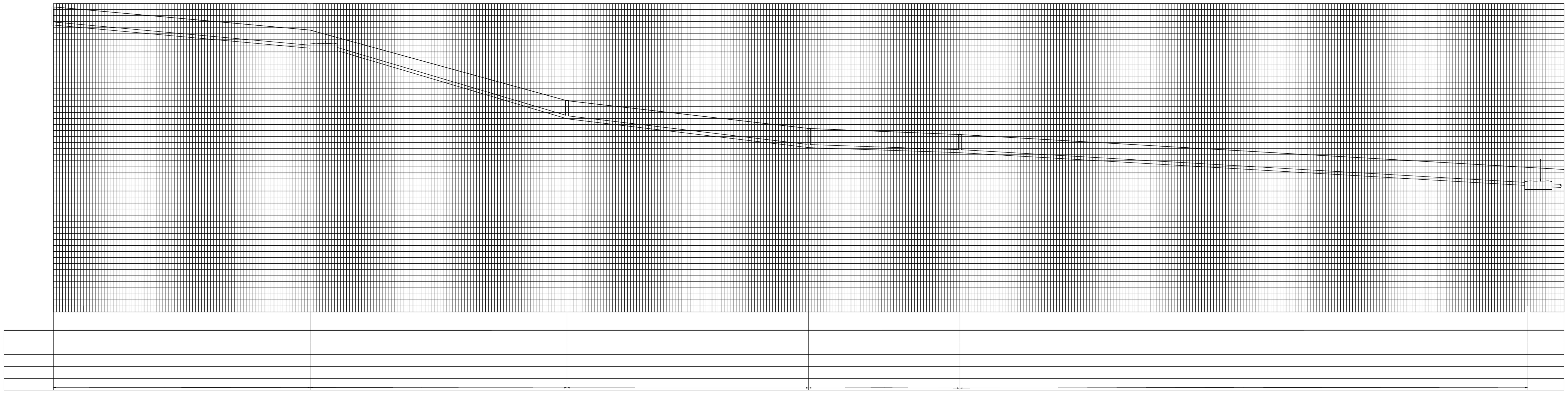
Manager (Stormwater Eng.)

Deputy Head

G.S. EVANS HEAD : ENGINEERING

Drawing No. 0 0 0 Sheet of Rev.

Appendix 6: Long Section of Attenuation Facilities Based System



NU N D RM RM N M N N N

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REDUCED PLAN USE SCALE BELOW

0 10 20 30 40 50 60 70

70mm ON ORIGINAL PLAN

LEGEND

EXISTING UNDERGROUND SERVICES ARE AS SHOWN BELOW

SEWERS AND M.H.'S

STORM WATER DRAIN AND M.H.'S

WATER MAINS AND VALVES

ELECTRICITY CABLES

G.P.O. TELEPHONE CABLES

Revision	Date	Description

NOTE: No construction work to commence until land and servitude acquisitions have been completed

Acquisitions completed: –

Date Engineer

UNDERGROUND SERVICES CHECKED

SERVICE	DATE	SIGNATURE
S.W DRAINS	00000	
SEWERS	00000	
WATER MAINS	00000	
G.P.O CABLES	00000	
ELECTRIC CABLES	00000	
S.A.R. CABLES		
E.S.C. CABLES		
OIL PIPE LINE		

NOTE: Only underground services affected by new constuction work are shown.
Care must be taken during excavations for road foundations, trenches etc, to avoid damage to underground services such as sewers, drains, cables, water mains and connections. Wherever possible these must be located before work proceeds.

Contract No. 0 0 0

Project Title

Drawing Title

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SCALES	AS SHOWN	Date	JAN 2019
Designed	B.VELLA	Checked	
Drawn	N.NGIDI	Surveyed	

Manager (Stormwater Eng.)

Deputy Head

G.S. EVANS HEAD : ENGINEERING

Drawing No. 0 0 0	Sheet of	Rev.

Appendix 7: Long Section of Conventional Stormwater System

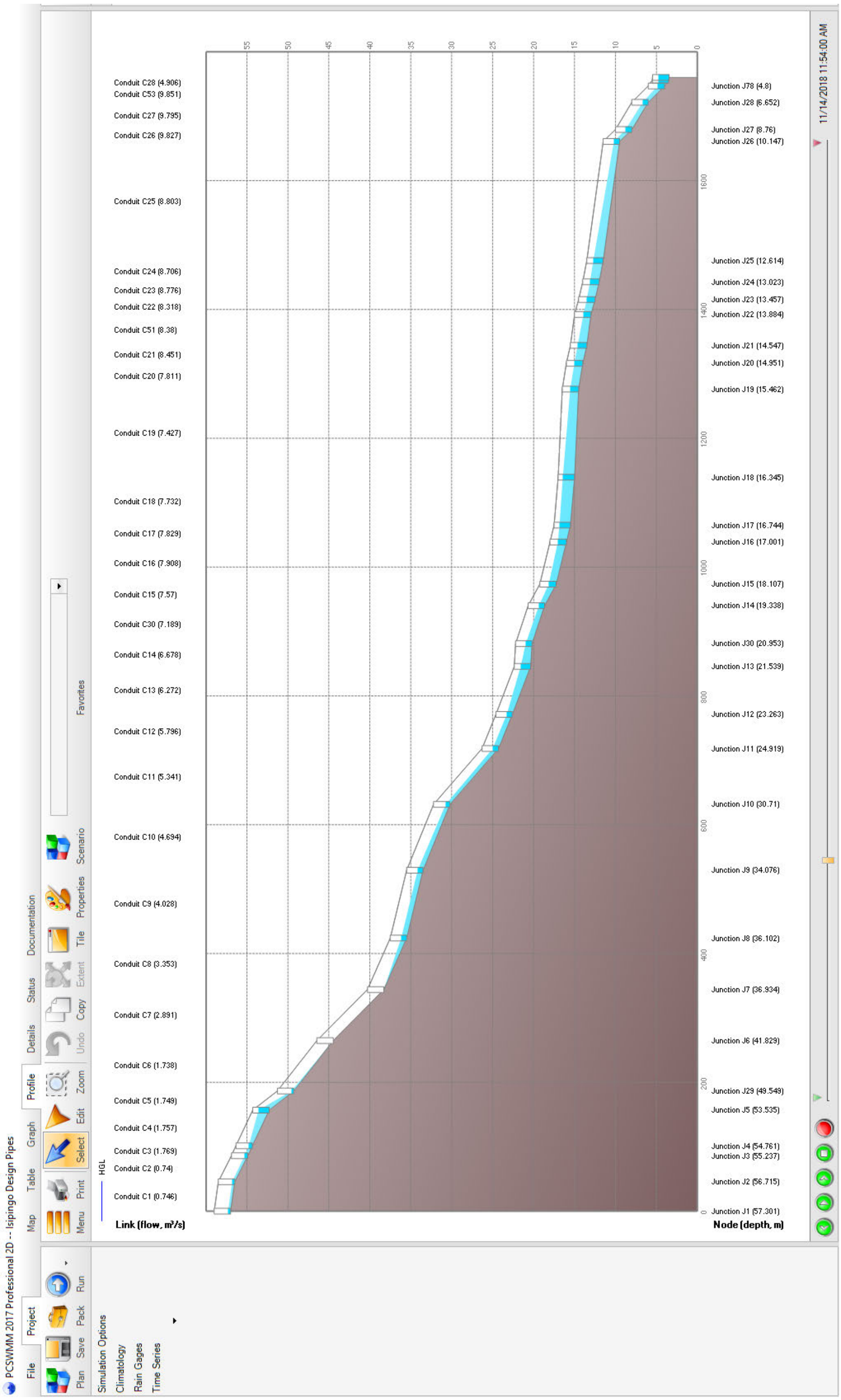

Figure 5: Long Section of Conventional Stormwater System

Source: Author generated from PCSWMM, 2018.

Appendix 8: Depiction of Flood on PCSWMM Model

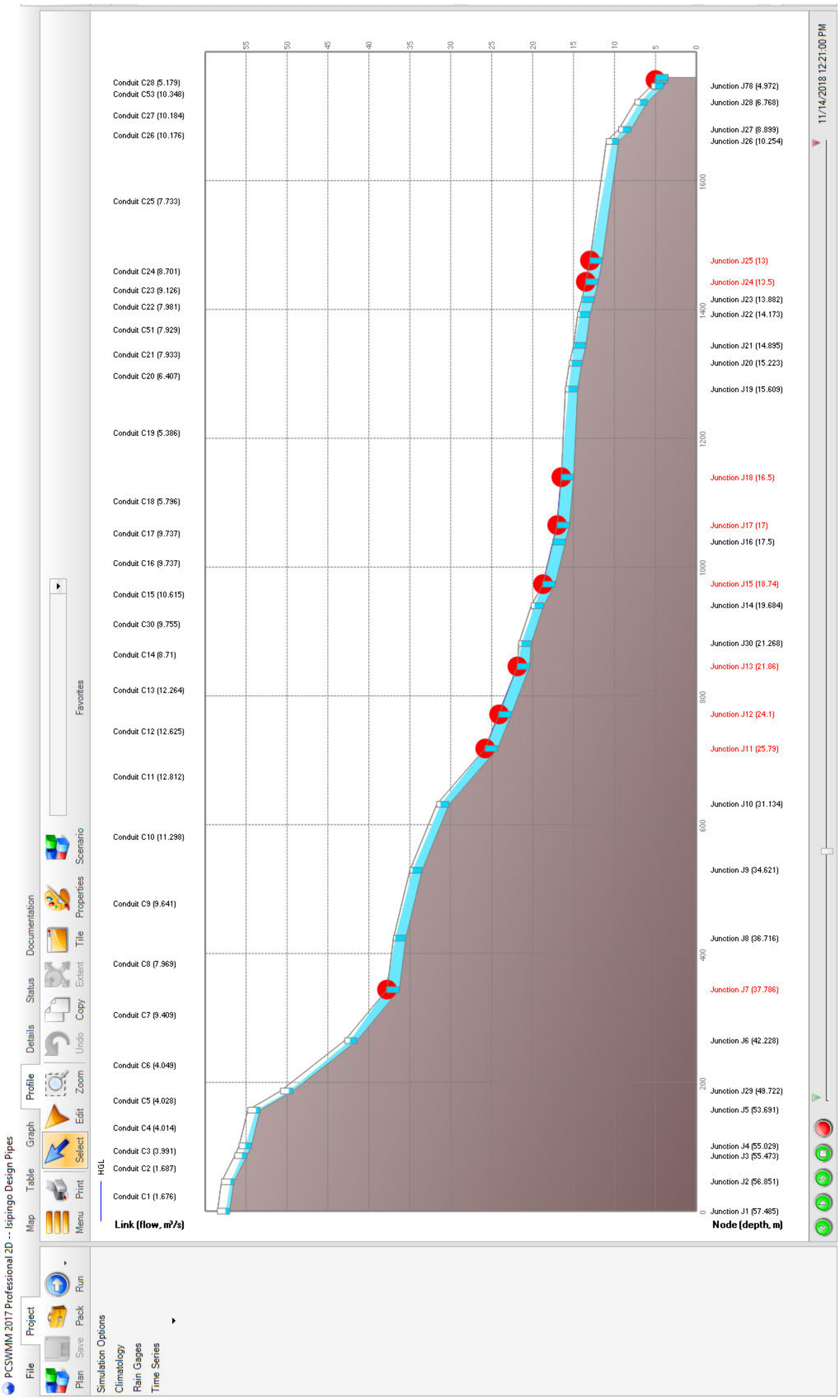

Figure 6: Depiction of Flooding on PCSWMM Model

Source: Author generated from PCSWMM, 2018.

Appendix 9: SUDS PCSWMM Model

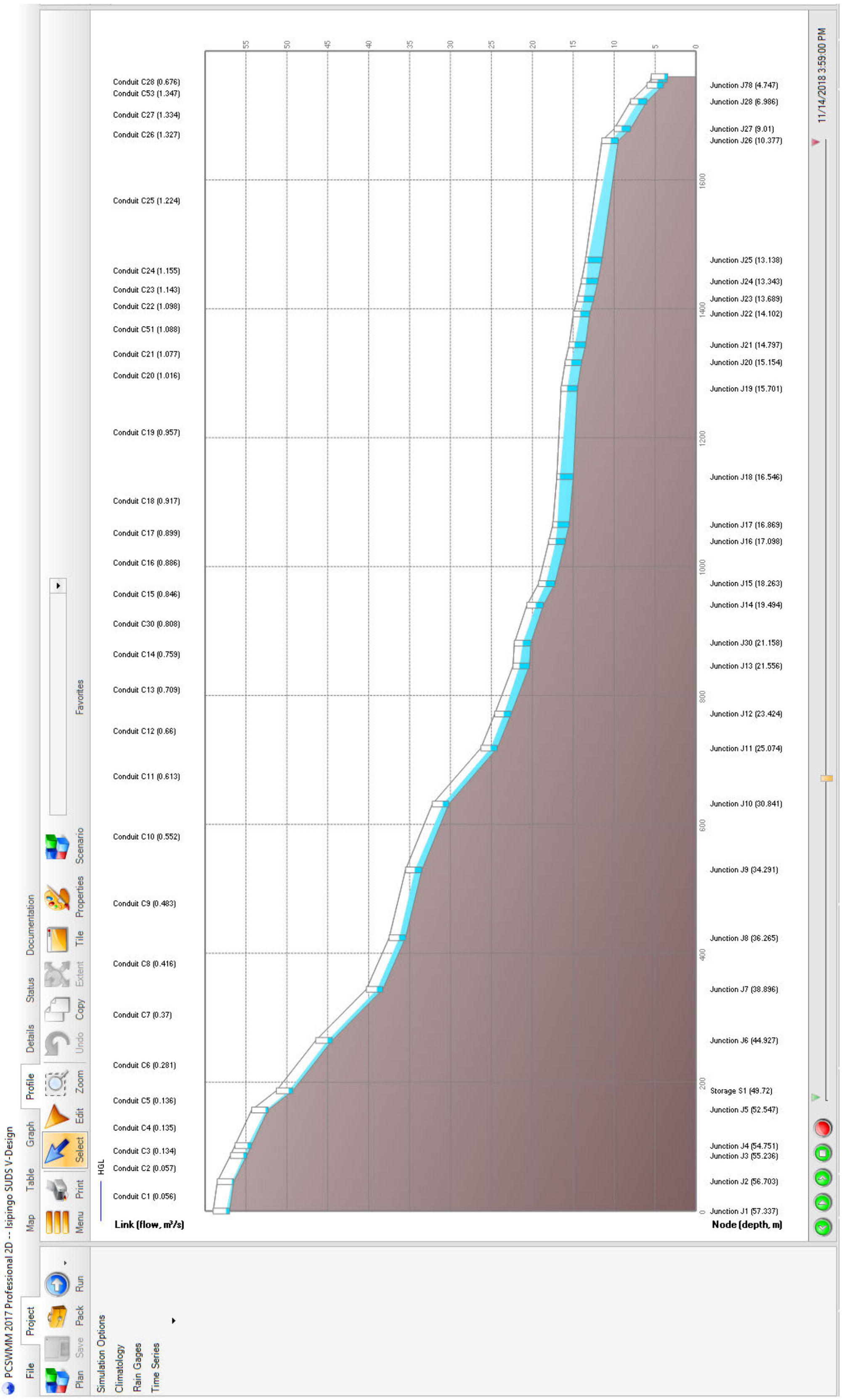

Figure 7: SUDS Model on PCSWMM

Source: Author generated from PCSWMM, 2018.

Appendix 10: Attenuation Facilities PCSMM Model

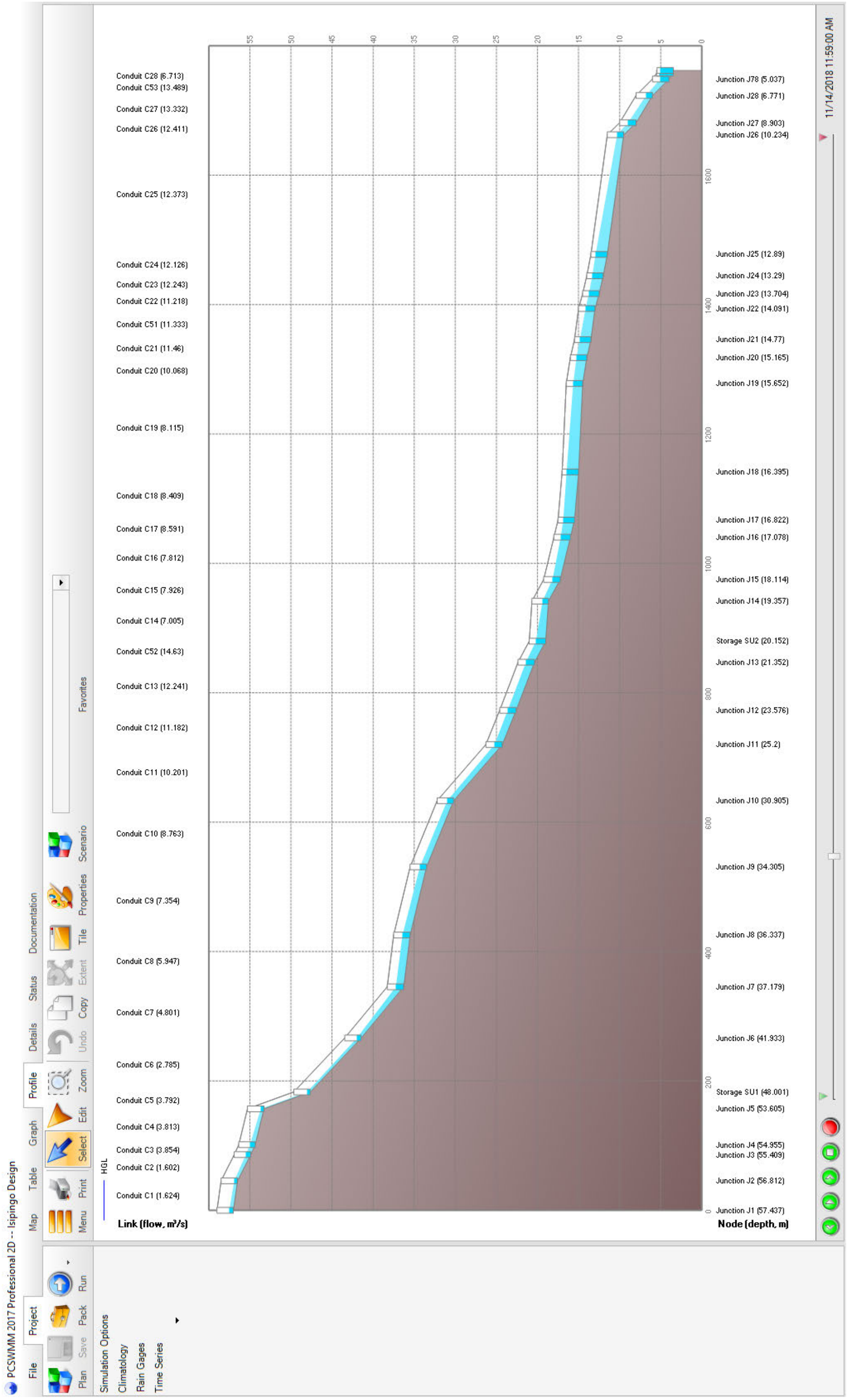

Figure 8: Attenuation Facilities PCSWMM Model

Source: Author generated from PCSWMM, 2018.

Appendix 11: Ethical Clearance

UNIVERSITY OF KWAZULU-NATAL™
INYUVESI YAKWAZULU-NATALI

28 August 2018

Ms Nqobile Thobeka Nkalipho Khuzwayo (208514336)
Graduate School of Business & Leadership
Westville Campus

Dear Ms Khuzwayo,

Protocol reference number: HSS/1178/018M
Project Title: A cost-effectiveness analysis of Stormwater Management Systems for Isipingo Prospecton

Approval Notification – Expedited Application

In response to your application received 02 August 2018, the Humanities & Social Sciences Research Ethics Committee has considered the abovementioned application and the protocol has been granted **FULL APPROVAL.**

Any alteration/s to the approved research protocol i.e. Questionnaire/Interview Schedule, Informed Consent Form, Title of the Project, Location of the Study, Research Approach and Methods must be reviewed and approved through the amendment /modification prior to its implementation. In case you have further queries, please quote the above reference number.

PLEASE NOTE: Research data should be securely stored in the discipline/department for a period of 5 years.

The ethical clearance certificate is only valid for a period of 3 years from the date of issue. Thereafter Recertification must be applied for on an annual basis.

I take this opportunity of wishing you everything of the best with your study.

Yours faithfully

[redacted]
....

pp **Professor Shenuka Singh (Chair)**

/ms

Cc Supervisor: Dr Mihalis Chasomeris
Cc Academic Leader Research: Professor Muhammad Hoque
Cc School Administrator: Ms Zarina Bullyraj

Appendix 12: Turn it in Report

A Cost-Effectiveness Analysis of Stormwater Management Systems: Isipingo/ Umlazi Area

ORIGINALITY REPORT

6%	6%	3%	2%
SIMILARITY INDEX	INTERNET SOURCES	PUBLICATIONS	STUDENT PAPERS

PRIMARY SOURCES

1	www.scielo.org.za Internet Source	1%
2	researchspace.ukzn.ac.za Internet Source	1%
3	www.bmj.com Internet Source	1%
4	community-wealth.org Internet Source	1%
5	www.ecologyandsociety.org Internet Source	<1%
6	journals.ufs.ac.za Internet Source	<1%
7	en.wikipedia.org Internet Source	<1%
8	www.computationalhydraulics.com Internet Source	<1%
9	Submitted to Atlantic International University	

Appendix 13: Gate Keepers Permission Letter

ETHEKWINI MUNICIPALITY

M I L E

MUNICIPAL INSTITUTE OF LEARNING

Pod 1, Second Floor, Intuthuko Junction, 750 Mary Thiphe Street, Umkhumbane, Cato Manor, Durban 4001.
Tel: 031 322 4513, Fax: 031 261 3405, Fax to email: 086 265 7160, Email: mile@durban.gov.za, Website: www.mile.org.za

For attention:
Chair of Ethics Committee
College of Law and Management Studies
Graduate School of Business and Leadership
UKZN, Westville Campus
Durban
4001

18 June 2018

RE: LETTER OF SUPPORT TO NTN KHUZWAYO, STUDENT NUMBER 208514336 - GRANTING PERMISSION TO USE ETHEKWINI MUNICIPALITY AS A CASE STUDY

Please be informed that the Engineering Unit and eThekwini Municipal Academy (EMA), have considered a request from **NKALIPHO THOBEKA NQOBILE KHUZWAYO (Ms)** to use eThekwini Municipality as a research study site leading to the awarding of a Master's in Business Administration degree (MBA) entitled: ***"The Effectiveness Analysis of Stormwater Management Systems: Isipingo Prospection"***

We wish to inform you of the acceptance of her request and hereby assure her of our utmost cooperation towards achieving her academic goals; the outcome which we believe will help our municipality improve its service delivery. **The student is reminded of the ethical considerations which have to be prioritized when engaging our city officials during the course of the research. We also stipulate as conditional that the student is accompanied by her supervisor to present the results and recommendations of this study to the relevant city unit on completion of the research study. The forum will be facilitated by MILE and the student must contact the MILE Office on 031 3224513 or by mail,** collin.pillay3@durban.gov..za **to confirm a date for this presentation.**

Wishing Ms Khuzwayo all the best in her studies.

[redacted]

Mr Greg Evans
Head: Engineering Unit
EThekwini Municipality

[redacted]

Dr M. Ngubane
Head: eThekwini Municipal Academy
eThekwini Municipality