DURBAN UNIVERSITY OF TECHNOLOGY
INYUVESI YASETHEKWINI YEZOBUCHWEPHESHE

ASSESSMENT OF THE LOWER ISIPINGO CATCHMENT'S ABILITY TO MITIGATE FLOODING, CONSIDERING THE EXISTING DRAINAGE SYSTEM

Submitted in fulfilment of the requirements for the degree of

Master of Engineering

in the Department of Civil Engineering and Geomatics

Faculty of Engineering and the Built Environment

Durban University of Technology

Zinhle Nomfundo Nzuza

March 2025

Supervisor:_ ______________
Bloodless Dzwairo (DTech Eng: Civil)

Date: 9 March 2025

ABSTRACT

The Lower Isipingo Catchment is located south of Durban in the KwaZulu-Natal Province, South Africa. It presents a particular challenge to urban flood risk. The Lower Isipingo Catchment comprises the split Isipingo and Umlazi River estuarine systems. The significance of the catchment is that it has become one of Durban's most industrially developed areas. The Isipingo wetland was converted into a flatland to facilitate the economic development of industries in the 1940s. The Isipingo Diversion Works System was implemented in 1960 as a flood mitigation strategy using canals at the tail end of the Isipingo and Umlazi rivers. This strategy was not successful, as extreme flooding is a regular occurrence within the Lower Isipingo Catchment, causing constant socio-economic losses and infrastructure damage.

The study evaluated the catchment's capacity to mitigate flooding, considering the existing drainage system. The study's findings can be used to improve the resilience of the catchment against flooding events**.** The study objectives were made up of three components. The first was to evaluate the effects of urbanisation on the catchment's drainage system. This was achieved by calculating the peak flow. The Rational Method was used to quantify the volumetric flow rate of surface water draining from the catchment area over 20 years. Peak flows were assessed for pre- and post-development scenarios in 2002 and 2022. The catchment was split into four sub-catchments: Isipingo 1, Isipingo 2a, Isipingo 2b, and Isipingo 2c.

The findings demonstrated that there has been a rise in economic activity through developments in the Prospecton industrial area and the Isipingo Central Business District (CBD) in the lower catchment. As a result, the upper catchment now includes denser residential zones with fewer green spaces and lower surface infiltration. The unit hydrographs show higher peak flows and reduced lag time under post-development scenarios. Isipingo 1 produced the highest increase in runoff flow at 50%, followed by Isipingo 2a and 2b with 33%, and lastly Isipingo 2c with an increase of only 25%. Development in the catchment has led to more impervious surfaces, which has increased stormwater runoff. This increases the vulnerability to flooding as conventional drainage systems do not consider the effects of urbanisation on runoff volume.

The second objective was to determine the extent to which solid waste impacts the drainage system’s functionality. This was achieved by physically inspecting the drainage infrastructure using visual inspections. The study found that the system was not functioning at its designed capacity due to the accumulation of debris and waste within the drainage inlets conveyed by runoff in all four sub-catchments. The drainage structures are blocked with silt and debris and damaged in certain instances, preventing the flow of stormwater within the stormwater networks. It was observed that the culverts in Isipingo 2b are under-maintained to withstand the flows and volumes of stormwater. The result of these factors is that stormwater is unable to enter or leave the stormwater systems efficiently, which can further reduce mitigation capacity and increase the risk of flooding.

The third objective was to assess the performance of the existing drainage system with varying rainfall data. This was achieved through the completion of a stormwater hydraulic model for the drainage networks. The Personalized Computer Storm Water Management Model detailed the hydrological characteristics of the catchment and the configuration of the drainage network system. The models are based on a 1-hour storm simulation using the 1 in 5-year design rainfall and the 2019 and 2022 flood rainfall experienced on the catchment. The results specified the flooding networks and the severity of flooding, depending on the digital elevation model data and the distribution and intensity of the rainfall.

The model’s results indicated that stormwater infrastructure is sufficient to mitigate stormwater runoff for the 1 in 5-year design rainfall and the April 2019 and 2022 flood rainfall. However, due to hydraulic inconsistency of the stormwater network pipe sizes, slopes, cover, and invert levels, the hydraulic capacity has proven to be insufficient in certain areas. This has resulted in localised flooding in Isipingo CBD located downstream in the sub-catchments of Isipingo 1, 2a and 2b along Phila Ndwandwe Road, Thie Road, Clark Road, Pardy Road, and Lotus Road. There is also visible flooding in Isipingo 2c, the Prospecton industrial area, with the following areas being vulnerable: the N2, Prospecton Road, Winter Road, Avenue East Road, Joyner Road, Ocean Road, Delta Road, Duiker Road, and Inner Circuit Road. It was also noted that relying entirely on model outputs and ignoring real-site circumstances might result in an underestimation of flood hazards associated with high rainfall occurrences.

The findings of this study can assist eThekwini Municipality to be more proactive rather than reactive to the frequent flooding in the Lower Isipingo Catchment. Knowing the location of the vulnerable areas within the catchment, including the factors increasing the flood risk, can assist in improved resource allocation and preparedness against frequent floods. The implementation of this study’s recommendations could have positive economic, social, and environmental effects on the Lower Isipingo Catchment. Adopting water-sensitive urban design principles with the use of sustainable urban drainage systems is the new approach to the management of stormwater. Treating stormwater as a resource in the water cycle rather than a nuisance. Sustainable urban drainage systems can be retrofitted into the existing drainage network to increase flood mitigation capacity for frequent heavy rainfalls and reduce stormwater contaminants in receiving waters. An all-inclusive strategy that combines modelling with on-site inspections and maintenance will offer a clearer understanding of the system's capabilities and limits, resulting in improved readiness and reaction strategies in the face of changing weather patterns.

A holistic approach can be used through cross-sector collaboration amongst various stakeholders to implement innovative institutional structures, policies, and management methods. This network can implement the following: infrastructure planning and upgrading, public participation, early warning systems, stormwater management, and asset management.

DECLARATION BY STUDENT

I hereby declare that this thesis for the degree of Master of Engineering in the Department of Civil Engineering and Geomatics at the Durban University of Technology is my original work, and it has not been submitted previously to any other institution of higher education. I further declare that all the sources cited and quoted are indicated and acknowledged in the references.

Zinhle Nomfundo Nzuza
Student No. 21511336

DEDICATION

Firstly, I want to express my gratitude to our Father in Heaven, Jehovah, the creator of all things, for accompanying me on this journey. Thank you to my parents, Miss Gugulethu Mtshali and Mr Vusumuzi Nzuza, and my sister, Wandile Nzuza, for their continuous support and encouragement. Lastly, my partner and friends for keeping me determined to live life to the fullest during my studies.

In the wise words of Richard Feynman, “Science is not a boy’s game; it’s not a girl’s game. It’s everyone’s game. It’s about where we are and where we’re going.” Let this serve as a reminder of how crucial diversity and inclusiveness are in STEM professions. Science and technology are communal endeavours that call for the involvement of all people regardless of gender, ethnicity, and social background.

We are all deserving and worthy.

ACKNOWLEDGEMENTS

- My supervisor, Bloodless Dzwairo, for her constant support and patience throughout all the challenges I have faced and overcome in the completion of this thesis.
- Thank you to the DUT scholarship for funding the final year of my studies.
- Thank you to CHI for providing me with a PCSWMM educational license for the duration of my studies.
- Miss Nombuso Dlamini and Nonhlelo Kunene for their constant technical support and guidance.
- My research assistant, Mr Thabiso Sibiya, for assisting with the visual site inspections.
- Mr Sphe Sibiya, for assisting with the spatial data analysis on ArcMap.
- My writing tutor, Mr Nathi Phetha, from the Alan Pittendrigh Library writing centre, thank you for always availing yourself and going beyond your working hours to ensure my academic writing was up to standard.

TABLE OF CONTENTS

LIST OF ABBREVIATIONS

BOD	Biochemical Oxygen Demand
COD	Chemical Oxygen Demand
CSIR	The Council for Scientific and Industrial Research
ENSO	El Niño Southern
EWS	Early Warning System
GIS	Geospatial Information Systems
IDP	Integrated Development Plan
IPCC	Intergovernmental Panel on Climate Change
PCSWMM	Personal Computer Storm Water Management Model
RCS	Representative Concentration Pathways
SAWS	South African Weather Services
SUDS	Sustainable Urban Drainage Systems
TSS	Total Suspended Solids
WSUD	Water Sensitive Urban Design

LIST OF FIGURES

LIST OF TABLES

LIST OF EQUATIONS

CHAPTER ONE: BACKGROUND

1.1 Introduction

All activities and developments associated with human advancement have a cost, which has become increasingly significant within social, economic and sustainability engineering fields. Urban floods can be viewed as the cost of economic growth and the increase of urbanisation in present-day cities in urban drainage and stormwater management. Extreme weather events, such as flooding, are becoming more frequent due to a warming climate as they affect the intensity and frequency of precipitation (EPA 2021). Due to larger impermeable surfaces, which result in increased runoff with higher peak discharges (Park and Park 2018), urban areas are more vulnerable to flood disasters.

It is crucial to acknowledge that the effects of climate change and flooding, for example, have varied degrees of impact on social and economic activities, livelihoods, public and private infrastructure, and the environment (Andersson *et al.* 2017; Kikwasi and Mbuya 2019). Housing, roads, bridges, stormwater drainage structures, such as culverts, and environmental ecosystems such as wetlands, rivers, mangroves, and open areas are all impacted by climate change (Zivkovic 2019). Extreme flooding is not new to eThekwini Municipality; it is a regular issue that, with adequate preparation, can be significantly alleviated. The city has experienced the impact of climate change in the form of frequent heavy rainfall leading to rapid flooding events. These flooding events have led to damage to municipal infrastructure such as roads and bridges (Ngema 2022), as well as private infrastructure such as houses (Smit 2022; Xolo 2022), loss of life (Nyoka 2022), and degrading of river and wetland ecosystems (Palfreman 2022; Khan 2023).

Flooding also affects the most vulnerable communities located in low-lying areas near riverine systems (Nicolson 2022). The most recent significant rainfall event in April 2022 was proclaimed a national disaster by President Cyril Ramaphosa (South African Government 2022) and described by scientists as one of the most catastrophic floods recorded in KZN (WITS 2023). eThekwini municipality is situated on South Africa's eastern coastline in the province of KwaZulu-Natal. It covers an area of roughly 2 555 km^2 and has approximately 3 987 648 residents; it is also ranked the third highest metropolitan municipality in population size in South Africa (COGTA 2020). It has three neighbouring district municipalities: Ugu, iLembe and uMgungundlovu as shown in Figure 1.

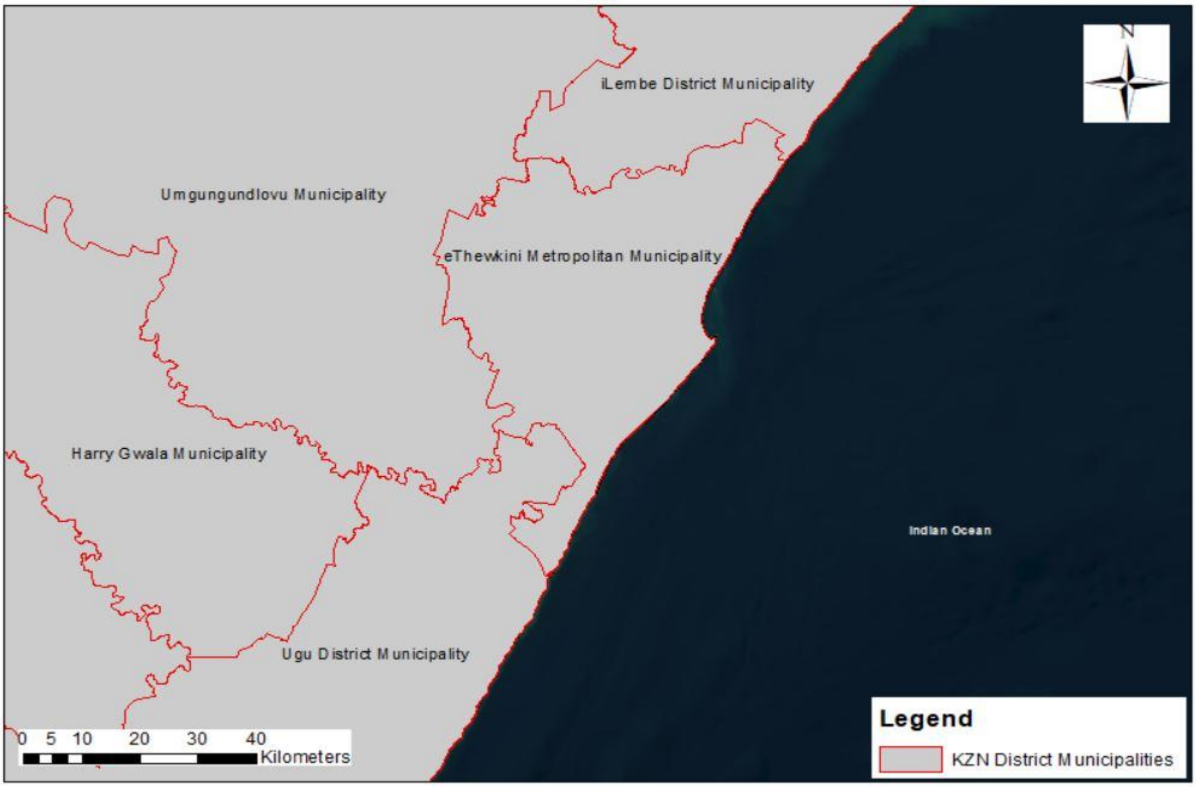


Figure 1: eThekwini Municipality Locality
Source: (ESRI) ArcGIS 10.0 and eThekwini Municipality GIS files

A recent publication by Schulze (2023), which provides a historical review of extreme rainfall events within KwaZulu-Natal from 1855 to 2022, illustrated that Durban has experienced exceptionally higher rainfall quantities and intensities at a range of durations. These historical rainfall events were concluded to be of a higher magnitude than the recorded April 2022 flood rainfall. Given this analysis, one might question why the April 2022 floods were so devastating if there had been previous floods of larger magnitude. The higher magnitude may be attributable to a higher degree of urbanisation than in previous years. An increase in impervious surfaces increases the surface run-off, subsequently increasing peak discharges (Swan 2010). It is vital to emphasise that the effects of floods are further exacerbated by poor urban planning, such as the development of floodplains, various anthropogenic activities, and global climate change (Chimnonyerem *et al.* 2016).

The rate at which extreme rainfall events occur should also be taken into consideration. Three significant rainfall events have occurred in Durban in recent years: October 2017 (SAWS 2017), April 2019 (SAWS 2019a, 2019b), and April 2022 (SAWS 2022a, 2022b). This can be attributed to a warming climate. Global warming causes rising global temperatures, which in turn increases atmospheric water vapour and, as a result, alters precipitation frequency (Wang *et al.* 2016a). Any slight shift in variation in precipitation can lead to a considerable rise in rainfall. Therefore, heavy rainfall will become more severe and frequent (Shadid *et al.* 2016).

1.2 Climate Change

A region's climate is its average weather over a certain period. Therefore, climate change refers to a continuing alteration in a region's regular or typical weather. In the previous few decades, anthropogenic activities have gradually accelerated climate change, including an increase in global temperature on land, sea, and atmosphere (Masson-Delmotte et al. 2021). The Intergovernmental Panel on Climate Change (IPCC) observed the following negative changes: the amount of snow and ice on the Arctic and Antarctic continents has reduced, the atmosphere and sea waters have warmed, and sea levels have increased. According to Figure 2, the average temperature on earth increased by approximately 1°F from 1880 to 2020 (NASA 2023).

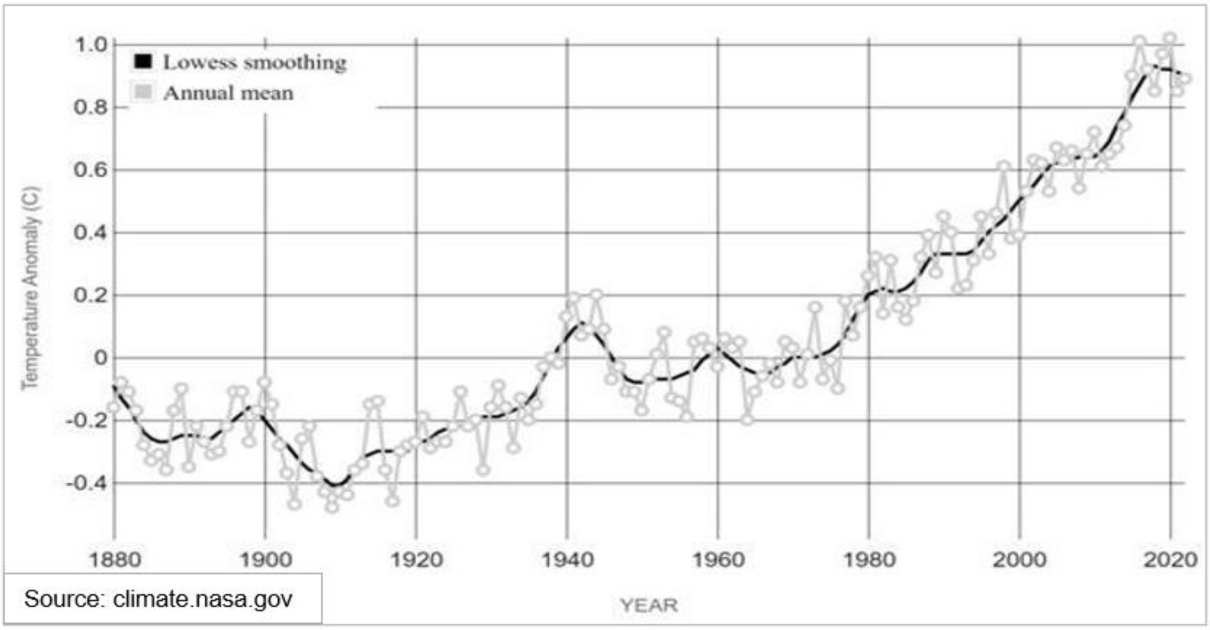


Figure 2: Global land-ocean temperature index.

Source: (NASA 2023)

Climate change is caused by the production of greenhouse gases. Although numerous greenhouse gases are found naturally in the atmosphere, human influence generates additional deposition (European Parliament 2023). As a result, the effect of greenhouse gases expands in the atmosphere, altering the climate. Warming temperatures in eThekwini are anticipated to rise by 1.50°C and 2.50°C by 2065, respectively, and by 3.00°C and 5.00°C by 2100. Variations in precipitation over the years predict a 500mm rise by 2100 (eThekwini Municipality 2021). The projected increase in temperature, combined with increases in rainfall variations, poses the following risks: increased frequency of floods and droughts, insufficient water supply, reduced water quality, diseases, and the loss of ecosystems (Future Water and Climate Adaptation Services 2018). Such impacts can be worsened by a lack of infrastructure maintenance, poor planning, and governance (eThekwini Municipality 2022a).

In light of the increasing damage from the severe storms experienced in Durban in October 2017 and April 2019, it became evident to the eThekwini Municipality that there was an urgency to do things differently and to transform the city to cope with climate change. As a result of this, numerous policies were created, such as the Durban Climate Action Plan and the Durban Climate Change Strategy that is reviewed annually. Such policies secured partnerships with various stakeholders that ensured the city made the shift to building a resilient metropolitan municipality. The eThekwini municipality joined the cities network with the climate leadership group to honour the Paris Agreement, which pledged to limit global warming to 1.5°C (eThekwini Municipality 2019). A climate impact atlas was created that includes the most recent climate predictions and the outcomes of the risk and vulnerability assessments that can be used for informed decision-making and prioritising action (eThekwini Municipality and C40 Cities 2023).

Further partnerships were secured with the CSIR, national treasury, and ABSA, which led to the recent development of the eThekwini strategic hub with the Metroview Greenbook Tool (eThekwini Municipality 2023). The greenbook tool comprises two components: the climate risk profile tool and the climate actions tool, which provide spatial data on climate hazards and susceptibility to develop an understanding of the potential impacts and the required decisions to respond to them. The greenbook tool and the climate impact atlas can be used to inform and prioritise adaptation strategies and to build long-term climate change resilience.

1.3 Extreme Rainfall and Flood Vulnerability

Globally, the average precipitation on land has risen since 1950, with a heightened rate of increase since the 1980s (Masson-Delmotte et al. 2021). Although there is uncertainty about future rainfall variations, with different models and emission scenarios producing different results, the prevailing consensus is that rainfall intensities will increase (IPCC 2007). Climate change estimates are critical in estimating urban flood vulnerability and investigating adaptation solutions (Wang *et al.* 2023).

The CSIR created a model to simulate the occurrence of excessive precipitation (CSIR 2019). The simulation is based on three periods: baseline 1961–1990, projected change for 2021–2050, and 2071–2100. The results for the eastern region where the Lower Isipingo Catchment is located are as follows:

- 1961–1990: More than 10 extreme rainfall events occurred on average.
- 2021–2050: The RCP 4.5 scenario predicted a rise in the frequency of intense rainfall events.
- 2071–2100: The RCP 4.5 scenario predicted a lower frequency of intense rainfall events.
- With the RCP 8.5 scenario, extreme rainfall incidents under low mitigation conditions are noted to be very similar to patterns expected under mitigating conditions.

CSIR's Flood Hazard Index (FHI) is based on catchment features and the design rainfall and is calculated as an average at the quinary catchments. Figure 3 details the flood hazard index in KwaZulu-Natal. The Lower Catchment, located south of Durban, is covered in a lighter shade of orange, which is towards the higher flood hazard risk range.

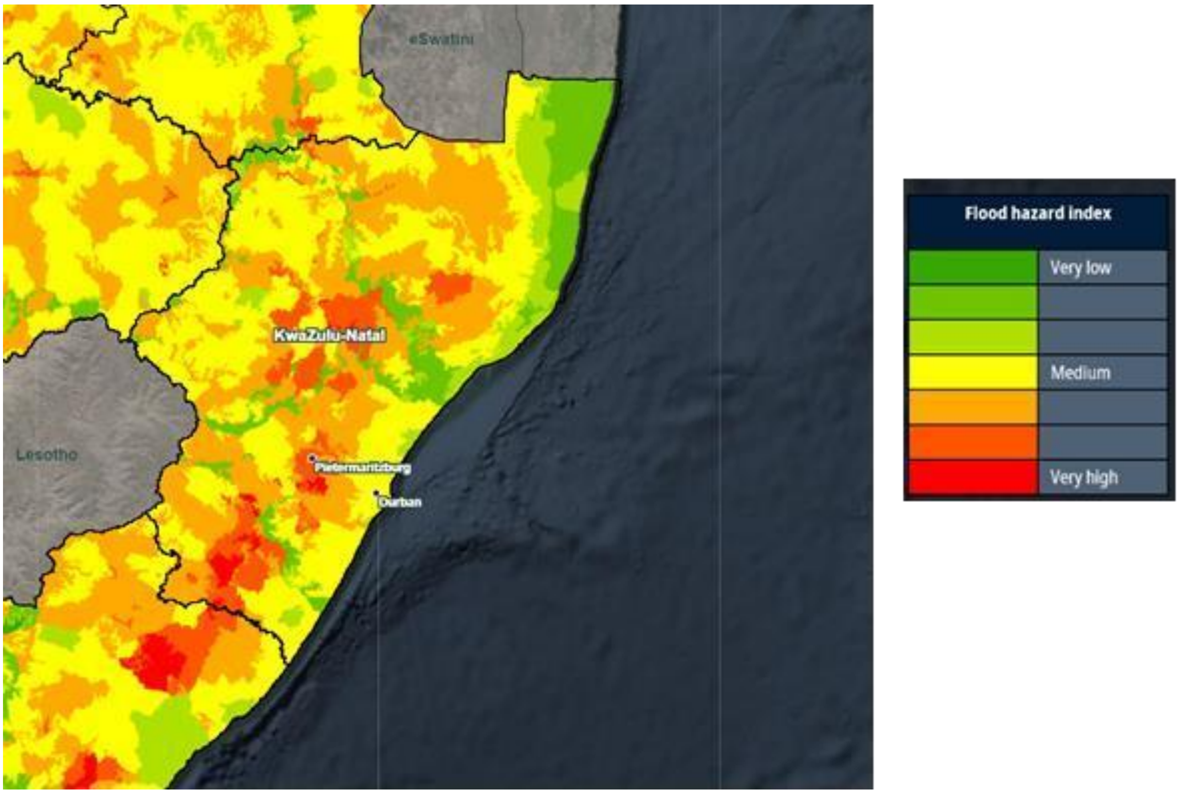


Figure 3: CSIR flood hazard index for KwaZulu-Natal.
Source:(CSIR 2019)

eThekwini Municipality has projected that the 1 in 10-year return period rainfall will increase by 22 mm from 78 mm in 2023 to 100 mm in 2050 and will also appear more often, which is projected to occur three times per ten years (eThekwini Municipality and C40 Cities 2023). The design rainfall is expected to rise, which will also increase the amount of stormwater runoff, leading to an increase in the occurrence of floods. A conclusion can be drawn that the possible adaptation measures within the Lower Isipingo Catchment must consider an increase in the frequency heavy rainfall events and floods.

1.4 Urban Flood Risk

A hazard is an occurrence, activity, or condition that has the potential to cause death, injury, property destruction, disruption of services, socioeconomic instability, and deterioration of the environment (IFRC 2021). Risk refers to the possibility of detrimental outcomes caused by natural or human-induced hazards (European Commission-Joint Research Centre *et al.* 2004). Flood risk is thus an assessment of the vulnerability to floods as well as the total worth of the assets in danger of flooding. The total probability of flood risks and the assets at risk of these hazards determine flood risk. Several characteristics, including exposure, degree of sensitivity, possible consequences, and adaptive ability, are used to assess the severity potential of assets exposed to the hazards (Bles *et al.* 2016). Given the financial and political significance of urban areas, flooding in cities is a relatively new hazard occurrence that is generating international interest (Chimnonyerem *et al.* 2016). Floods in cities have significant human and financial consequences due to the high population and number of assets (Chen and Ravallion 2007). Flood risk management is a UNISDR technique that advocates adapting to living with floods rather than dying from them (UNISDR 2004). The primary purpose of this technique is to reduce disaster risk, which reduces economic, social, and environmental losses. Hazards may be unavoidable, but disasters are not and can be avoided.

For a flood risk assessment, UNISDR suggests the following three approaches:

- Historical flood risk assessment: previous floods that have occurred.
- Predictive analysis assessment: use of modelling to locate areas vulnerable to flooding.
- Expert opinions: agencies to identify flood-prone areas and associated risks.

This method guides land-use planning to avoid creating additional flood risk by placing new assets in flood-prone zones and lowering the current level of risk through land-use modification approaches such as zoning or the development of adequate flood protection. The flood and risk maps produced by the assessment identify the exposed and vulnerable assets.

Conventionally, studies evaluating flood risk included the physical vulnerability of structures and assets as a metric of flood risk (Filatova 2014). Flood risk research has progressively focused on investigating the changes in flood risk, hazard, exposure, and susceptibility across historical, contemporary, and prospective timeframes (Pham et al. 2021). Various methodologies are employed in flood risk assessment, including historical hazard statistics, which typically forecast the frequency, depth, and losses associated with flood events (Chen et al. 2022; Che et al. 2024), the coupling method employs GIS and remote sensing to get data on flooding area and duration (Luo et al.

2023; Efraimidou and Spiliotis 2024), scenario analysis method hydrological and hydrodynamic models (Lin et al. 2020), a multi-criteria decision-making approach identifies various direct and indirect index factors associated with the emergence of urban flood events this includes slope, land use, precipitation, and population density. This process establishes a flood risk assessment index system. It employs specific mathematical models or methodologies to assess the overall influence of these diverse factors on flood risk (Asiri et al. 2024; Mukhtar et al. 2024).

The indicator system for risk weighting includes the Analytic Hierarchy Process (Chen et al. 2024), the CRITIC method (Giannakidou et al. 2020), and the entropy method (Miao et al. 2021). A novel approach utilising artificial intelligence via machine learning has emerged, which depends on sophisticated algorithms to discern the attributes of flood risk. This method autonomously establishes the input-output relationship between various driving factors and flood risk, thereby offering a more adaptable, objective, and expedited means of assessing flood risk (Li et al. 2023). A typical approach to flood risk assessments involves the integration of various evaluation methods, indicators, and weighting systems. Sun et al. (2023) employed a multi-criteria decision analysis utilising the entropy weighting method to create a flood risk map in Beijing. Asiri et al. (2024) applied a multi-criteria decision analysis through the Analytical Hierarchy Process integrating a machine-learning approach. Additionally, Peng et al. (2024) conducted a study utilising a GIS-based spatial multi-index conceptual model to compare the flood risk in Beijing and Munich.

1.5 Problem Statement

Climate change is defined as the shift in temperature and weather patterns caused by global warming (Wang *et al.* 2016b; Salimi and Al-Ghamd 2020). Globally, most urban areas have become vulnerable to devastating urban floods due to climate change (Guhathakurta and Sreejith 2011; Labropoulou and McKirdy 2017; Read 2019). Due to the recent flooding events, eThekwini Municipality has been trying to manage the frequent urban floods, with the Isipingo Catchment being the most vulnerable to flooding (C40 Cities Finance Facility 2020). According to researchers, Mahmoud and Gan (2018), Tabari (2020) and Noor et al. (2022), climate change is projected to increase vulnerability to flood hazards. It is anticipated that the future consequences of climate change will exacerbate the current conditions and pressures that threaten catchment ecosystems and infrastructure.

As more global municipalities are migrating to greener urban drainage infrastructure, the eThekwini Municipality should be more active in the research and implementation of innovative methods for conventional stormwater management. This will drive the city and ultimately the country toward sustainable futures.

1.6 Justification for the study

The Lower Isipingo Catchment has been substantially modified, as conventional stormwater management strategies and systems are not sustainable. The study offers a comprehensive approach to solving the problem, including integrating sustainable technologies such as soft infrastructure into the existing system and raising awareness of the possible use of non-structural techniques. This is critical for facilitating both behavioural change and social support for the successful implementation of mitigation and adaptation methods against climate change. This study will provide eThekwini Municipality with an opportunity to be proactive rather than reactive regarding the constant flooding problem within the Lower Isipingo Catchment.

1.7 Research Objectives

Aim

To investigate the Lower Isipingo Catchment’s ability to mitigate flooding, considering the existing drainage system.

Specific Objectives

- To evaluate the effects of urbanisation on the catchment's drainage system.
- To determine the extent to which solid waste impacts the drainage system’s functionality.
- To assess the performance of the existing drainage system with varying rainfall data.

1.8 Research Methods

For this study, the following methods were implemented to achieve each of the specific objectives:

- The Rational Method was used to calculate the flow for the pre- and post-development scenarios over a 20-year period.
- To explore the functionality of the drainage system, visual examinations of the drainage infrastructure were undertaken.
- Stormwater hydraulic modelling was completed for drainage networks to assess the performance of the drainage system with varying rainfall data.

1.9 Study Area

The Lower Isipingo Catchment is located south of Durban, as shown in Figure 4, in eThekwini Municipality on KwaZulu-Natal’s east coast. The catchment is highly urbanised, making it vulnerable to flooding. An analysis of the current site conditions and the potential impacts of risks such as urbanisation and the existing infrastructure is necessary for a possible flood risk management plan. The eThekwini Municipality is divided into five administrative planning boundaries, which are the north, central, south, inner west and outer west. The Lower Isipingo Catchment is located in the south region.

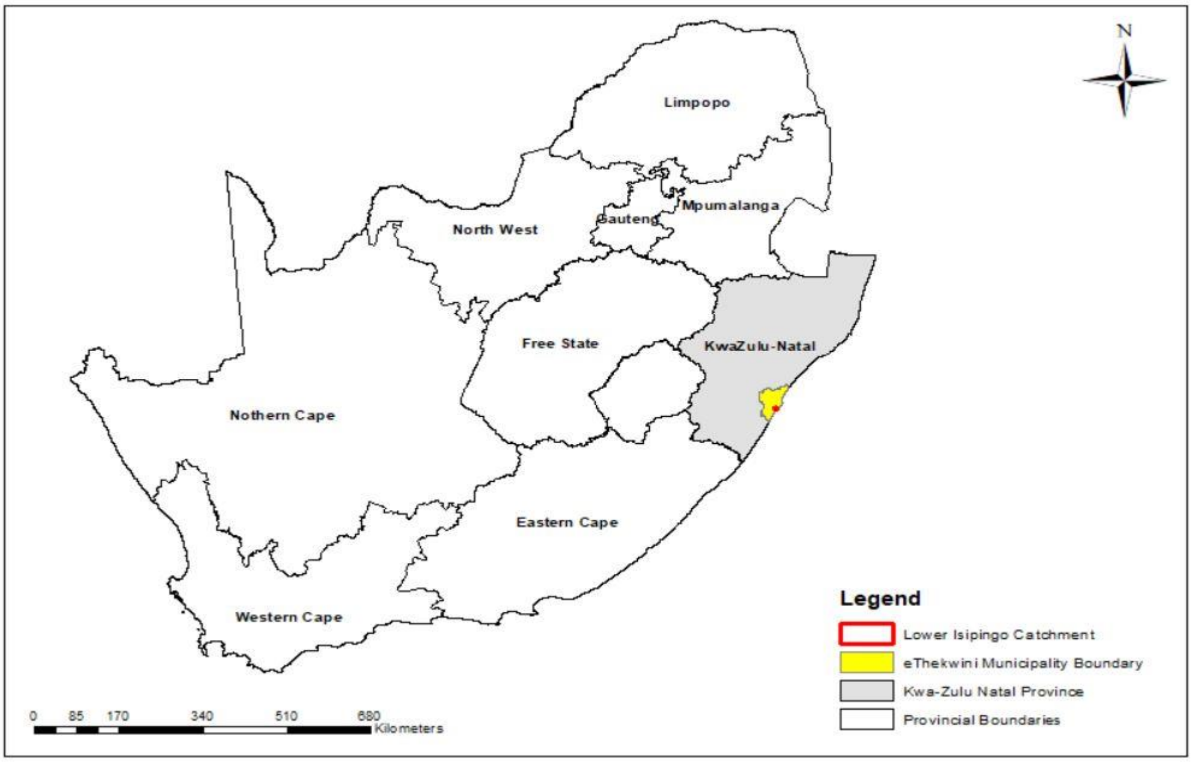


Figure 4: Lower Isipingo Catchment Locality

Source: (ESRI) ArcMap 10.0 with eThekwini Municipality shapefiles.

1.10 Overview of Chapters

Chapter 1: Introduction

This chapter covered the problem statement, aim, strategic objectives, research questions, limitations and definitions of terms.

Chapter 2: Literature Review

This chapter provides a critical evaluation to address each of the three study objectives.

Chapter 3: Study Area

The background, history, and characteristics of the research area are presented in this chapter.

Chapter 4: Methods and Materials

This chapter outlines the structure for data collection, measurement, and analysis. The chosen method combined the different components of the study logically and effectively to adequately address the research question.

Chapter 5: Results and Discussion
The key findings and interpretation of the outcomes are discussed in this chapter.

Chapter 6: Conclusions and Recommendations
This chapter provides an overview of the study's findings and recommendations.

1.11 Limitations of the Study

The research is restricted to the Lower Isipingo Catchment in the eThekwini Municipality region only. The hydraulic models are based on current geospatial data from existing stormwater infrastructure, such as manholes, pipes, cover and invert levels provided by eThekwini Municipality. The Personal Computer Storm Water Management Model (PCSWMM) hydraulic models do not account for manholes or pipes that are not functioning owing to blockages or broken infrastructure, as the model simulation assumes the stormwater networks are completely functional. The models with varying rainfall were developed using the recorded rainfall data from the catchment's April 2019 and April 2022 floods.

CHAPTER TWO: LITERATURE REVIEW

2.1 Introduction

It is important to highlight that climate is not the only driver of flood risk. There are other factors, such as population growth, changes in land use and land cover, anthropogenic activities, infrastructure development and stormwater management, which increase vulnerability. This literature review illustrates these factors, their relationship and impact in the context of their contribution to this study and the objectives aimed to achieve. Subsequently, urban development increases the risk of flooding in cities, as localised alterations to the hydrological conditions within catchment areas result in greater flood hazards and urban densities that further increase vulnerability (Huong and Pathirana 2013). For instance, urban infrastructure, such as buildings, industrial areas and roads, replaces green fields. Subsequently, the number of impervious surfaces increases, which then decreases runoff infiltration. Impervious surfaces threaten freshwater ecosystems as they also interfere with surface runoff infiltration into the soil, which causes water scarcity and lowers groundwater recharge (Dhakal and Chevalier 2017).

Furthermore, urbanisation also creates challenges with effective stormwater and drainage management within cities as surface runoff rises with the number of impermeable surfaces (Park and Park 2018). The current drainage system designs do not consider rainfall variations over time as they are based on historical rainfall characteristics assessed over a specific time; this is referred to as design return periods (Pour *et al.* 2020). The existing drainage systems also do not consider the effect of current and continuous land-use changes on flood peaks and runoff volume. Consequently, this leaves cities vulnerable to damage to infrastructure, properties, and the possible loss of life (Mahmood *et al.* 2017; Tate *et al.* 2021; Piadeh *et al.* 2022). Due to the impacts of climate change, severe rainfall events will increase in frequency and intensity (Shadid *et al.* 2016). Frequent floods are expected due to climate change (Wasko *et al.* 2021); thus, more research needs to be done to find and implement possible sustainable methods in urban drainage management.

2.2 Population Growth

Urban growth rates are rapidly increasing due to rural-urban migration as people relocate to developed cities to access economic opportunities (Rogers 1982). Due to urban areas being highly desirable, population sizes continue to grow concurrently with the demand for the development of services such as housing, schools, healthcare facilities, central business districts, and commercial zones. The eThekwini municipality, being a metropolitan city, is not immune to rapid population growth and rural migration. According to eThekwini Municipality (2018), by 2030, the population is predicted to expand by 1.1% annually to reach 4.4 million residents. This will increase the demand for development in urban areas, which will increase the stormwater runoff due to additional impermeable land. Additionally, the city notes on its IDP 2023 that there remains a tremendous demand for affordable housing. As a result, it is utterly impossible to meet the enormous demand due to a lack of funding, land allocation, and the existing housing backlog.

In the long run, this causes people to either expand existing informal settlements into ecologically sensitive areas or establish new ones of their own. This is visible on the Lower Isipingo Catchment. Dakota Beach Settlement is an informal settlement in the Prospecton industrial area. The Prospecton industrial area is part of the South Durban Basin and can be described as an economic hotspot in Durban (eProp 2013). It contains auto manufacturers, oil refineries, paper mills, and various other forms of industrial activities. Due to its economic status, this catchment area attracts employment seekers. The removal of buildings on Clark Road in 2002, together with the highly developed catchment, has led individuals to create an informal settlement in the open area between Ernest Clockie Road and Clark Road. An informal settlement started to appear on Google Earth satellite images in 2002 shown on Figure 5, and a satellite image in Figure 6 shows the settlement condition in 2023.

Figure 5: Dakota Beach Settlement. Picture taken 04/11/2002.

Source: Google Earth Image Maxar Technologies

Figure 6: Dakota Beach Settlement. Picture taken 01/04/2023.

Source: Google Earth Image Airbus Satellite

2.3 Urbanisation and Development

One of the most noticeable aspects of anthropogenic activity is urbanisation. Urbanisation is a process typically accompanied by changes in surface terrain, land use, and hydrological characteristics such as hydraulic permeability (Chen *et al.* 2021). Urban environments can significantly alter hydrological processes. The development of impermeable regions decreases soil infiltration, increasing surface runoff while decreasing evapotranspiration and groundwater recharge (Vizintin *et al.* 2009; Salvadore *et al.* 2015). The hydrological cycle in urban catchments is altered by several factors, such as human activity, impervious surfaces, drainage systems, and receiving water courses. Due to the lack of vegetation, evapotranspiration may be less common in urbanised catchments than in rural catchments (Taha 1997). This is attributed to urban areas having more runoff than their rural counterparts due to their large impermeable surfaces and higher runoff quantities. The urban surface energy balance is impacted when considering runoff water flows, which are rapidly collected and ultimately result in less surface water available for evapotranspiration.

Floods become more frequent and severe as a result of urbanisation, and they can also place urban cities at greater risk of flooding (Konrad 2003). Hydrographs are an effective tool for indicating rainfall discharge. As shown in Figure 7, the increase in the proportion of impervious surfaces results in a shorter time to peak flow and runoff peak, which in turn leads to a decrease in the recharge of groundwater and a corresponding decline in baseflow. Numerous variables, such as the duration and intensity of rainfall, geographical location, vegetation, and hydrological conditions, affect a flood's peak discharge. Additionally, land use and land cover and anthropogenic activities also influence peak discharge as they alter precipitation land surface storage and flow.

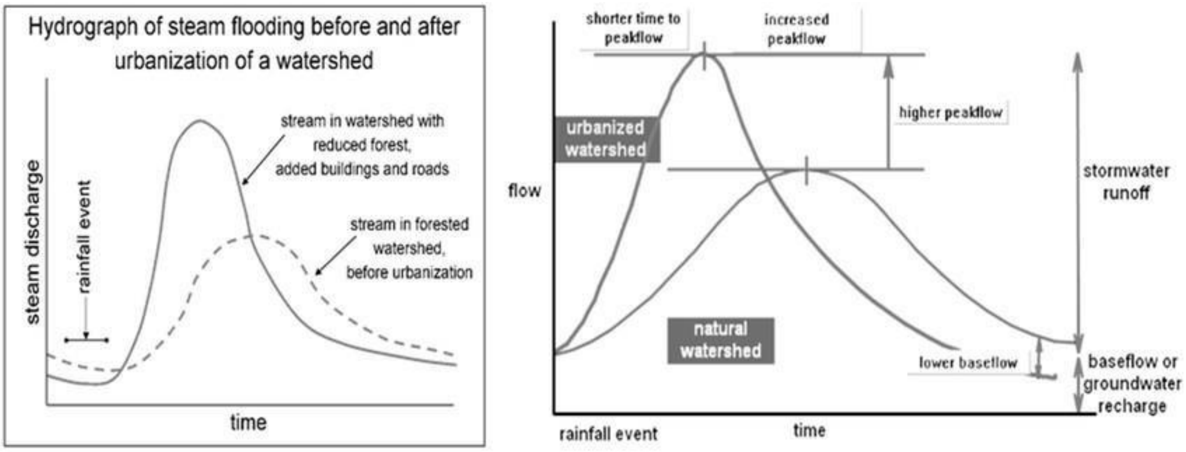


Figure 7: Link between Urbanisation and Outflow
Source: (USEPA 1983)

Yin *et al.* (2015) conducted research to assess the effects of anthropogenic activities on the hazards associated with urban flooding. The study considered three anthropogenic variables: land use, urbanisation, and flood defence. They indicated that the risk of flooding increases as a result of land use and urbanisation, while flood defences are quite beneficial in reducing the overall area that is flooded. While flood defences can mitigate the negative effects of urbanisation and land use, it is important to note that in urban areas such as Isipingo, development alongside floodplains and rivers is evident and can raise flood water levels equivalent to a particular flow and modify a channel's ability to convey runoff. Bridges and other infrastructure that intrude on the floodplain can worsen upstream flooding by reducing the river capacity.

2.4 Urbanisation and Ecosystem Depletion

The relationship between land use change and water resources has been studied. It is predicted that safe drinking water will be scarcer in the future due to the significant disparity between the needs of people and the availability of water resources, which has worsened by the rapid population increase, ongoing urbanisation, and climate change (Jeremy et al. 2001). Baseflow is an important factor between groundwater and surface flow and plays a role in the urban water supply. Baseflow is a significant factor of steam flow, which is sustained from delayed subsurface pathways such as subsoil infiltration and wetland areas (Price 2011).

The baseflow-associated hydrological processes are currently at risk, given the effects of both climate change and urbanisation. Urbanisation has a negative impact on catchments due to the increase in impervious surfaces and the underground pipe networks of civil engineering services (Kauffman *et al.* 2009); which in turn modifies the natural catchment subsurface characteristics and alters the baseflow quantity. Since urbanisation reduces the baseflow during dry weather, which is vital to the health of rivers and streams, it alters streamflow and poses a hazard to freshwater ecosystems as stormwater is an essential source.

The distinction between various types of impermeable surfaces and the natural ground cover in urban environments is shown in Figure 8. The impermeable surfaces cause at least a 50% increase in surface water runoff and a direct decrease in deep penetration of water. Ten per cent (10%) of natural ground cover experiences runoff under pre-development conditions with 25% shallow and deep infiltration. About 20% runoff will occur when there is 10 to 20% impermeable cover with approximately 21% shallow and deep infiltration. When the impermeable cover is between 35 and 50%, there will be 30% runoff and between 20% and 15% shallow and deep infiltration. When it is between 75% and 100%, there will be 55% runoff with even lesser shallow and deep infiltration from 10% to 5%.

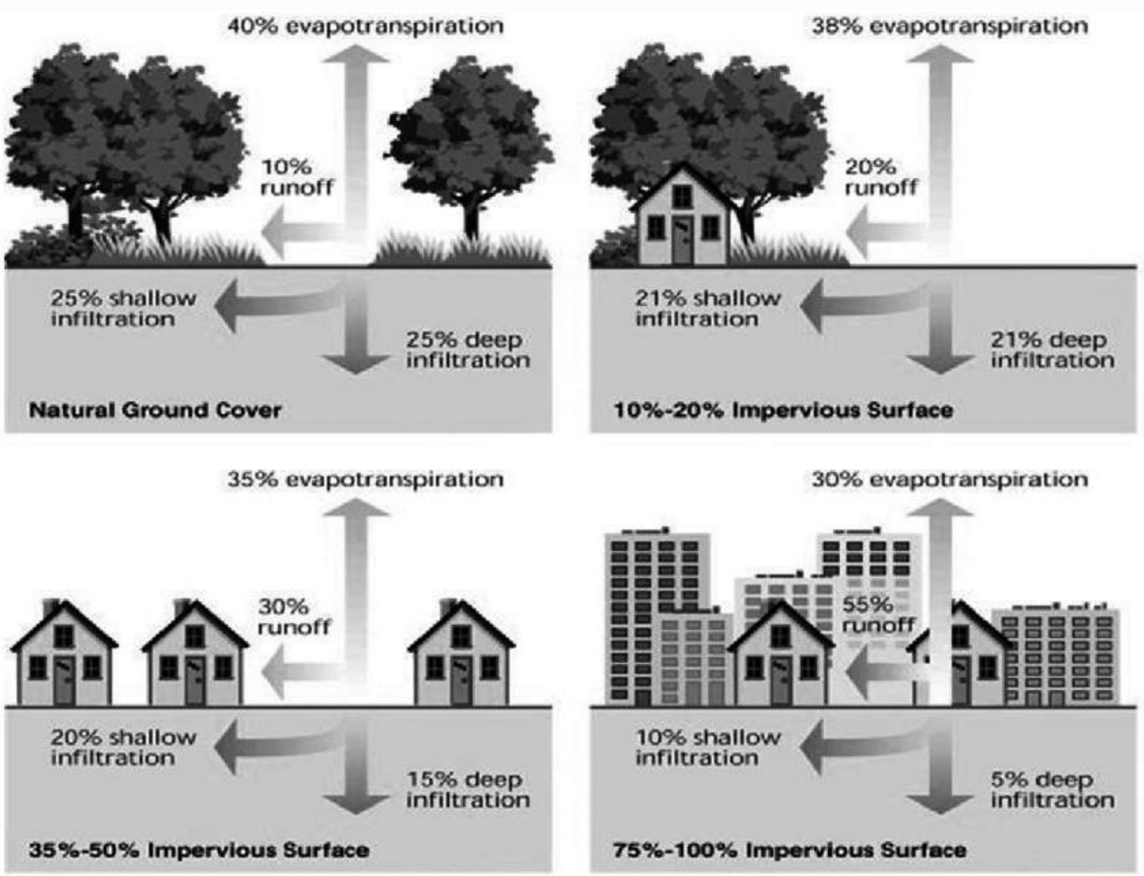


Figure 8: The effects of impervious cover on surface runoff.
Source: (USEPA 1983)

Water quality has decreased as a result of urban growth and an increase in urban runoff. Urban runoff and wastewater emerging from residential, commercial, and industrial developments are among the pollution sources that end up in surface waterways in developed areas (Björklund *et al.* 2018). Contaminants in urban runoff are one of the main reasons behind poor water quality in waterways. Various pollutants are carried in large quantities by runoff varying from dissolved, suspended, solid matter, nutrients, heavy metals, and organic and inorganic chemicals, which leads to the subsequent contamination of natural water sources (Gnecco *et al.* 2005; Zhang *et al.* 2020). Therefore, stormwater runoff has emerged as one of the main causes of water contamination (Wijesiri *et al.* 2015).

2.5 Climate Vulnerability and Extremes

The sharp increase in global temperature due to climate change has increased evaporation and atmospheric moisture concentrations and altered rainfall patterns (Wang *et al.* 2016a). As a result, there will be more frequent and intense floods because of heavier precipitation. Global climate models (GCMs) are the primary instruments for predicting extended future variations. The future amounts of greenhouse gas emissions in the atmosphere, which in turn represent societal behaviour and governmental decisions, will determine anticipated modifications to the earth's climate. Simulation findings from global climate models (Semadeni-Davies *et al.* 2008; Shadid *et al.* 2016; Wen *et al.* 2016; Chen *et al.* 2021; Bangelesa *et al.* 2023) have shown future flooding and severe rainfall events will increase in frequency and intensity due to the impacts of climate change.

The IPCC states that there have been several severe rainfall events since the 1950s, and the majority of these changes have been attributed to anthropogenic activity. This includes an increase in the frequency of severe storms in some locations due to extreme temperatures that occur more frequently (IPCC 2021b). As shown in Figure 9, the effect of extreme rainfall is not projected equally throughout the world, as Southern Africa is projected to be drier than Central and Eastern Africa. It is caused by the impact of the El Niño Southern Oscillation (ENSO), which causes climatic variations in some parts of Africa (Tarmizi *et al.* 2019). It is a phenomenon that occurs frequently, with a decrease in precipitation and a rise in surface temperature. Predicting future precipitation is essential to reducing floods and adapting to the possibility of future severe weather conditions.

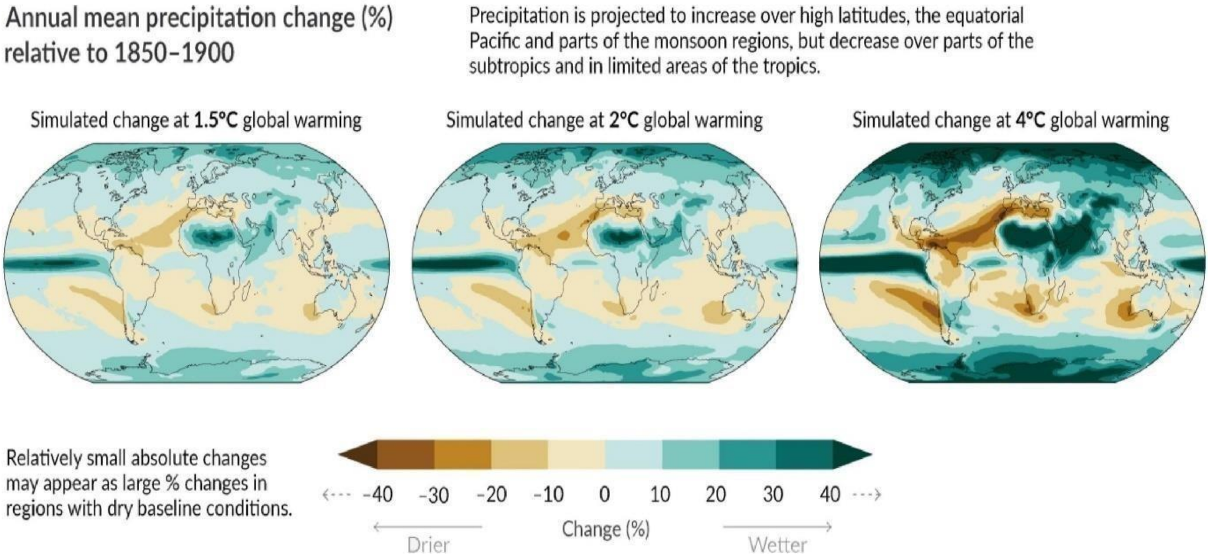


Figure 9: Alterations in precipitation.

Source: (IPCC 2021b)

2.5.1 South African Climate Models

Understanding the behaviour of the past and current climate systems and projecting climate change depend on climate models. Climate shifts affect several historic and geographic characteristics; associated events are studied using data and a framework of climate forecasts. There is a large range of models from conceptual climate models and global climate models to earth system models, and it is entirely up to climate scientists to select the climate model that they believe is appropriate for addressing the key issues in their area of expertise (Dijkstra 2024). The management of resources and the foundation of a long-term strategy for sustainable development can both benefit from an understanding of historical and future climatic changes.

Due to its subtropical latitude and high elevation, South Africa has a semi-arid climate with a unique yearly variation. From November to March, easterly gusts bring in warm air from the Agulhas Current and the warm Southwest Indian Ocean, which experiences abundant rainfall (Jury 2018), except for periods when the El Niño Southern Oscillation (ENSO) brings a decrease in precipitation. From April through to October, western gusts bring in dry air from the chilly South Atlantic Ocean and its Benguela Current (Dieppois *et al.* 2015). Engelbrecht *et al.* (2024) assessed future rainfall patterns as per six CMIP6 GCMs and found three of the six projections hint at an increase in precipitation in KwaZulu-Natal, as shown in Figure 10, while all six models predict a drier climate in the Western Cape.

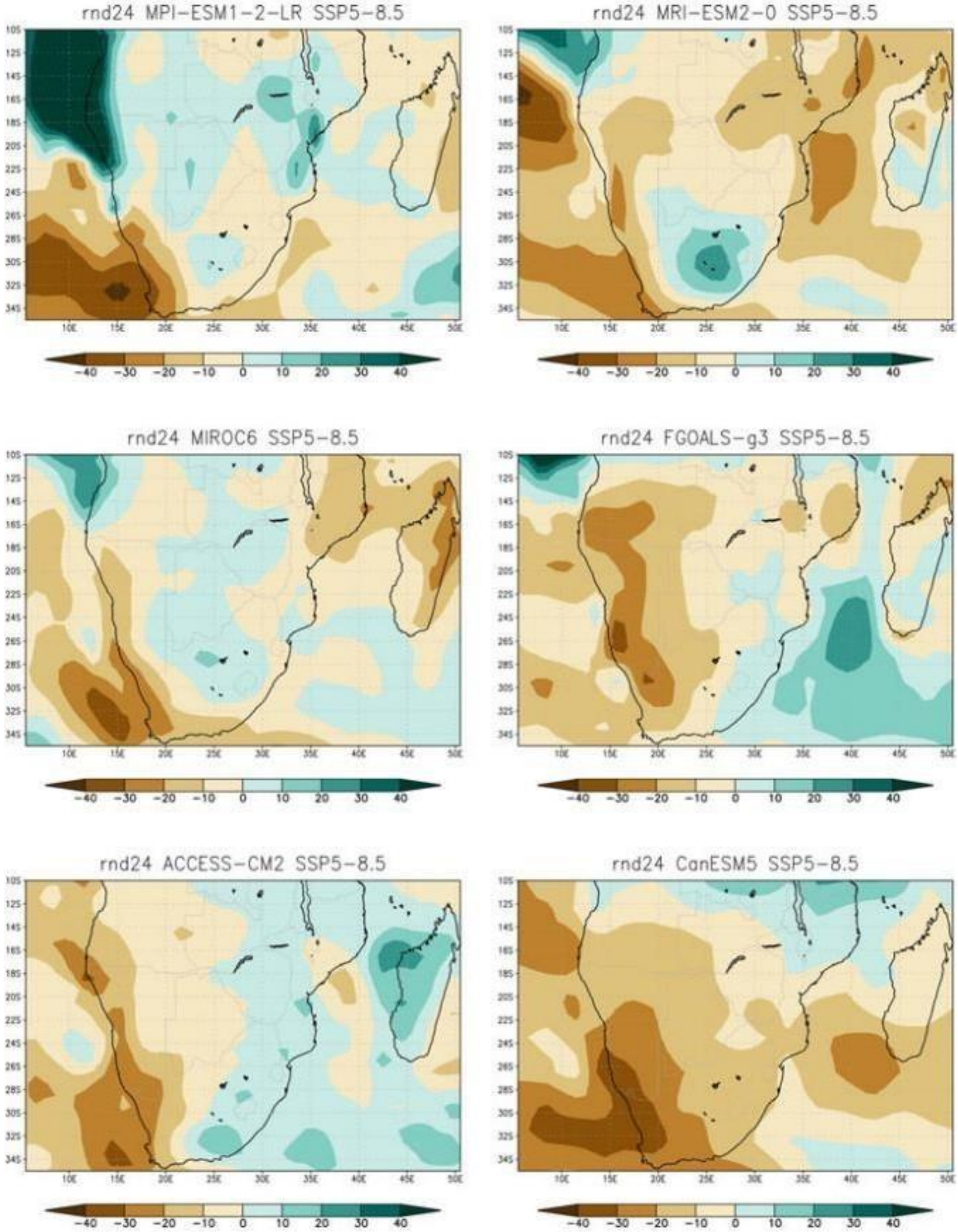
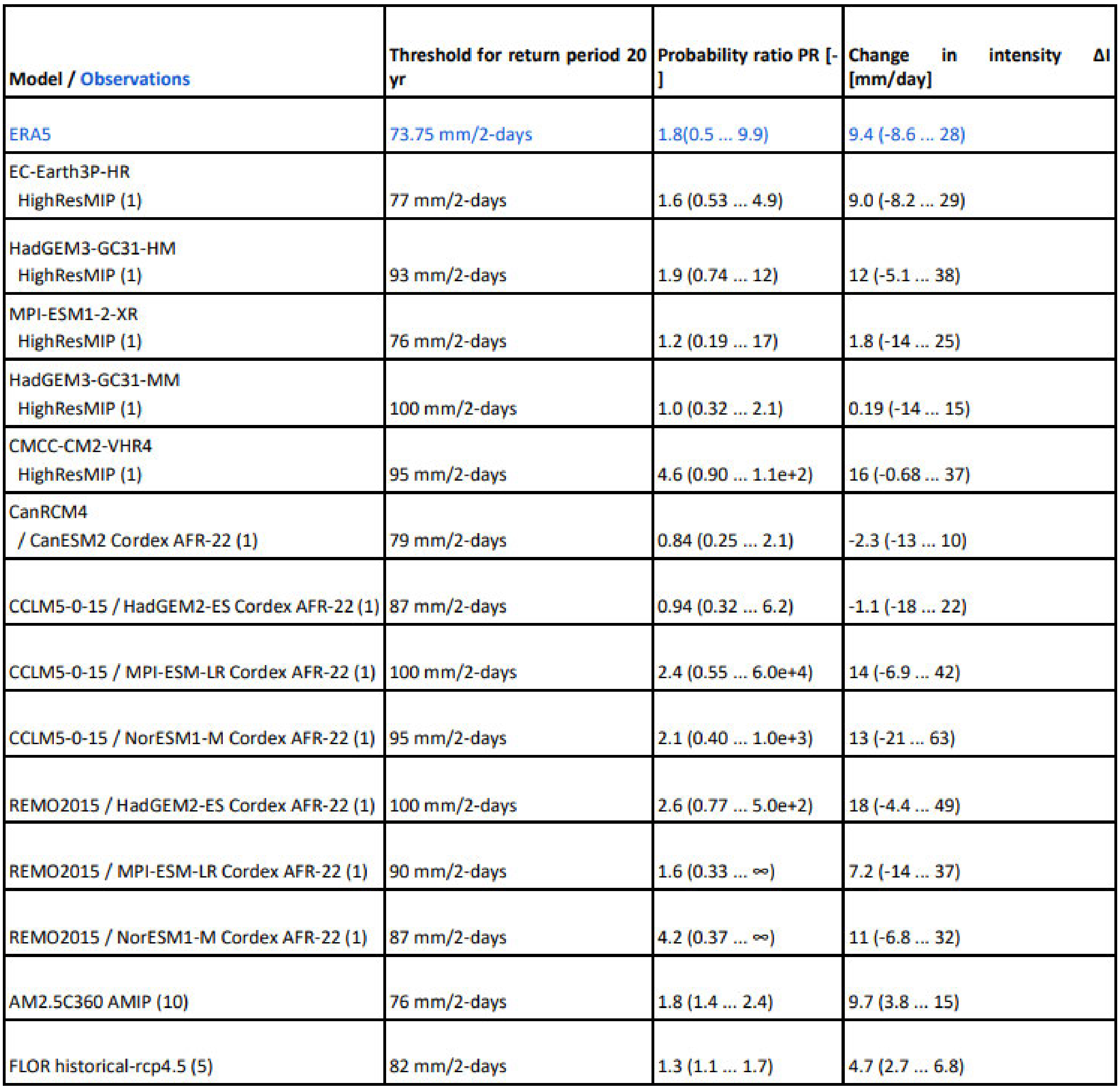


Figure 10: Predicted future rainfall patterns.

Source: (Engelbrecht *et al.* 2024)

A similar study was done by Pinto *et al.* (2022) which assessed 15 various models (CCM, GCM, ESM) probability proportions and change in rainfall intensity for the 20-year return period for 5 selected weather stations within the KwaZulu-Natal province. Table 1 details the results, some 13 models showed an increase in rainfall intensity, while only 2 models observed a decrease.

Table 1: Observations of Change in Rainfall Intensity for 20-year return period Source: (Pinto 2022)



Model / Observations	**Threshold for return period 20 yr**	**Probability ratio PR [-]**	**Change in intensity ΔI [mm/day]**
ERA5	73.75 mm/2-days	1.8(0.5 ... 9.9)	9.4 (-8.6 ... 28)
EC-Earth3P-HR HighResMIP (1)	77 mm/2-days	1.6 (0.53 ... 4.9)	9.0 (-8.2 ... 29)
HadGEM3-GC31-HM HighResMIP (1)	93 mm/2-days	1.9 (0.74 ... 12)	12 (-5.1 ... 38)
MPI-ESM1-2-XR HighResMIP (1)	76 mm/2-days	1.2 (0.19 ... 17)	1.8 (-14 ... 25)
HadGEM3-GC31-MM HighResMIP (1)	100 mm/2-days	1.0 (0.32 ... 2.1)	0.19 (-14 ... 15)
CMCC-CM2-VHR4 HighResMIP (1)	95 mm/2-days	4.6 (0.90 ... 1.1e+2)	16 (-0.68 ... 37)
CanRCM4 / CanESM2 Cordex AFR-22 (1)	79 mm/2-days	0.84 (0.25 ... 2.1)	-2.3 (-13 ... 10)
CCLM5-0-15 / HadGEM2-ES Cordex AFR-22 (1)	87 mm/2-days	0.94 (0.32 ... 6.2)	-1.1 (-18 ... 22)
CCLM5-0-15 / MPI-ESM-LR Cordex AFR-22 (1)	100 mm/2-days	2.4 (0.55 ... 6.0e+4)	14 (-6.9 ... 42)
CCLM5-0-15 / NorESM1-M Cordex AFR-22 (1)	95 mm/2-days	2.1 (0.40 ... 1.0e+3)	13 (-21 ... 63)
REMO2015 / HadGEM2-ES Cordex AFR-22 (1)	100 mm/2-days	2.6 (0.77 ... 5.0e+2)	18 (-4.4 ... 49)
REMO2015 / MPI-ESM-LR Cordex AFR-22 (1)	90 mm/2-days	1.6 (0.33 ... ∞)	7.2 (-14 ... 37)
REMO2015 / NorESM1-M Cordex AFR-22 (1)	87 mm/2-days	4.2 (0.37 ... ∞)	11 (-6.8 ... 32)
AM2.5C360 AMIP (10)	76 mm/2-days	1.8 (1.4 ... 2.4)	9.7 (3.8 ... 15)
FLOR historical-rcp4.5 (5)	82 mm/2-days	1.3 (1.1 ... 1.7)	4.7 (2.7 ... 6.8)

A study done by Jury (2018), which assessed the Hadley2 earth system model, also found an increase in the frequency of heavy rainfall in Kwa-Zulu Natal. The results are shown on Figure 11.

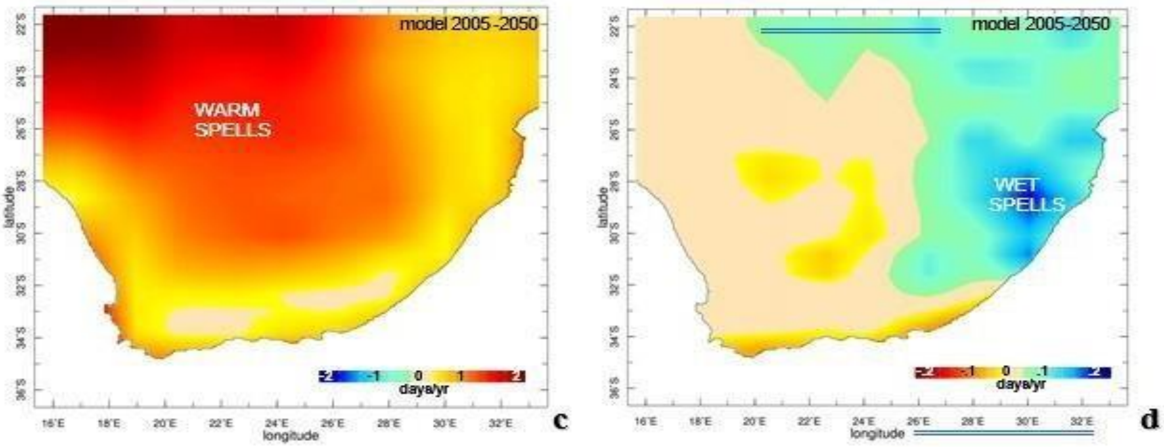


Figure 11: Hadley2 Model 2005-2050

Source: (Jury 2018)

Such models indicate the most probable forecast of Southern Africa's climate change: a region-wide climatic system that is significantly warmer, drier overall and characterised by more severe precipitation events in the east. Adaptation methods and strategies must prepare for this expected reality in South Africa.

2.6 Urban Flooding and Vulnerability

Urban flooding is a catastrophic event responsible for significant death tolls, economic damage, and societal repercussions around the globe (EEA 2016). Rainfall is the primary source of flooding in urban areas, which affects people, property, and infrastructure through pluvial and fluvial floods. High water levels in river channels surpass bank heights, causing fluvial flooding, whereas pluvial flooding occurs when the rainfall intensity is beyond the capacity of the drainage system (Sörensen *et al.* 2016; Pariartha *et al.* 2023). Pluvial flooding is most common in urban areas. The quantity of stormwater runoff that requires management and mitigation is significantly impacted by land development, rainfall frequency, timing, and severity.

Due to climate change caused by global warming and land-use variations caused by urbanisation, urban areas such as Isipingo have a higher flood risk than rural areas (Shepherd *et al.* 2013; Liu and Niyogi 2019). The frequency and severity of flood damage vary in urban areas because of varying characteristics, which include land uses, flood depth, flow velocity, flood duration, and infrastructure, which can make the process of assessing flood damage more difficult. Over the previous decade, urban floods have doubled in frequency and emerged as the most prevalent disaster, which has cost cities approximately $651 billion in damages (Mizutori and Guha-Sapir 2020).

The provincial government estimated damages of over R17 billion during the April 2022 floods in Durban (Fokazi 2022). The National Treasury has a framework for disaster relief funds that are accessible through Schedule 7 grants in the Division of Revenue Act, 2022. A total of R1 billion was allocated as emergency relief (South African National Treasury 2022). Due to insufficient funding, the city of Durban is still struggling to reconstruct and recover from the massive damage to its infrastructure, with water and sanitation systems suffering the most. A comprehensive evaluation of an urban area's vulnerability to flooding can help to improve flood risk management. Consequently, given the paucity of research on flood vulnerability based on urbanisation and climate change, efforts should be directed at expanding our understanding of flood risk (Wang *et al.* 2023).

2.7 Urban Flood Modelling

For effective management of flood hazards, precise evaluation of the likelihood of severe rainfall events in the existing and future climate is necessary. Sufficient stormwater collection and conveyance systems are essential to mitigate the dangers of urban floods. The development and application of flow models for drainage and flooding simulation have facilitated the assessment of the viability of different techniques for flood mitigation planning and management. Many types of models can produce hydrological processes, such as rainfall and routing runoff, but very few of them can simulate the hydraulics of drainage networks.

Stormwater management models developed by the US Environmental Protection Agency are used as rainfall-runoff models in the assessment of urban flooding, which provide simulations of runoff quantity and water quality (Jung *et al.* 2014). The model splits the catchment into sub-catchments based on variations in terrain, drainage system, land use, and soil properties. A collection of physical elements, such as manholes, pipes, and outlets, define the drainage system in the model. Various technical software is used to produce flood and drainage simulations, including

PCSWMM, Hydroworks, TUFLOW, and OpenFlow. These software tools offer advanced 2D modelling, which is essential for modelling the flood dispersion dynamics in broad regions if the overland flow exceeds the drainage network design capacity (Chang *et al.* 2013).

The 2D model typically ignores the centrifugal factors but takes the backwater flooding into account and relies on non-inertia wave surface flow dynamics. Such models can be used to quantify environmental, social, and economic risk areas leading to improved infrastructure maintenance and management and the development of resilient infrastructure (Jury 2018).

2.8 Conventional Stormwater Management

As global cities encounter increasing flooding risks due to climate change and urbanisation, the significance of stormwater management for efficient runoff management has grown (Goulden *et al.* 2018). Previously, stormwater management systems were mainly designed to focus on water quantity control through grey infrastructure drainage systems that discharge into the nearest waterway (Chocat *et al.* 2007). Grey infrastructure includes pipe networks, canals, open channels, culverts, and outlets that are under municipal authority. The municipality is, therefore, in charge of the maintenance and management of the drainage system. Since stormwater discharges directly into waterways, there is no infrastructure in place to filter out contaminants that can impact water quality.

In addition to environmental issues, traditional drainage networks' poor adaptability to future climate unpredictability and urbanisation have come under increased scrutiny. The performance of drainage networks can be impacted by variations in rainfall intensity linked to climate change and fast urbanisation. Currently, the most effective drainage systems have frequently become insufficient due to rising impermeability and fluctuations in rainfall intensity (Chang *et al.* 2013; Zhou *et al.* 2019). Recent studies have found that drainage systems that were constructed using historic patterns of rainfall are often underperforming due to climate change and a constant increase in urban areas (Kleidorfer *et al.* 2014; Hussain 2022). The predicted rise in frequent heavy rainfalls will unfavourably increase pluvial flooding, making cities vulnerable to infrastructure and property damage.

A new strategy has been developed that shifts stormwater management from the previous method of ‘out of sight, out of mind’ and has been transformed into a highly integrated approach (Fletcher *et al.* 2014). Modern drainage techniques emphasise the necessity of a holistic approach in urban water management, which considers water quality, amenity, recreation, environmental preservation, and multiple water uses (Bohman *et al.* 2020). An effective drainage management system should be adaptable and determined by local climate conditions while taking into account aspects of urbanisation and sustainability considerations. Presently, conventional stormwater systems do not fulfil this criterion.

2.9 Stormwater Runoff Pollution

The effects of urbanisation and climate change have led to a rise in pollutants from industrial and agricultural processes, as well as the disposal of waste and wastewater, which in turn degrades water quality. Groundwater and surface water resource contamination is primarily caused by urbanisation (Carle *et al.* 2005). Surface runoff is highly polluted as there is no infrastructure to filter out contaminants before discharging into waterways. Studies have demonstrated that impervious land uses and surface water quality are interconnected (Giri and Qiu 2016; Cheng *et al.* 2022). In some catchments, waterways become unstable when the impervious area exceeds 10% because of increased erosion and sedimentation damage (Vargus 2009). Water quality concerns differ from area to area and are influenced by local contaminants, land use and population density (Fletcher and Deletic 2007).

Conventional stormwater management contaminants include suspended solids, bacteria, nutrients that contain phosphorus and nitrogen, and various heavy metals (Hendricks *et al.* 2018), which all have adverse effects on receiving water bodies (Björklund *et al.* 2018). According to Hou *et al.* (2020), surface runoff plays a significant role in non-point pollution, with the amount of pollutants identified in runoff being influenced by rainfall and climate change predictions. Initial stormwater runoff produces higher concentrations of pollutants, which are found in the early stages (known as the first flush), and decreasing concentrations are found in the final stages

(Lee *et al.* 2011; Wang *et al.* 2013).

Most organic materials, heavy metals, suspended particles, and other contaminants are conveyed during the first flush (Vorreiter and Hickey 1994). There are several approaches to categorising and combining stormwater contaminants' contributors, but because of the interrelation between the sources, it can be a very complex process. Various approaches can be used, such as land use (e.g., buildings), inherent sources (e.g., vehicular transportation), non-inherent sources (e.g., industrial) and behaviour (e.g., pesticide use). Müller *et al.* (2020) classified the contaminants' contributors according to the method of travel and interactions among the source classifications as shown in Figure 12.

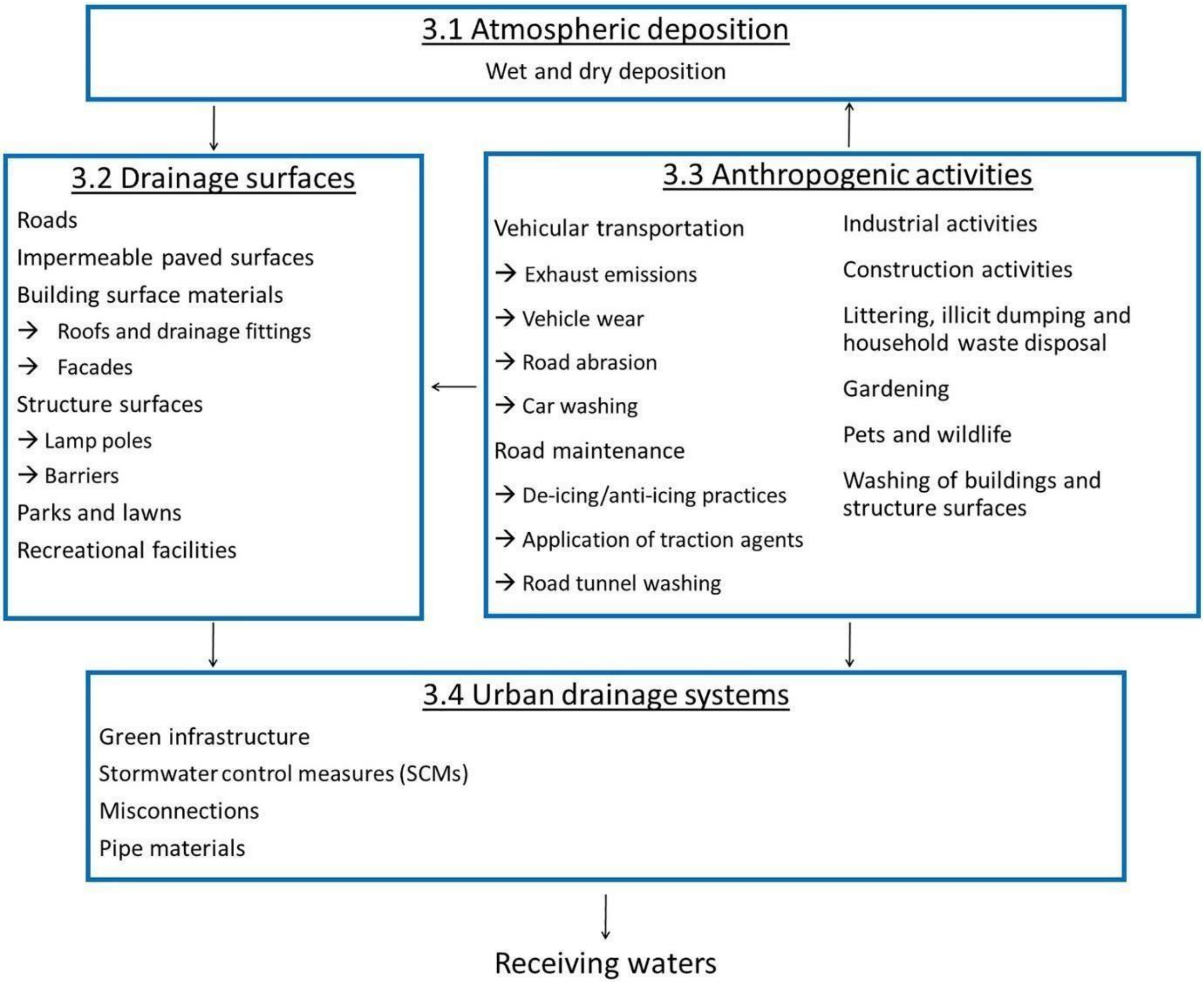


Figure 12: Grouping and classification of stormwater runoff pollutants.
Source: (Müller *et al.* 2020)

2.9.1 Atmospheric Deposition

Rainfall carries an intricate combination of rainfall, suspended particles, human and natural waste products, and chemical contaminants from urban areas and ends up as urban stormwater runoff (Gilbreath and McKee 2015). It is important to note that through precipitation, the atmosphere is more of a pollutant transport channel than a source of pollution (Goonetilleke and Lampard 2019). Atmospheric deposition aids in transporting materials and pollutants from the atmosphere to the surface of urban catchments. Atmospheric deposition is higher in urban areas, where rising anthropogenic activities result in higher chances of pollutants in the atmosphere (Gunawardena *et al.* 2013).

Wet or dry depositions can carry pollutants. The particles and gases that settle directly onto land or water surfaces are known as dry deposition (Azimi *et al.* 2003). Wet depositions are the primary source of stormwater pollution, as rainfall collects pollutants from the air (Chang *et al.* 2006). Several studies have identified wet depositions as a significant source of contaminants found in runoff. Shafi *et al.* (2024) found that rainfall is a huge source of plastics in waterways, which are transported by runoff. According to Jing Suna *et al.* (2021), runoff washes microplastics from the landfill leachate into neighbouring rivers. A study by Chang *et al.* (2006) discovered that TSS and COD exceed China’s national surface water quality standards by more than four times due to pollutants carried by runoff.

2.9.2 Anthropogenic Activities

Anthropogenic activities can be described as human behaviours carried out in urban areas with varying frequency and intensities that develop into sources of stormwater runoff pollution. Examples include car transportation, road maintenance, industries, waste management, and agricultural practices. Vehicular traffic frequently releases dangerously high quantities of metals like copper, lead and zinc along with fuels and polycyclic aromatic hydrocarbons (PAHs) created by hydrocarbons produced by burning fuels, including wear and tear on automobiles and roadways (Markiewicz *et al.* 2017). Researchers have discovered that pavement materials, bitumen and asphalt contribute to the formation polycyclic aromatic hydrocarbons (Brandt and Groot 2001).

Unmanaged litter and waste in urban cities can be carried from the ground by rainfall and swept into nearby water bodies by stormwater runoff. Gunawardena *et al.* (2013) stated that stormwater runoff is a key pathway for microplastics to enter waterways through current waste disposal methods, which have resulted in the bulk of waste ending up in landfills and the environment (Geyer *et al.* 2017). Müller *et al.* (2020) acknowledged that industrial and agricultural operations are contributors to chemical pollution, which arises from surface runoff from industrial and agricultural land uses.

2.9.3 Organic Contaminants

Another key issue affecting urban water quality is the conveyance of TSS and nutrients like phosphorus and nitrogen via stormwater runoff to waterways. Insecticides, industrial solvents, fertilisers, sewage effluents, and biogenic materials are among the organic pollutants found in urban stormwater runoff, which can interfere with the aquatic environment and human health and have long-term effects on affected organisms (Kapelewska *et al.* 2018; Yang and Lusk 2018). High quantities of nutrients result in eutrophication characterised by an abundance of algae, decreased oxygen levels, unpleasant odours, and the extinction of important organisms (Dubrovsky *et al.* 2010).

Filters may capture particles in water, which are total suspended solids (James Environmental 2021). Increased TSS concentrations cause turbidity, inhibit the growth of aquatic species, and serve as substrates for the build-up and movement of other contaminants, such as metals and nutrients (MPCA 2023). When assessing water quality, it is common practice to focus solely on one parameter, biological oxygen demand (BOD), which is an indicator of the overall status of the organic matter composition (Gamerith *et al.* 2011). McCabe *et al.* (2021) found that stormwater runoff has far greater BOD values than natural watercourse concentrations, while Schertzinger *et al.* (2019) revealed that aquatic creatures can be exposed to hazardous circumstances as a result of both pollution build-up and oxygen deprivation.

2.9.4 Heavy Metal Contaminants

Industries, agriculture, urban effluents, and transportation have discharged several amounts of metals, which are washed into receiving water bodies by runoff. The sources of heavy metals and the quantity of these substances that end up in stormwater runoff rely heavily on land use (Herngrena *et al.* 2005). The most common heavy metal contaminants found in stormwater runoff are copper, iron, lead, zinc, arsenic, chromium, and mercury (Gardner and Carey 2004; Zhao *et al.* 2010; Kanamarlapudi *et al.* 2018), which are transported during rainfall into receiving water bodies from traffic-related traffic sources. Zhu *et al.* (2007) found that areas with heavy traffic densities had the greatest quantities of metal contaminants. A study by Duong and Lee (2011) found that metal contamination concentrations were higher on concrete highway pavements than on asphalt pavements.

Al-Musharafia *et al.* (2013) found high concentrations of heavy metals that were monitored from treated sewage effluent and were detected, even at the minimal levels permitted for wastewater discharge. It is crucial to remember that many heavy metal contaminants cannot decompose naturally in the aquatic environment; therefore, their concentrations can easily rise over acceptable limits, which can be hazardous (Singh *et al.* 2022). Fish exposed to heavy metal contaminants have a higher risk of contracting infectious diseases and ultimately dying (Afzaal *et al.* 2022). Due to the hazardous impact of heavy metal contaminants, there is concern about the dangers they pose to human health and other living things through the food chain, as they can lead to serious illnesses in humans (Nyairo and Owuor 2015).

2.9.5 Solid waste

Littering causes the deposition of litter into stormwater inlets, where it can become dislodged and carried by runoff, causing blockages in drainage facilities, streams, and rivers. Microplastics, also described as plastic litter, are major contributors to solid waste pollution. They not only pose a problem with stormwater management but also with the marine coastal management profession, as they carry plastic waste from rivers and streams into oceans (Foekema *et al.* 2013; Jambeck *et al.* 2015). Plastics are used in various applications such as packaging, water supply systems, textiles and alternative materials for metals. This is mainly because many plastic goods have a short lifespan, which results in a waste problem. To enhance the performance of plastics, several chemical compounds are added to plastic polymers, which might affect how disposable and recyclable plastics are and can harm the environment and human health (Hahladakis *et al.* 2018). Intentional and inadvertent mishandling of plastic waste leads to the deposition of litter in catchment areas, which is then transported by runoff. Magnusson *et al.* (2016) found that one of the main causes of plastic waste contamination in marine ecology is littering. This can be attributed to poor waste management systems in countries.

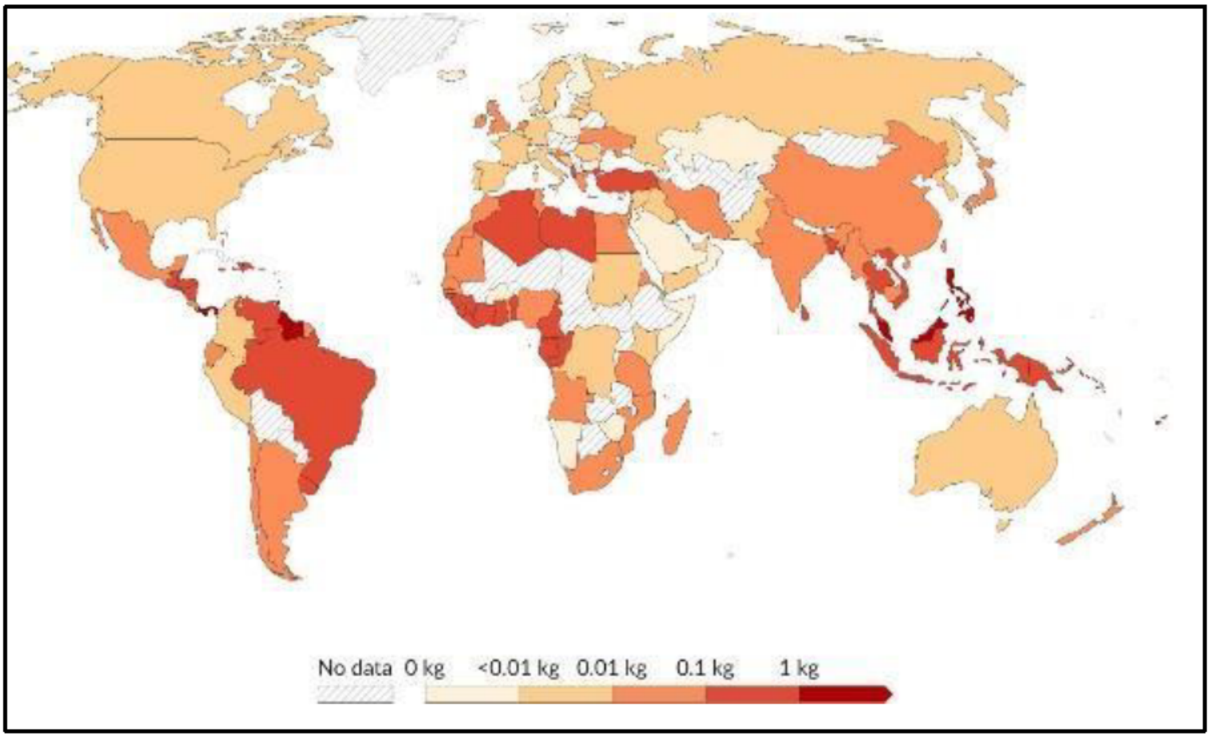


Figure 13: Mismanagement of plastic waste worldwide in 2019.
Source: OurWordinData.org/plastic-pollution

As per Figure 13, South Africa is one of the largest contributors to waste mismanagement globally. As per the National Environmental Management: Waste Act 59 of 2008, municipalities are required to create an Integrated Waste Management Plan (IWMP), which outlines each waste source and establishes a strategy, including a set of procedures for achieving waste management services in that specific municipality. The eThekwini Municipality Waste Removal By-law (2016), issued in the KwaZulu-Natal Provincial Gazette no. 1722 on August 25, 2016, serves as the basis for the sustainable waste management guidance for the municipality. The implementation of this strategy is not effective, as a study done by the World Bank Group (2016) found that approximately 75% of waste accumulated in informal settlements in the eThekwini Municipality is not collected. This uncollected waste ends up in drainage infrastructure and rivers. The eThekwini Municipality officials are aware of the waste problem, as they noted that flooding within the city is worsened by illegal dumping and widespread littering, which is the main cause of blockage of drainage systems (Erasmus 2019).

Landfilling is a commonly used method for disposing of waste around the globe. Large quantities of plastic waste are dumped in landfills. Such waste undergoes extreme weather, microbiological deterioration, and physical stressors, which results in the production of leachate (He *et al.* 2019). The resultant leachate carries pollutants such as microplastics to adjacent aquatic bodies or through surrounding soils, where they may be absorbed by rainwater or seep into groundwater. Recycling of waste such as plastics is likely to increase with increased efforts from relevant stakeholders such as municipal departments, environmental organisations, industry, and the general public. However, there are still various challenges, such as a lack of education and advocacy regarding waste pollution and recycling. These challenges need to be addressed through public participation and stakeholder collaboration to ensure the use, disposal, and recycling of waste becomes a way of life for residents to truly implement the principles of sustainable waste management in cities.

2.9.6 Emerging Contaminants (ECs)

Recently, research on water pollution has diverted its attention from traditional organic priority pollutants to emergent contaminants, several of which are not monitored or regulated. Emerging contaminants (ECs) consist of natural and artificial substances that are not regularly monitored but have a risk of causing negative effects on human health and the environment (Shafi *et al.* 2023). Pharmaceuticals (Ellis 2006), hygiene items (Heinz *et al.* 2009), fire extinguishers, insecticides, and chemical fertilisers are examples of emerging pollutants used by humans frequently. The two main causes of emerging contaminants in surface water bodies are sewage overflows and treated effluent discharged from wastewater treatment plants (Gani and Kazmi 2016).

Combined sewer overflows can discharge untreated industrial and human waste into nearby waterways. Every wastewater treatment plant is designed and built to have a specific hydraulic capacity based on peak dry weather flow before considering stormwater inflow (Department of Public Works 2012). Combined sewage overflow structures are frequently constructed inside sewer systems to prevent the downstream sewers and treatment plants from overflowing during heavy rainfall events, which discharge excess flow into the nearest surface waterway (Gelhaus 2017). This is to prevent a capacity overload on the treatment plant during heavy precipitation. During heavy rainfall, stormwater runoff can transport effluents from deteriorated and damaged sewer infrastructure, which can leak effluents into the environment and get transported by stormwater runoff into streams and rivers.

The World Bank Group (2016) found that numerous areas within eThekwini Municipality have insufficient and deteriorated sewage infrastructure, resulting in effluent discharge into rivers. It is imperative to acknowledge that a considerable proportion of the existing sewer systems are outdated primarily due to the additional strain that comes with climate change-related increases in precipitation and population growth, which has led to the development of additional areas (Botturi *et al.* 2021). This leads to a rise in the frequency and intensity of combined sewer overflow, increasing their environmental risk (Tabari *et al.* 2015; Petrie 2021). Further research is required to define contaminant concentrations for environmental and human health risk assessment of emerging pollutants, especially faecal pollution. This will provide greater knowledge for the creation of guidelines and best management practices.

2.10 Mitigation and Adaptation

The objective of mitigation strategies is to lessen or prevent the effects of climate change, and adaptation responses are focused on ensuring that municipal stakeholders, key role players, while residents implement the necessary changes required to adapt to the effects of climate change. Urban flood risk management is a suitable adaptive strategy that can be taken to minimise disruptions and expenses related to urban development over time. This involves evaluating and lowering flood risk and planning for an efficient response to and recuperation from recurring floods (Fletcher *et al.* 2014). It is important to highlight that climate change models and projections are essential for determining the vulnerability of urban areas to flooding and investigating mitigation strategies (Hou *et al.* 2022).

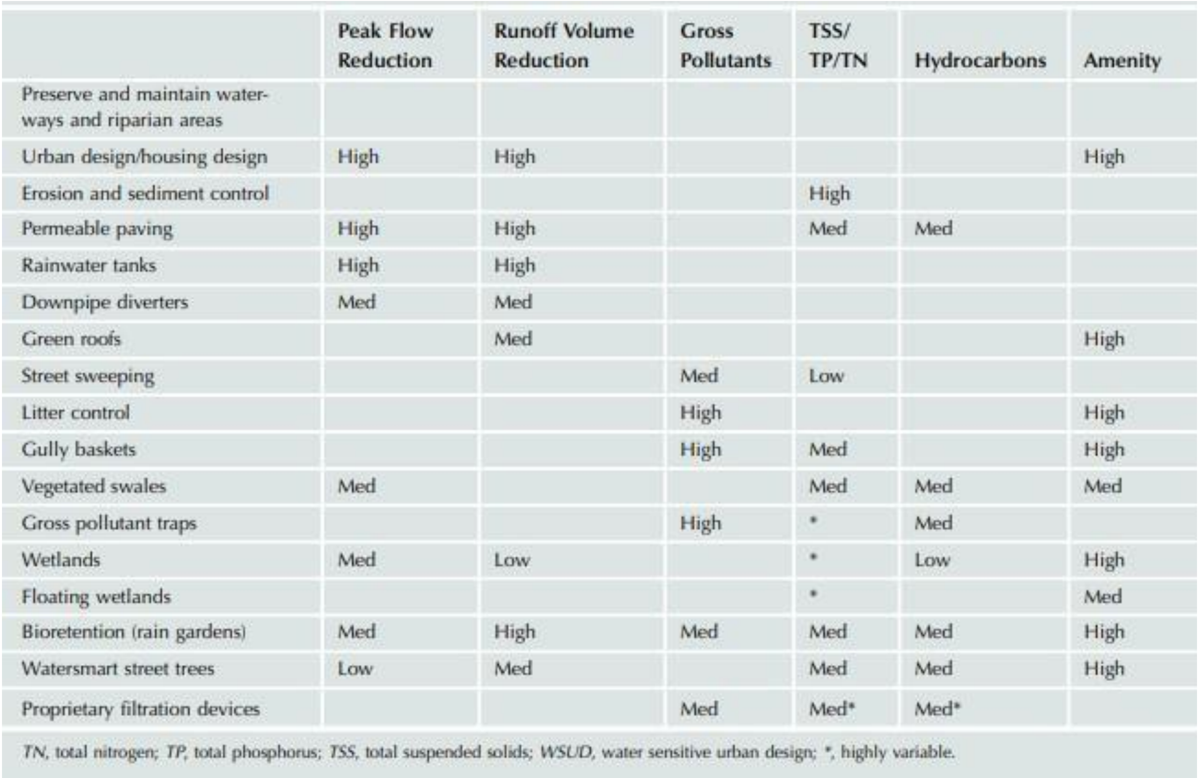
Locating areas that are vulnerable to floods and where providing protection will be beneficial from a social, economic, and technological standpoint is more crucial for adaptation measures (Sörensen *et al.* 2016). To strengthen the drainage catchment's resilience and enhance its capacity to endure times with heavy rainfall, a mix of structural and non-structural flood prevention techniques is required. Resilience can be described as a system's ability to continue evolving following a desired and anticipated route (Cohen *et al.* 2011). This is a challenging task presented to planners and civil engineers to pragmatically account for nonstationary conditions in drainage infrastructure planning and design while safeguarding present and future public interests.

2.10.1 Sustainable Urban Drainage Systems

To lower the amounts of surface runoff produced by urbanised catchments, the sustainable techniques to manage stormwater runoff is strongly promoted. Multiple titles are used in various parts of the world: water-sensitive urban design in Australia, sustainable urban drainage systems in the UK, low-impact urban development in the US, and low-impact urban development in New Zealand (Fletchera *et al.* 2015). Sustainable urban drainage systems (SUDS) is currently in use in South Africa (Armitage *et al.* 2013). A broader consciousness regarding sustainability has led to the increased significance of managing all water resources in the design of urban drainage systems.

SUDS address problems with water quantity and quality by promoting reuse and minimising the effect of urban stormwater through landscaping (Wong 2006). SUDS have gained recognition as cutting-edge methods for managing stormwater and restoring groundwater while re-establishing the natural hydrological process (Thomson and Newman 2018). Numerous models have demonstrated that even in the face of climate change, SUDS may increase stormwater runoff reduction or improve the drainage network's operational adaptability (Mugume and Butler 2017; Ghodsi *et al.* 2020). Sustainable drainage systems include various innovations designed to mimic the natural pre-development conditions as much as possible (Ballard and Kellagher 2007). Their capacity to lessen the quantity of stormwater runoff and prolong its peak flow characteristics makes them an effective climate change adaptation technique.

Table 2: SUDS Approaches and benefits.
Source: (Hoban 2019)



	Peak Flow Reduction	Runoff Volume Reduction	Gross Pollutants	TSS/ TP/TN	Hydrocarbons	Amenity
Preserve and maintain waterways and riparian areas						
Urban design/housing design	High	High				High
Erosion and sediment control				High		
Permeable paving	High	High		Med	Med	
Rainwater tanks	High	High				
Downpipe diverters	Med	Med				
Green roofs		Med				High
Street sweeping			Med	Low		
Litter control			High			High
Gully baskets			High	Med		High
Vegetated swales	Med			Med	Med	Med
Gross pollutant traps			High	*	Med	
Wetlands	Med	Low		*	Low	High
Floating wetlands				*		Med
Bioretention (rain gardens)	Med	High	Med	Med	Med	High
Watersmart street trees	Low	Med		Med	Med	High
Proprietary filtration devices			Med	Med*	Med*	

TN, total nitrogen; *TP*, total phosphorus; *TSS*, total suspended solids; *WSUD*, water sensitive urban design; *, highly variable.

Table 2 details various SUDS approaches and benefits, and with the promotion of sustainability in urban cities has led to the worldwide application of SUDS (Ashley *et al.* 2007; Stewart and Hytiris 2008). The University of Cape Town in South Africa concluded the South African SUDS guidelines for the Water Research Commission. It is crucial to bear in mind that the guideline was meant to serve as a means for professionals to recognise and capitalise on opportunities to enhance South Africa's stormwater management practices, rather than as a design manual (Armitage 2011). This guideline was later adopted and published in The Neighbourhood Planning and Design Guide Creating Sustainable Human Settlements, 2019.

The Red Book 2019 highlights that since publishing the predecessor, Red Book 2000, there has been substantial progress in knowledge of human settlements both globally and domestically. The revised design manual offers guidance on adapting to worldwide issues, including climate change and its impact on the built environment. It aligns theoretical methods for settlement planning with present research and government initiatives, structures and strategies (Department of Human Settlements 2019).

The new design method, as per the Red Book 2019, for stormwater systems is based on Water Sensitive Urban Design (WSUD) principles, which include every component of the water cycle. It contains four crucial intervention stages for stormwater management as shown in Figure 14. Each stage has a variety of SUDS options that may be combined to create unique SUDS combinations for retrofitting.

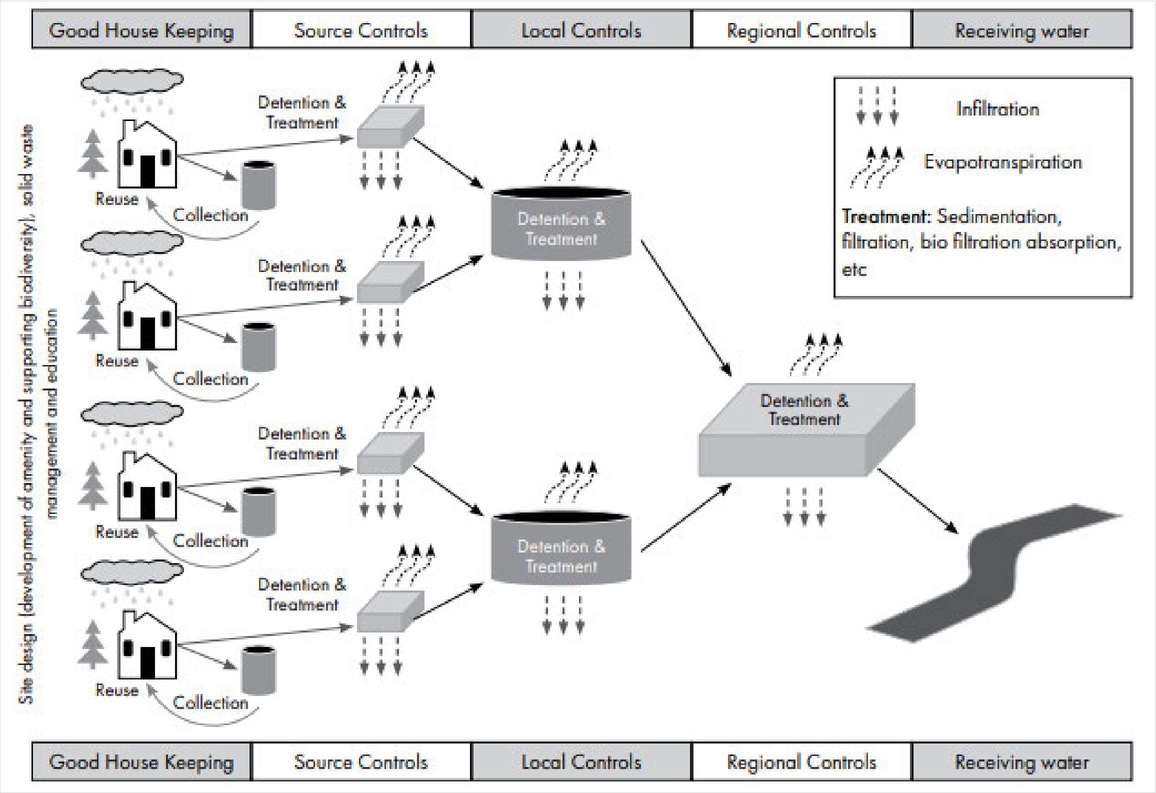


Figure 14: SUDS Treatment Train

Source: (Department of Human Settlements 2019)

2.10.2 Retrofitting Existing Infrastructure.

Retrofitting is the process of modifying current infrastructure to adhere to updated design standards, which may arise from higher capacity requirements and revised regulations and standards. Existing stormwater systems can be upgraded through retrofitting to meet new stormwater management guidelines, such as sustainable urban drainage systems, which align with sustainable urban drainage and quality standards for receiving waters. Stormwater management techniques such as SUDS can be used when surface runoff surpasses the drainage system's capacity (Ghodsi *et al.* 2020). A legitimate option for assessing SUDS' performance before implementation at a municipal scale, considering both quantity and quality stormwater management, is to incorporate modelling based on performance in simulation evaluations (D'Ambrosio *et al.* 2022). A study by Meng *et al.* (2022) assessed whether runoff might be reduced by integrating traditional SUDS solutions with the current stormwater pipes. The study found that a combination of traditional band SUDS increased evapotranspiration and infiltration while decreasing stormwater runoff.

Rainwater harvesting can supplement domestic water supplies for reuse. It has further advantages, such as lessening the strain on downstream drainage and sewage systems and lowering the demand for water supply networks (Han and Mun 2011). The majority of urban areas are made up of developments that can be adapted and upgraded, while new developments make up a very tiny portion of the overall urban area. If SUDS retrofitting can be integrated into already developed areas as shown on Figure 15, sustainable options will significantly increase the potential for additional stormwater management (Green *et al.* 2021). There is a slow shift from conventional to the implementation of sustainable methods in various regions of the world (Ellis and Lundy 2016). China has developed a breakthrough concept known as sponge cities', which reduce peak discharges and excess stormwater by increasing infiltration through natural processes (Chan *et al.* 2018).

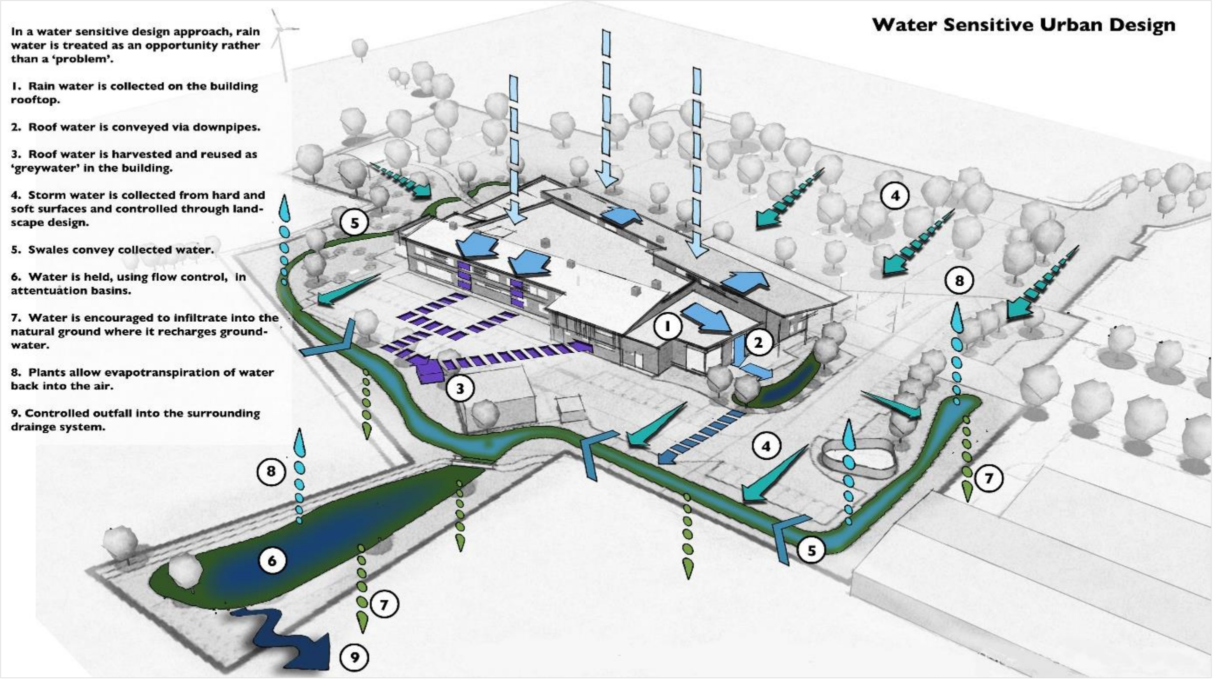


Figure 15: SUDS retrofitting.

Source: (Susdrain 2016)

Dhakal and Chevalier (2017) assessed the challenges and possibilities for policy for sustainable infrastructure and examined 29 barriers across five categories. The study found that the key barriers were cognitive, caused by a lack of education regarding sustainable methods, and socio-institutional barriers. The study also emphasises how crucial it is for educational institutions, particularly those with departments of civil and environmental engineering, to create curricula that incorporate sustainable infrastructure and generate the professionals needed to support sustainable infrastructure. There is a need for South African researchers to evaluate the applicability of these findings in our society, even though the obstacles noted, and the policy solutions suggested are particularly pertinent to the US.

2.11 Alternative Flood Management

2.11.1 Public Participation

A combination of technical and philosophical strategies can be utilised to shift from conventional methods of managing stormwater to adaptive, interactive, and sustainable methods. One of the main obstacles to developing and implementing sustainable stormwater management systems is the absence of community involvement in decision-making processes (Brown and Farrelly 2009). Conventional stormwater management systems may not allow other types of public involvement in decision-making and mitigation efforts since their primary focus is on technical solutions for floods and water quality issues (Cousins 2018). This can ignore several social and environmental objectives, which can also cause conflict between engineers and the general public.

Scarlett *et al.* (2021) conducted research to determine whether race, gender, and education can influence an individual's interest in and willingness to participate in stormwater management. The results revealed that vulnerable individuals and communities were more eager to assist in stormwater management and their readiness to participate was related to their increased anxiety about flooding as flood hazards affect them directly. Hendricks *et al.* (2018) suggest that public participation, as an alternative method for infrastructure management through condition assessments, can effectively be used to handle necessary preventive maintenance and repairs as residents can report infrastructure damage and vulnerabilities to municipal authorities. Without evaluations of the state of the infrastructure, municipal authorities supervise infrastructure maintenance projects in vulnerable communities without enough understanding of the whole scope of the infrastructure requirements or the capacity to prioritise those requirements. This may lead to further conflict with the public regarding resource allocation.

An attempt should be made to simplify technical spaces through awareness, advocacy, and education to prevent a lack of knowledge from being a barrier to public participation. This is essential to facilitate both behavioural change and societal support for the successful implementation of mitigation and adaptation strategies. Furthermore, this type of research must be conducted in South African communities because societal demographics vary and may affect the results.

2.11.2 Early Warning Systems

The use of early warning systems (EWS) is an effective flood mitigation tool, as they have contributed to a certain extent to lowering the number of fatalities, injuries, displaced people, and damage to municipal infrastructure and private property (Ringo *et al.* 2024). One of the main causes and triggers of flash floods is precipitation. Flash floods are more likely to occur during significant rainfall events, especially when there is a substantial rainfall over a brief period (Liu *et al.* 2018). Although climate models have predicted intensified flooding hazards, it is impossible to predict with certainty where, when, or to quantify the flood risk. Experts predict that some coastline and river catchment areas, as well as currently flood-prone regions, will become more susceptible to catastrophic floods (Bushesha and Mbura 2015).

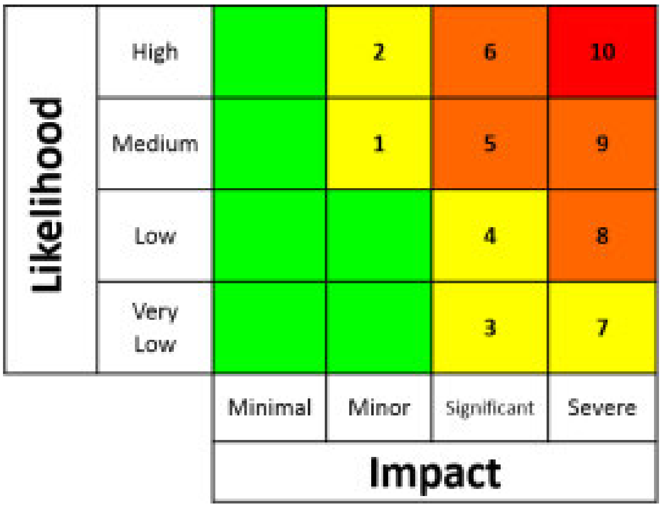
The South African Weather Services (SAWS) is the primary source of information for early warning forecasting. Under the Weather Services Act of 2001, they are required to produce weather and climate data in addition to early warning signals. (Department of Environmental Affairs N.D). The National Disaster Management Centre (NDMC) of the Department of Cooperative Governance, provincial government agencies, local governments, communities, and additional members of the general population who may be impacted are all notified of these severe weather alerts provided by SAWS.

The warning system formerly relied only on weather indications. Since then, an Impact-

Based Severe Weather Warning System has been created by SAWS (ImpB-SWWS), as shown in Table 3, whose purpose is to alert the public to potential dangers associated with severe weather. This includes rainfall, drought, winds, and fires. The system is colour-coordinated and numbered according to a combination of the effect intensity and the effect's chance of happening (SAWS 2020).

Table 3: Risk matrix table

Source: (SAWS 2020)



		Impact			
Likelihood		Minimal	Minor	Significant	Severe
	High	🟩	2	6	10
	Medium	🟩	1	5	9
	Low	🟩	🟩	4	8
	Very Low	🟩	🟩	3	7

There are four tiers for the weather alerts issued by SAWS:

1. No alert: no hazard is expected.
2. Advisory: a potential hazard may occur in the next two to six days.
3. Watch: hazardous weather is likely to occur in the next one to three days.
4. Warning: hazardous conditions are occurring or are about to occur in the next one to 24 hours.

The ineffectiveness of the alert and warning distribution stems from communities and municipalities not having enough time to plan for emergency measures in the case of an extreme weather occurrence. The eThekwini municipality and the South African Weather Service distributed warnings during the April 2022 floods. However, there are several hints that the alerts were not widely disseminated and that those impacted might have been unaware of what to do in response to them (The Witness 2022). According to Pinto *et al.* (2022), several media releases for disruptive rain with an increase in impact were posted on the municipal disaster management WhatsApp group by the South African Weather Service from 7–11 April 2022.

Unlike other African countries, SAWS and disaster management teams only rely on social mass media such as web posts, tweets, Instagram and Facebook posts, and WhatsApp messages to get alerts and warnings to the public and authorities. Tanzania, Zimbabwe, and Nigeria use flood sirens, and the monitoring station receives a signal to trigger the alarm within a five-kilometre radius when the water reaches a specific level (Magomelo *et al.* 2014). Uganda, Kenya, and Mozambique use flood SMS and MMS to notify the public once the river gauge notices the water level is increasing abnormally (Hoedjes *et al.* 2014).

The eThekwini Municipality's CSCM department, Deltares, a Dutch engineering research institute, and the University of KwaZulu-Natal collaborated to develop an EWS to increase flood risk knowledge, strengthen forecasting, and implement early warning systems. The early warning system operates by reducing the outcomes from global models, which were able to predict a significant rainstorm three days before the 2022 floods (Pringle 2022).

This demonstrates how difficult it is to forecast the weather and make subsequent decisions, as national models did not predict severe rainfall. Instead, they only raised alert levels to signal that the weather had become more severe and raised the impact levels. More work is required to build and enhance this system, according to observations made during the most recent flooding event in April 2022. Furthermore, funding and inputs from the national government, South African institutions, and municipalities are needed.

CHAPTER THREE: STUDY AREA

3.1 Introduction

The Isipingo Catchment, which originally comprised of the merged Isipingo River and Estuary ecosystem, is situated in the KwaZulu-Natal, southwest of Durban. It is one of the province's smallest catchments, with an approximate area of about 52 km^2 (Begg 1978). This is a significant catchment since it has become Durban's most industrially developed area. Toyota's largest auto assembly plant in South Africa is located in the industrial area of Isipingo, called Prospecton. Many residents of Isipingo and surrounding areas are employed in the Prospecton area (MILE eThekwini Municipality n.d.). The Isipingo River begins adjacent to the Inwabi area, which is situated north-west of the Isipingo Estuary and then runs for approximately 27 km (Pillay 2013).

The Lower Isipingo Catchment covers an area of 14.465 km^2, and the remaining Isipingo River runs for approximately 3.018 km into the Isipingo Estuary mouth as shown in Figure 16. The highly developed lower catchment compromises the Isipingo Wastewater Treatment Works (WWTWs), Isipingo railway station, Prospecton industrial zone, and the Isipingo Diversion Works System.

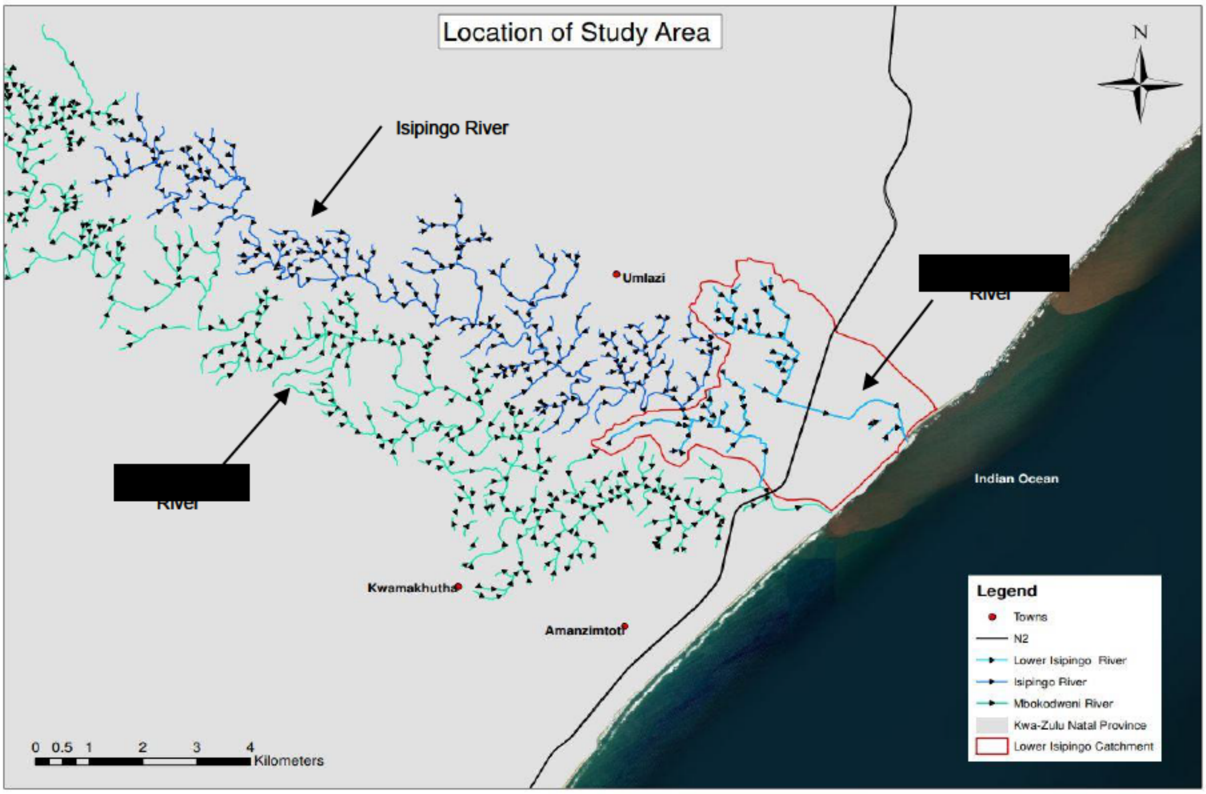


Figure 16: Location of study area: Lower Isipingo Catchment

Source: (ESRI) ArcGIS 10.0 and eThekwini Municipality GIS files

3.2 Lower Isipingo Catchment Modification

The Umlazi River initially merged with the Isipingo River upstream of the estuary mouth as shown on Figure 17. These were later strategically split to develop an industrial zone and airport within Durban. The combined flow from both the Umlazi and Isipingo Rivers near the estuary mouth is approximately 102 × 10^6 m^3/year (Swart 1986). In 1952, the Durban airfield was built in the Umlazi River flood banks in Figure 18, necessitating the river's redirection (SSI Engineers and Marine and Estuarine Research 2011).

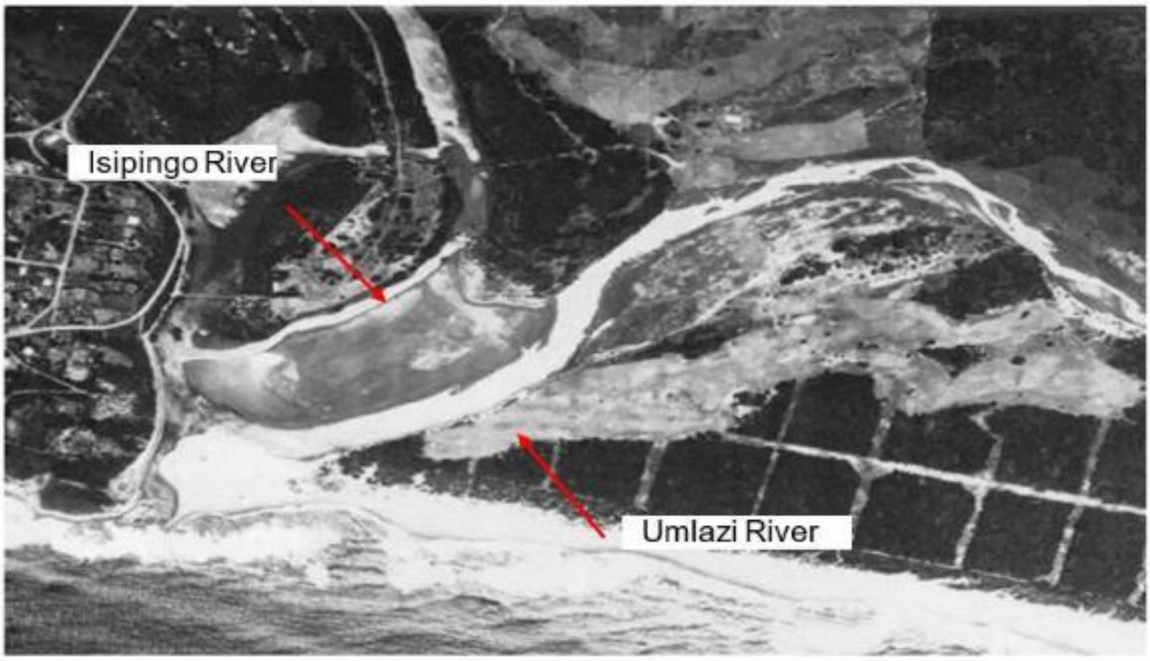


Figure 17: Aerial View of the joint Umlazi and Isipingo River and Estuary system.

Source: (Kalicharran and Diab 1993)

Figure 18: Development of the Durban Airport on the floodplain in 1945.

Source: (Pillay 2013)

In 1945, a berm across the Umlazi River was built to divert the flow away from the

Isipingo estuary. Later in 1952, this was expanded to a concrete canal that discharges into Reunion Rocks, which is now known as Cuttings Beach (Ward 1980). The annual average flow of the Isipingo River decreased to 6 x 106 m3/year (Swart 1986). Figure 19 shows the two one-meter-diameter concrete pipes that were constructed beneath the sandbar in 1961 to promote water flow between the estuary and the ocean, thereby reducing sand accumulation at the mouth of the estuary (Ward 1980).

Figure 19: Two x 1m diameter concrete pipes for tidal exchange.
Source: (Pillay 2013)

Prospecton was identified for development as an industrial region in the 1960s due to a scarcity of suitable industrial areas near Durban. This resulted in the implementation of the Diversion Works System in 1970, which used sluice gates to restrict the flow into the lower Isipingo River (Swart 1986). To regulate the flow from the upper catchment and minimise flooding, the Isipingo River was redirected into the Mbokodweni River, and sluice gates were erected at the top of the Prospecton Canal System. The Isipingo River's flow was further lowered to 3×10^6 m^3/year (Swart 1986). The sluice gate is shown in Figure 20, maintenance is performed every three months and immediately after large rainfall events to maintain the level of water and clear the water hyacinth and silt from the pond. According to the eThekwini Municipality's engineers, the maximum amount of water that can be admitted through the entrance of the sluice gates is 5.4 m^3/s (Pillay 2013).

Figure 20: Sluice Gates at the head of the Prospecton Canal System.
(Picture taken 16 November 2010)
Source: (Pillay 2013)

3.3 Prospecton Canal System

The Prospecton Canal System was designed and implemented as a flood mitigation strategy to redirect high-flow volumes to the Mbokodweni River while enabling moderate river levels to pass onto the Prospecton Canal System. The design of the Prospecton Canal System is detailed in Figure 21, and its implementation is shown on Figure 22. Due to the irregular maintenance of the system and the regular heavy rain, the Prospecton industrial area is frequently severely flooded (SANRAL 2019b; Edwards 2022; Mthalane 2022; Wicks 2022).

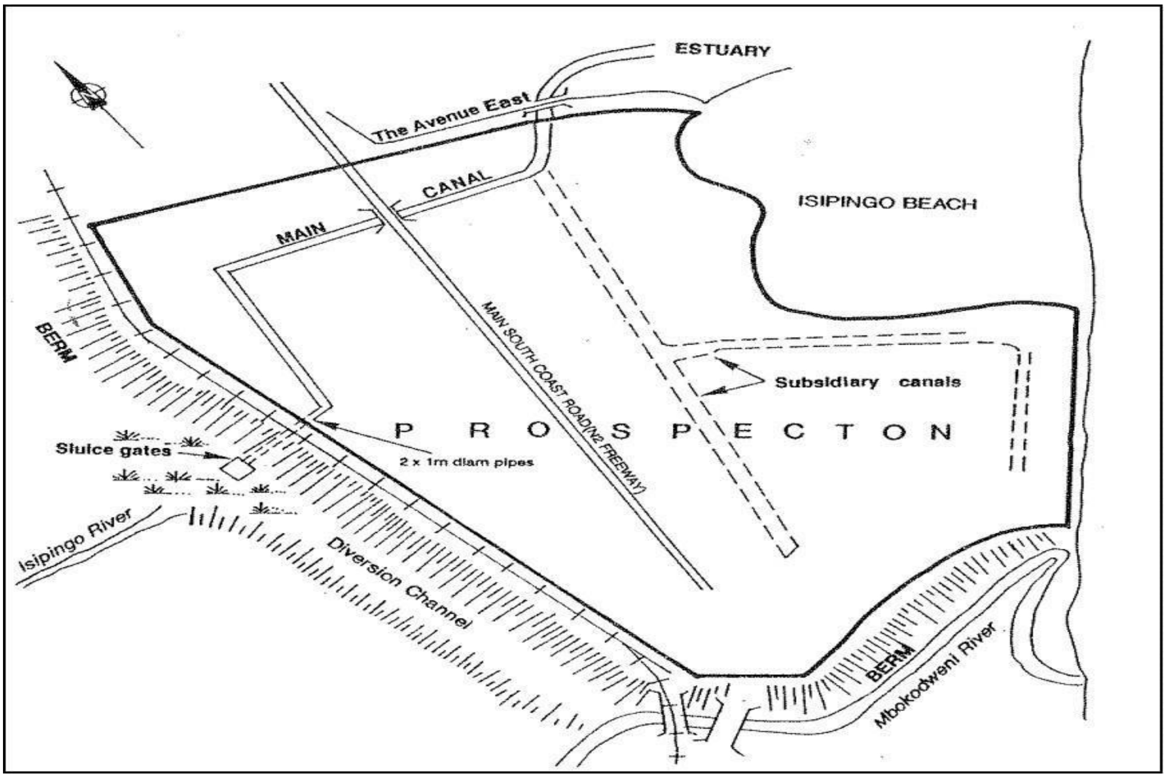


Figure 21: Design of the Isipingo River Diversion and Prospecton Canals.

Source: (Begg 1978)

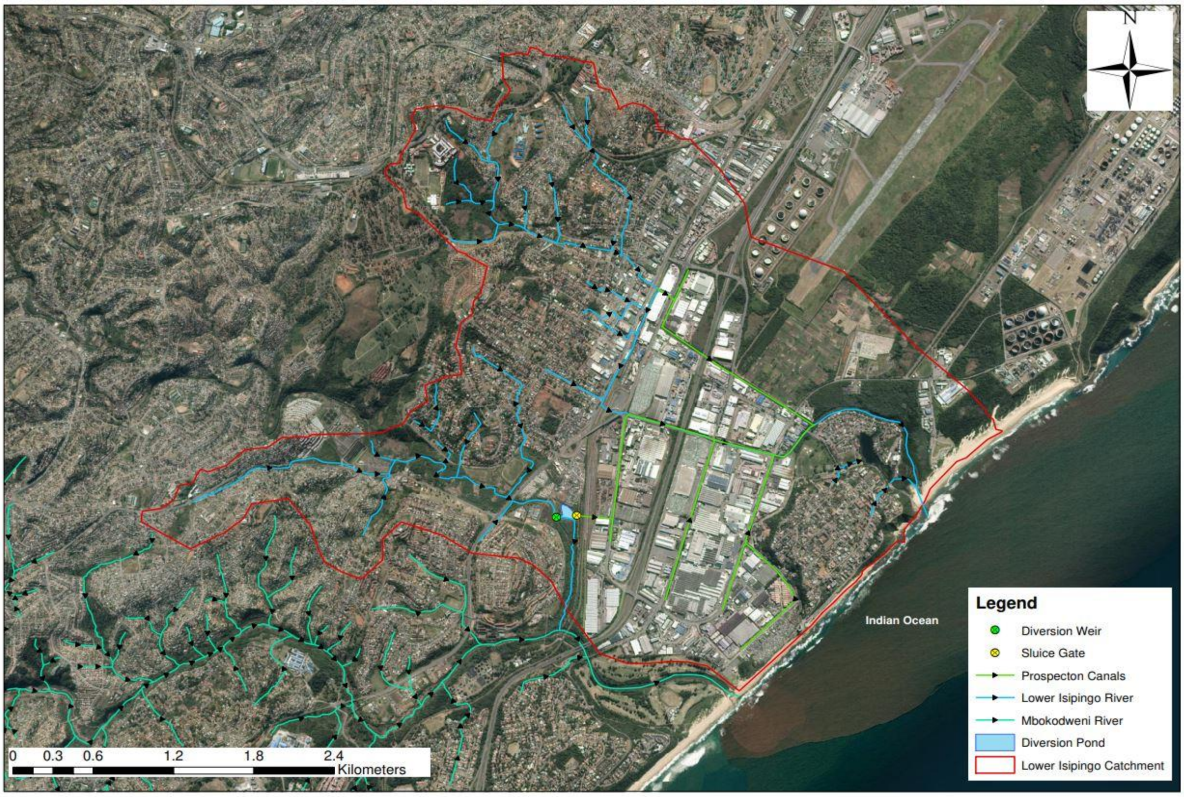


Figure 22: Isipingo River Diversion and the Prospecton Canals Locality

Source: (ESRI) ArcGIS 10.0 and eThekwini Municipality GIS files

The Lower Isipingo Catchment and flood banks of the Isipingo Estuary are heavily developed. As a result, the catchment is more susceptible to flooding due to the Isipingo River's canalisation and the extensive hardened surfaces of the estuary. Considering the region is low-lying, both industrial and residential developments are extremely vulnerable to flooding. The figure details a DEM (digital elevation model) using a LIDAR image. LIDAR stands for Light Detection and Ranging, which is a remote sensing method that generates the earth's terrain parameters (Heavy AI).

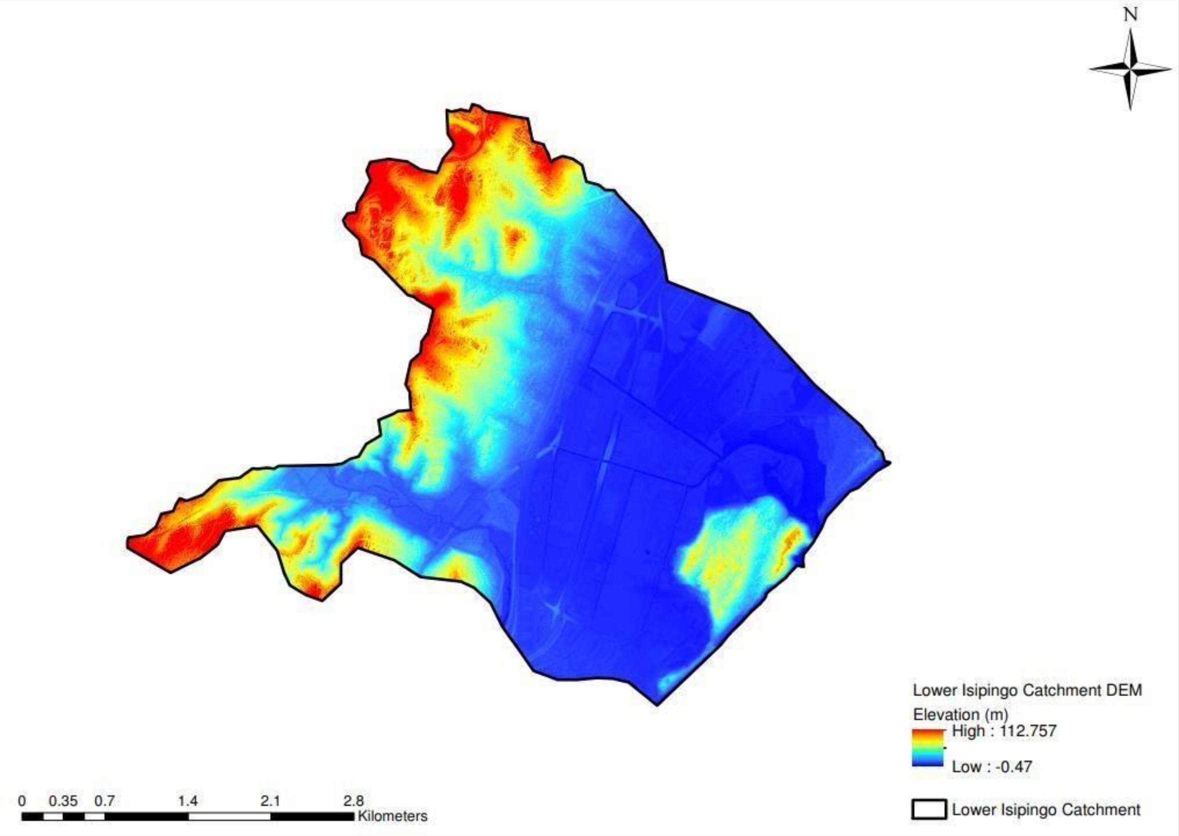


Figure 23: Lower Isipingo Catchment digital elevation model.
Source: (ESRI) ArcGIS 10.0 and eThekwini Municipality GIS files

The upper catchment elevation is 112.757 MSL, while the lower catchment elevation is -0.41 MSL, which is below mean sea level. The N2 and the Prospecton industrial area and canals are located at the mean sea level, and this explains the reoccurring extreme flooding experienced within the catchment during heavy rainfalls. This is also understandable considering the catchment's natural topography before its alteration and urbanisation.

3.4 Flooding

According to SSI Engineers (2011) both the industrial and low-lying residential areas within the Lower Isipingo Catchment were flooded during the major September 1987 floods. Despite not being as severe, this issue still persists during torrential downpours. This is largely a result of inadequate inter-tidal exchange and poor maintenance of the diversion works system (Pillay 2013).

The images below are camera photographs captured from the 9th to 12 April 2022 floods, demonstrating the accumulation of surface runoff that led to the flooding in the Prospecton canals adjacent to Toyota Automobiles. The highest amount of rainfall was experienced on 12 April with a total of 158.40 mm. The images on Table 4 demonstrate that by 11 April 2022, the canal was already at 100% capacity due to the rainfall. As a result, it no longer had enough storage capacity to attenuate the additional run-off received on 12 April 2022. Extreme flooding in the Prospecton canals during the April 2022 floods caused nearby areas shown on Table 5, including the N2, industrial businesses, low-lying residential units, the Isipingo Lagoon, and the beach to flood.

This confirms that the Prospecton Canal’s current drainage system has reached the end of its design lifecycle and needs to be upgraded or retrofitted to adapt to future flooding events.

Table 4: Images of the Prospecton Canals during the April 2022 Floods

9 April 2022 with 35.8 mm of rainfall	
 Figure 24: Toyota Canal Hiace Gate 1	 Figure 25: Toyota Main Entrance

11 April 2022 with 36.79 mm of rainfall

Figure 26: Toyota Canal Hiace Gate 1

Figure 27: Toyota Main Entrance

12 April 2022 with 158.4 mm of rainfall

Figure 28: Toyota Canal Hiace Gate 1

Figure 29: Toyota Main Entrance

Source: (Coastal Stormwater and Catchment Management 2022)

Table 5: N2 and surrounding areas flood damage during April 2022.

N2 Isipingo Corridor	
 Figure 30: Near old Durban airport	 Figure 31: Near Toyota Automobiles
Source: (Edwards 2022)	Source: (Naidoo 2022)
 Figure 32: Toyota production plant	 Figure 33: SAPREF Refinery
Source: (Patel 2022)	Source: (Ncwane 2022)
 Figure 34: Culvert crossing near an industrial plant	 Figure 35: Sports Centre in Isipingo
Source: (Timeslive 2022)	Source: (Cotterell 2022)

3.5 Isipingo Estuary

A wetland area is where the ground is either entirely or occasionally saturated by water, whether it be saltwater, fresh, or both. Wetlands offer a variety of environmental services, such as flood prevention, water storage and purification, groundwater replenishment, and ecosystem habitat for various types of animal and plant species (Xiong *et al.* 2023). Wetlands are defined by their main source of water and estuaries are referred to as combined tidal and river systems that have some access to the ocean (Sirviente *et al.* 2023). These ecosystems are highly vulnerable to anthropogenic activities such as river channel modification, urbanisation, pollution, and climate change (Marambanyika and Beckedahl 2016).

The Isipingo Estuary is located downstream of the Prospecton Canal System and has degraded significantly as a result of the industrialisation of the Prospecton area. It has since become unsuitable for recreational purposes (Kalicharran and Diab 1993). This ecosystem has an ecological state score of 16, which places it in the severely deteriorated category F (SSI Engineers and Marine and Estuarine Research 2011). This is a result of freshwater shortage due to the diversion of water to the uMlazi Canal and Mbokodweni River, while pollutants and destruction of habitat are the consequence of heavy urbanisation and insufficient urban planning (Forbes and Demetriades 2008). Despite the installation of a set of two concrete pipes at the mouth of the estuary, there are still difficulties with the water quality, including fish deaths caused by low dissolved oxygen levels brought on by several chemical and organic impurities and a lack of tidal exchange (Pillay *et al.* 2014).

Wetlands offer a variety of hydrological services, such as flood mitigation, which can be used as an alternative method for enhancing catchment resistance to rainfall extremes while assisting hydrologic infrastructures downstream (Thorslund *et al.* 2017). Wetlands on floodplains such as Isipingo have a greater chance of lowering flood levels. A study done by Wu *et al. (*2023) concluded that wetlands located downstream of catchments have a significant hydrological impact on extreme floods. Additional studies are required to understand how human activities and modifications interact with wetlands ecosystems like the Isipingo Estuary and potential alternative modifications like the rerouting of the diverted Isipingo River to increase flow into the estuary system.

Table 6: Images of the Isipingo Estuary during the April 2022 floods.

Isipingo Estuary	
9 April 2022 with 35.8 mm of rainfall	12 April 2022 with 158.4 mm of rainfall
 Figure 36: Isipingo Estuary 9 April 2022	 Figure 37: Isipingo Estuary 12 April 2022
Source: (Coastal Stormwater and Catchment Management 2022)	

The images on Table 6 demonstrate the Isipingo Estuary during the April 2022 floods. Given the natural topography of the Lower Isipingo Catchment and its intensive modification to harbour development, a holistic approach is required for its rehabilitation. There is a need to improve communication and teamwork between engineering and environmental departments to resolve the discrepancies between the preservation of the environment and urban development and guarantee the sustainable use of land for the future.

3.6 Current Land Use and Future Development

The Isipingo area, which is home to several industrial businesses that offer employment to several eThekwini residents, is part of the South Durban Basin (SDB), a region that is a driving force behind the economic growth of the nation. Due to the substantial chemical, petrochemical, automobile, and pulp manufacturers, Isipingo maintains its place as a key industrial hotspot, Isipingo has been classed as an important secondary central business hub in Durban (eThekwini Municipality 2007).

The minibus industry dominates the greater part of unregulated informal economic activity in Isipingo. Despite eThekwini’s investment in public facility repairs, the Isipingo CBD has been neglected and degraded, and its infrastructure has deteriorated over time, leading to an increase in crime and grime (The Planning Initiative 2019). To address this issue, the Isipingo Regeneration Programme and Urban Design Framework were initiated by the eThekwini Municipality Strategic Spatial Planning Branch. To date, no adjustments have been implemented by the new urban design framework, which comprises spatial developments, an overview of the current CBD layout, and an improved urban design. Figure 38 details the current land use in the Lower Isipingo Catchment.

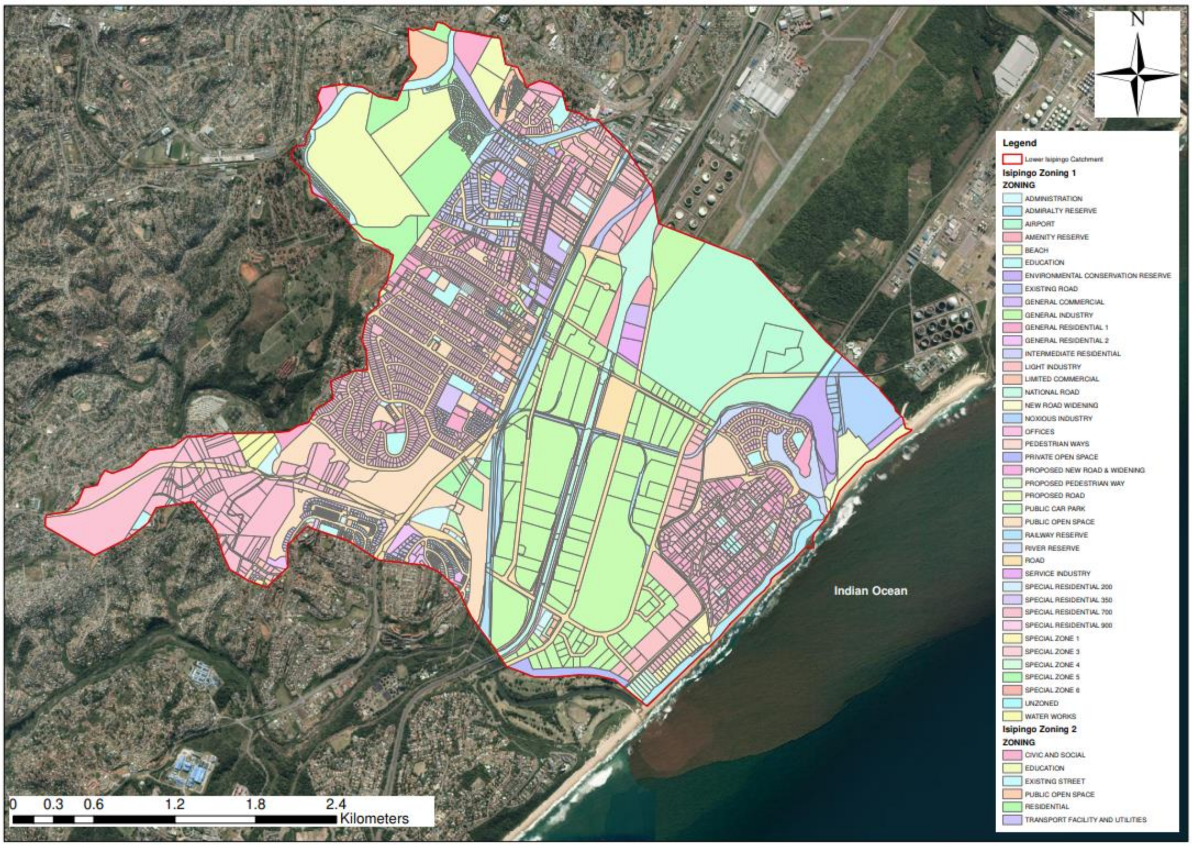


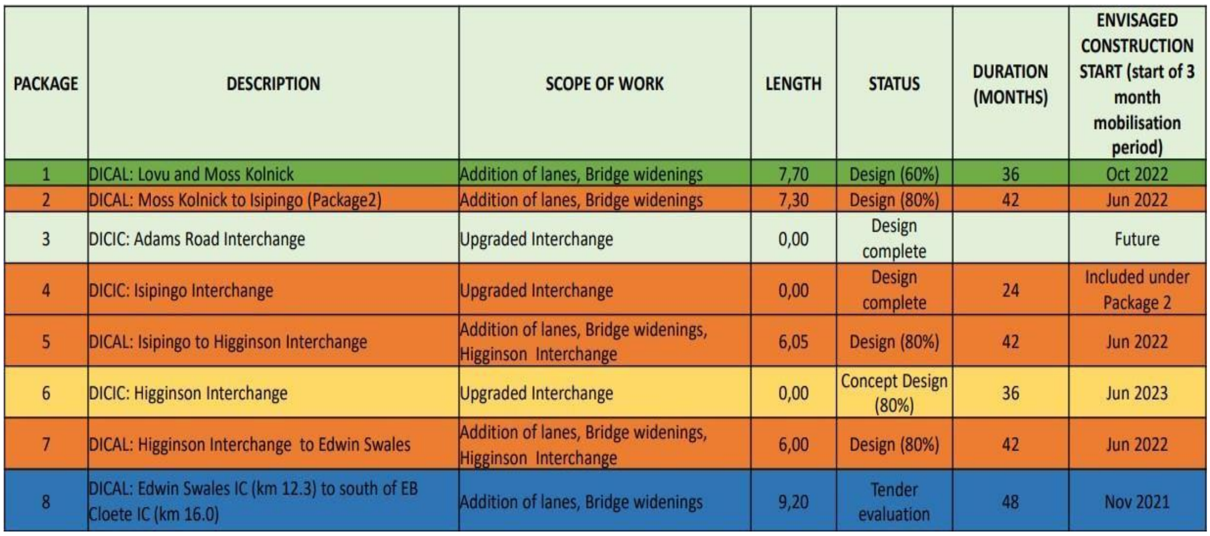
Figure 38: Lower Isipingo Catchment Zoning

Source: (ESRI) ArcGIS 10.0 and eThekwini Municipality GIS files

In attempts to reduce the amount of flooding within the Lower Isipingo catchment, national road agency SANRAL has proposed an upgrade of the N2 at the Isipingo interchange. The upgrade will accommodate the current traffic demand, including the future demands expected from Transnet's expansion into the Durban dig-out port at the Durban old airport (SANRAL 2019a). Additionally, the proposed upgrades also aim to make the offramps wider and increase their height. Many South Coast communities and business establishments have opposed this project due to concerns that the N2 could become a toll road following the upgrades (Baillache 2015). Table 7 shows that construction has not begun yet as the designs are yet to be finalised.

Table 7: N2 Priority Project Progress Planning 2021

Source: (SANRAL 2021)



PACKAGE	DESCRIPTION	SCOPE OF WORK	LENGTH	STATUS	DURATION (MONTHS)	ENVISAGED CONSTRUCTION START (start of 3 month mobilisation period)
1	DICAL: Lovu and Moss Kolnick	Addition of lanes, Bridge widenings	7,70	Design (60%)	36	Oct 2022
2	DICAL: Moss Kolnick to Isipingo (Package2)	Addition of lanes, Bridge widenings	7,30	Design (80%)	42	Jun 2022
3	DICIC: Adams Road Interchange	Upgraded Interchange	0,00	Design complete		Future
4	DICIC: Isipingo Interchange	Upgraded Interchange	0,00	Design complete	24	Included under Package 2
5	DICAL: Isipingo to Higginson Interchange	Addition of lanes, Bridge widenings, Higginson Interchange	6,05	Design (80%)	42	Jun 2022
6	DICIC: Higginson Interchange	Upgraded Interchange	0,00	Concept Design (80%)	36	Jun 2023
7	DICAL: Higginson Interchange to Edwin Swales	Addition of lanes, Bridge widenings, Higginson Interchange	6,00	Design (80%)	42	Jun 2022
8	DICAL: Edwin Swales IC (km 12.3) to south of EB Cloete IC (km 16.0)	Addition of lanes, Bridge widenings	9,20	Tender evaluation	48	Nov 2021

The eThekwini Municipality Coastal, Stormwater and Catchment Department has since attempted to reduce the risk of flooding. The proposed project design shown on Figure 39, is a stormwater culvert designed to discharge at Isipingo Beach. The proposed culvert is approximately 751 metres and starts at the Prospecton industrial area, crosses Ernest Clokie Road, and continues through the Isipingo Beach informal settlement. Figure 40 demonstrates the approximate position of the proposed culvert in a 1967 aerial photograph.

Since the culvert is greater than 300, it requires approval from Section 41 (1)(a) of the KwaZulu-Natal Amafa and Research Institute Act, 2018 (Act No. 5 of 2018), which states that developments require a Heritage Impact Assessment. No heritage sites were found during the site inspections for the heritage impact, as the majority of the study area has hardened and is covered in concrete (JLB Consulting 2022).

Figure 39: Proposed culvert locality.

Source: (JLB Consulting 2022)

Figure 40: Approximate position of culvert on 1967 aerial photograph.

Source: (JLB Consulting 2022)

CHAPTER FOUR: METHODS AND MATERIALS

4.1 Introduction

This chapter describes the research design as well as the methods of data collection, including the tools and techniques used for both data collection and analysis. The discussion also includes the approaches used to accomplish each of the specified objectives, the study's validity and reliability, and the ethical considerations that were taken into account while conducting the study.

4.2 Research Design

A description of the different research methods and their objectives needs to be defined to understand how the research was designed. Quantitative research is based on numerical data and is assessed using statistical methods. It aims to generate empirical facts that can be measured and expressed numerically (Watson 2015). Qualitative research is observational in nature, with the goal of producing precise descriptions of the phenomenon being examined, which can then be used to find new insights and interpretations (Saldana 2011).

Qualitative data was the chosen method for data collection and quantitative analysis methods were applied. The data was collected from text, images and videos, which were shared through data visualisation tools such as computational simulations, hydrographs and maps. Considering that this is an engineering-based study, it must be substantiated with numerical values. For objective 1, the Rational Method was utilised to quantify the associated varying peak flows based on the observations made on the changes in the catchment characteristics over time. For objectives 2 and 3, computational simulations quantified the amount of flooding within the drainage system, while the fieldwork inspections provided insights into the functionality of the system on-site. This was a logical technique to adopt to analyse the qualitative data and quantify it based on a structure established by the specific objectives the researcher aimed to attain. The chosen strategy integrated the different components of the study in a coherent manner, ensuring an effective method to address the research problem.

4.3 Research Instruments

The computational simulations were completed on Computational Hydraulics Inc. (CHI) hydraulic software, PCSWMM, which is used in the civil engineering industry, and by the eThekwini Municipality Coastal Stormwater and Catchment Management Department. Geographic information systems software, ArcMap 10.0, was used for spatial analysis and maps. Fieldwork instruments used include a smartphone equipped with the assessment sheet from the Safety Culture App, a measuring wheel, measuring tape and assessment maps.

4.4 Data Collection

Qualitative data was obtained from direct sources, which included fieldwork and extraction from existing records such as spatial data and technical and scientific papers. The spatial data for 2021 and 2022 was sourced from the eThekwini Municipality Coastal Stormwater and Catchment Management Department, which includes the rainfall, rivers, catchment characteristics, and other pertinent data.

4.5 Research Methods for Specific Objectives

4.5.1 Method for Specific Objective 1

To evaluate the effects of urbanisation on the catchment's drainage system.

A hydrological analysis was used to compute the peak flow for both pre-and post-development scenarios. This hydrological analysis was performed to quantify the volumetric flow rate of surface water draining from the catchment area over time. The pre-development assessment was based on the catchment conditions 20 years ago, in 2002. The post-development assessment was based on the current catchment conditions and characteristics in 2022. The Rational Method was used as the Lower Isipingo Catchment area is 15 km^2. The catchment was divided into four sub-catchments, which are Isipingo 1, 2a, 2b, and 2c as shown in Figure 41. The sub-catchments were generated using the minor catchments shapefile provided by eThekwini Municipality. Equation 1 details the Rational Method.

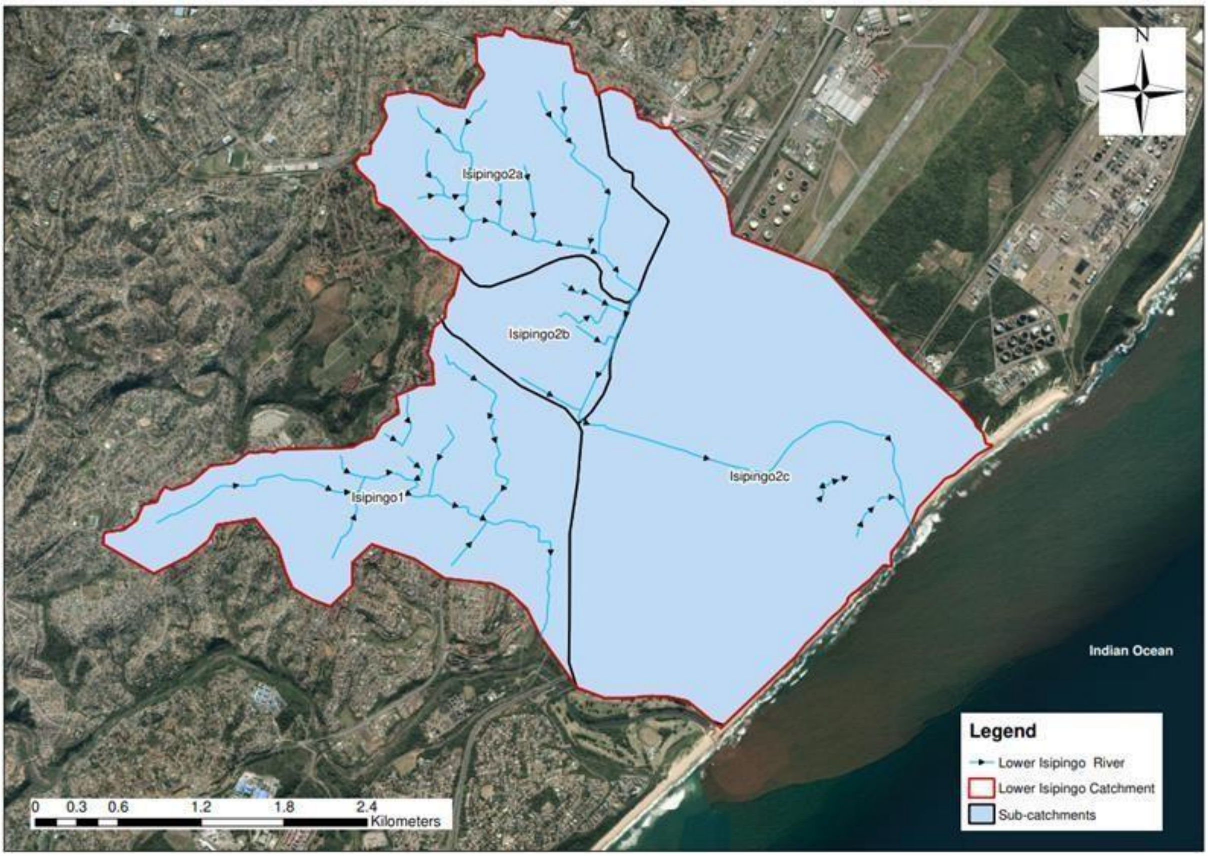


Figure 41: Lower Isipingo sub-catchments.

Source: (ESRI) ArcGIS 10.0 and eThekwini Municipality GIS files

Equation 1

$$\boldsymbol{Q_{20} = \frac{C_{20}\, I_{20}\, A}{360}}$$

Where:

Q_{20} = Peak flow rate for the 1 in 20-year return period

C_{20} = Combined runoff coefficient

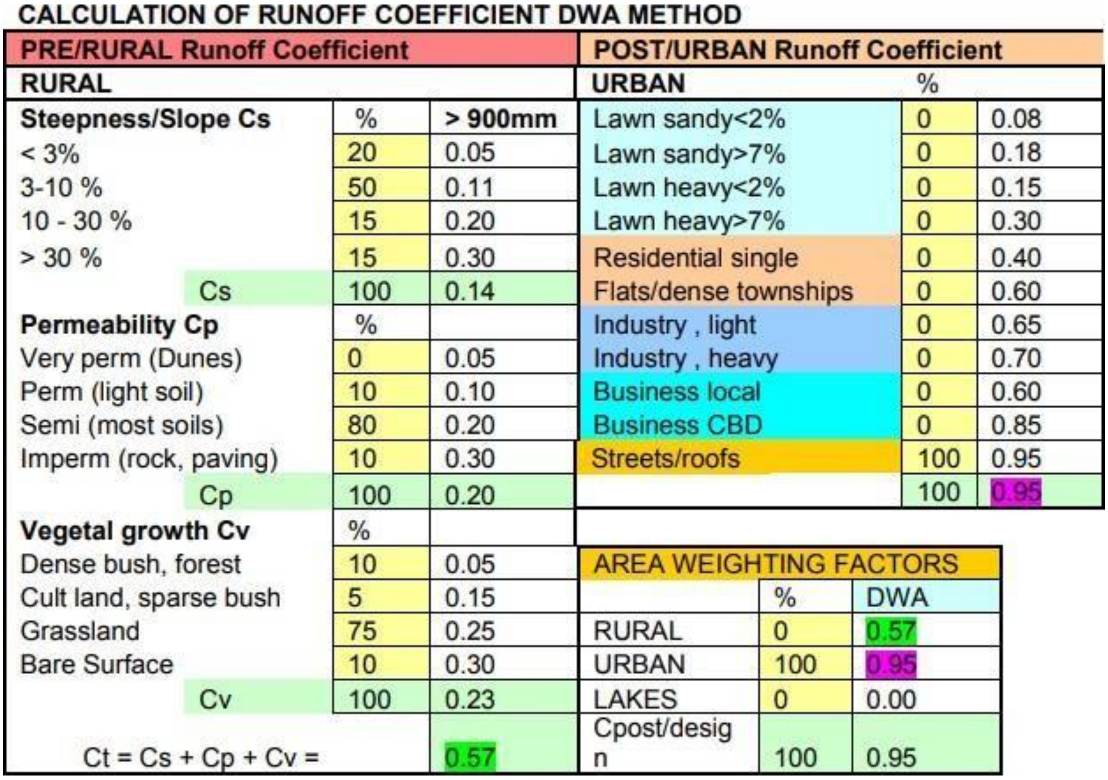
I_{20} = Rainfall intensity in mm/hr

A = Effective catchment area in km^2

360 = Conversion factor (m^3/s)

The runoff coefficient C represents the amount of rainfall that becomes runoff and is calculated in percentages. The DWA method (Grenzwertmethode method is German for "limit value method) was used to calculate the runoff coefficient. A Microsoft Excel table was constructed to calculate the pre- and post-runoff coefficients. The hydrological properties were determined using Google Earth satellite data. Table 8 details the recommended runoff coefficient values.

Table 8: Recommended values for run-off factor C in the Rational Method Source: (eThekwini Municipality 2008)



CALCULATION OF RUNOFF COEFFICIENT DWA METHOD

PRE/RURAL Runoff Coefficient			POST/URBAN Runoff Coefficient		
RURAL			**URBAN**	%	
Steepness/Slope Cs	%	**> 900mm**	Lawn sandy<2%	0	0.08
< 3%	20	0.05	Lawn sandy>7%	0	0.18
3-10 %	50	0.11	Lawn heavy<2%	0	0.15
10 - 30 %	15	0.20	Lawn heavy>7%	0	0.30
> 30 %	15	0.30	Residential single	0	0.40
Cs	100	0.14	Flats/dense townships	0	0.60
Permeability Cp	%		Industry , light	0	0.65
Very perm (Dunes)	0	0.05	Industry , heavy	0	0.70
Perm (light soil)	10	0.10	Business local	0	0.60
Semi (most soils)	80	0.20	Business CBD	0	0.85
Imperm (rock, paving)	10	0.30	Streets/roofs	100	0.95
Cp	100	0.20		100	0.95
Vegetal growth Cv	%				
Dense bush, forest	10	0.05	AREA WEIGHTING FACTORS		
Cult land, sparse bush	5	0.15		%	DWA
Grassland	75	0.25	RURAL	0	0.57
Bare Surface	10	0.30	URBAN	100	0.95
Cv	100	0.23	LAKES	0	0.00
Ct = Cs + Cp + Cv =		0.57	Cpost/design	100	0.95

The rural runoff coefficient is determined by the observed permeable, and vegetated areas within the catchment. It is assessed for slope, permeability, and vegetal growth. An estimated percentage is added for each of the probable values. It is calculated for the pre-and post-development years of 2002 and 2022. Equation 2 details the rural runoff coefficient calculation.

Equation 2

$C_t = C_s + C_p + C_v$

Where:

C_t= Rural Runoff Coefficient

C_s= ∑Slope Coefficient

C_p=∑Permeability Coefficient

C_v=∑Vegetal Coefficient

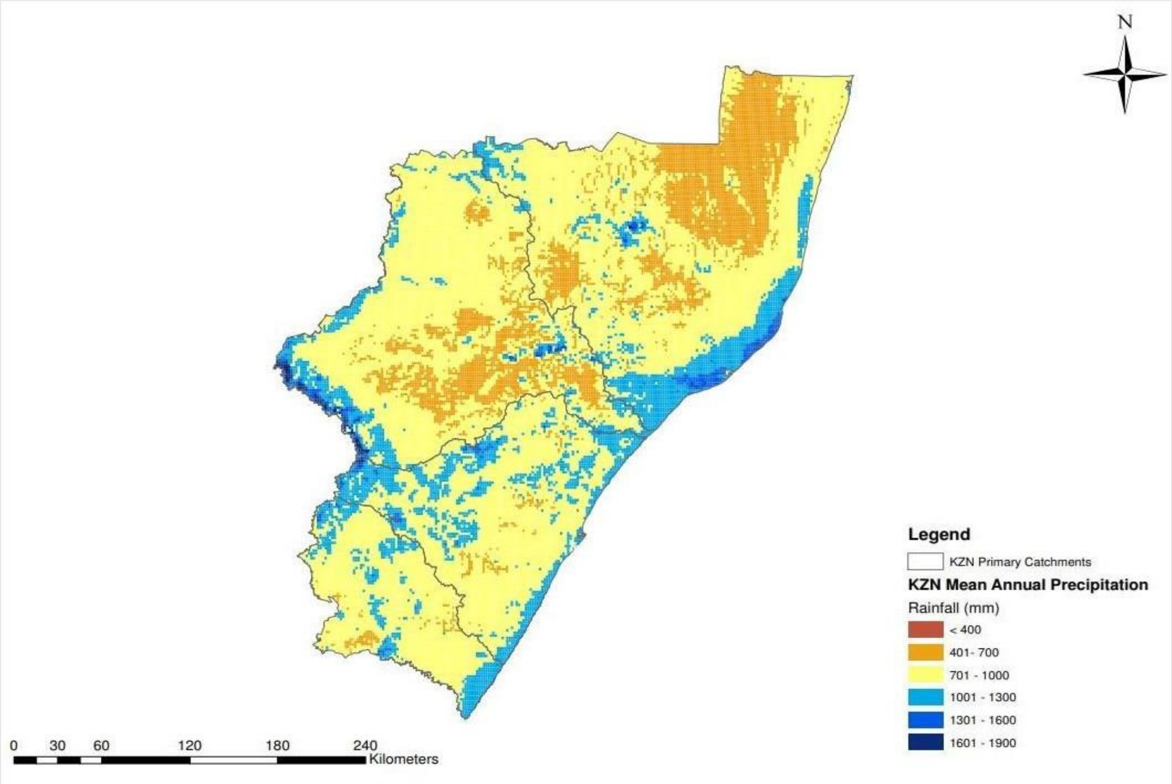


Figure 42: KwaZulu Natal Mean Annual Precipitation

Source: (ESRI) ArcGIS 10.0 and Water Resources of South Africa GIS files

The rural runoff coefficient is based on the mean annual precipitation in the eThekwini region as per the map in Figure 42, which is predominantly > 900 mm.

The urban runoff coefficient is determined by the values associated with the various urban land uses within the catchment. An estimated percentage is added for each of the probable values. It is calculated for the pre- and post-development years of 2002 and 2022. Equation 3 details the urban runoff coefficient calculation.

Equation 3

$C_{urban} = \sum \text{Coefficient values}$

Where:

C_{urban}= Urban Runoff Coefficient

The area weighting factor is determined by the percentage of urban and rural regions in the catchment for both pre- and post-development scenarios. The rural area percentage is considered permeable, while the urban area is the impervious region within the catchment. The final pre-development runoff coefficient depends on the estimated percentage of the rural and urban areas observed in the catchment in the pre-development year (2002). Equation 4 details the final pre-development runoff coefficient calculation.

Equation 4

$$C_{pre\text{-}development} = \left(Ct\ x\ \frac{Rural\ Area\ weighting\ \%}{100}\right) + \left(Curban\ x\ \frac{Urban\ Area\ weighting\ \%}{100}\right)$$

Where:

$C_t = \sum$Rural Runoff Coefficient values for the pre-development year 2002

$C_{urban} = \sum$Urban Coefficient values for the pre-development year 2002

The final post-development runoff coefficient depends on the estimated percentage of the rural and urban areas observed in the catchment in the post-development year (2022). Equation 5 details the final post-development runoff coefficient calculation.

Equation 5

$$C_{post\text{-}development} = \left(Ct\ x\ \frac{Rural\ Area\ weighting\ \%}{100}\right) + \left(Curban\ x\ \frac{Urban\ Area\ weighting\%}{100}\right)$$

Where:

$C_t = \sum$Rural Runoff Coefficient values for the post-development year 2022

$C_{urban} = \sum$Urban Coefficient values for the post-development year 2022

The catchment area refers to the region above a location of interest that contributes to runoff, whether via stream flow or overland flow. The area is estimated to be on a topographical map by following high points determined from contours and low areas that will drain towards the lowest point in the catchment. The catchment area was measured in km^2 using eThekwini Municipality shapefiles on ArcMap. The GIS measuring tools were used and recorded on the design spreadsheet for Isipingo 1, Isipingo 2a, Isipingo 2b, and Isipingo 2c.

The design rainfall shapefile was added to ArcMap to identify the rainfall station closest to the sub-catchment, as shown in Figure 43 to determine the intensity of the rainfall. The latitude degree, latitude minutes, longitude degree, and longitude minutes of the rainfall station were recorded. The rainfall station data was located using the coordinates recorded on the spreadsheet provided by the eThekwini Municipality rainfall page (eThekwini Municipality 2022d).

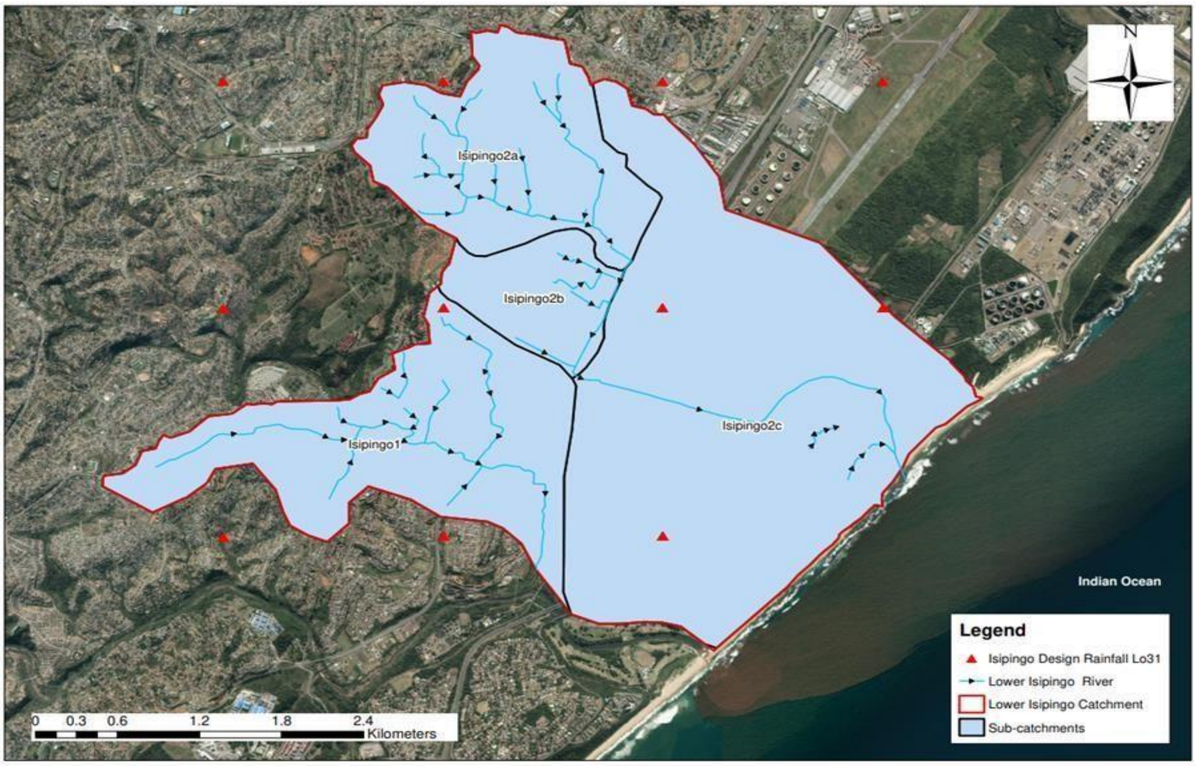


Figure 43: Rainfall stations.

Source: (ESRI) ArcGIS 10.0 and eThekwini Municipality GIS files

The time of concentration (TC) refers to how long it takes for additional rainfall from the farthest section of a catchment to reach the lowest point. As per the eThekwini

Municipality Engineering Unit design manual for stormwater drainage systems, the recommended time of concentration in urban areas for pre-development scenarios is 15 minutes and 10 minutes for post-development. Table 9 displays the design rainfall in minutes and records the station coordinates for each sub-catchment.

Table 9: Design rainfall station Coordinates

Isipingo 1	
LAT DEG	29
LAT MIN	59
LONG DEG	30
LONG MIN	55
Isipingo 2a and 2b	
LAT DEG	29
LAT MIN	59
LONGDEG	30
LONG MIN	56
Isipingo 2c	
LAT DEG	30
LAT MIN	0
LONG DEG	30
LONG MIN	56

The 15-minute rainfall (M15) was used for the pre-development and 10 minutes rainfall (M10) for a post-development scenario for a 1 in 20-year design storm. The rainfall intensity was determined using the following formula on Equation 6 and Equation 7:

Equation 6

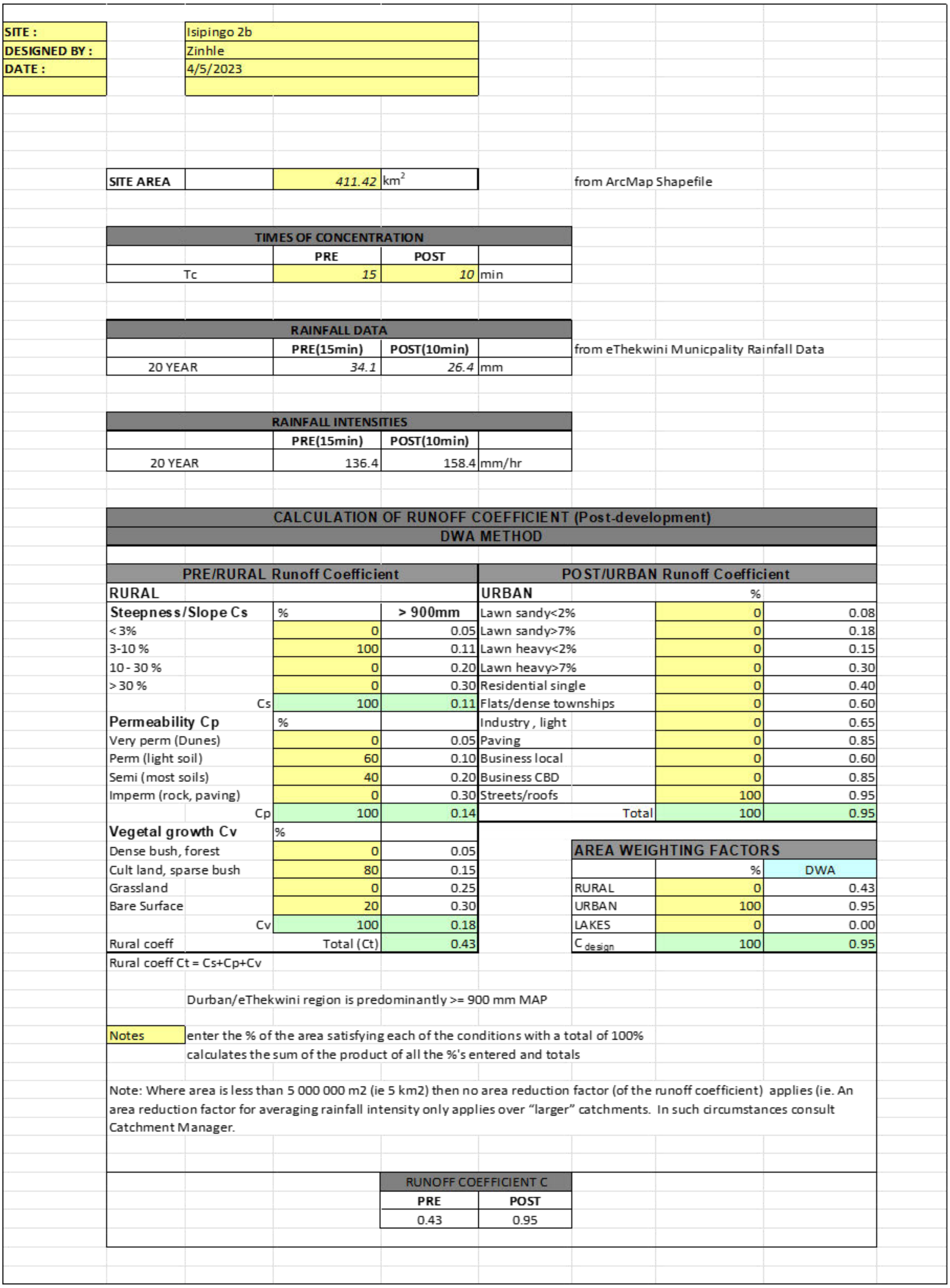
Pre-Development rainfall Intensity M15 x 4 = mm/hr

Equation 7

Post-Development Intensity rainfall M10 x 6= mm/hr

To get the peak flow (Q), 360 is used as the conversion factor into Cumecs (m^3/s). The unit hydrographs are produced to illustrate the output peak-flow for the pre- and post-development scenarios. Table 10 details the Rational Method calculation spreadsheet.

Table 10: Rational Method spreadsheet created on Microsoft Excel



SITE :	Isipingo 2b
DESIGNED BY :	Zinhle
DATE :	4/5/2023

SITE AREA	*411.42*	km^2	from ArcMap Shapefile

TIMES OF CONCENTRATION			
	PRE	**POST**	
Tc	*15*	*10*	min

RAINFALL DATA			
	PRE(15min)	**POST(10min)**	
20 YEAR	*34.1*	*26.4*	mm

from eThekwini Municpality Rainfall Data

RAINFALL INTENSITIES			
	PRE(15min)	**POST(10min)**	
20 YEAR	136.4	158.4	mm/hr

CALCULATION OF RUNOFF COEFFICIENT (Post-development)

DWA METHOD

PRE/RURAL Runoff Coefficient		
RURAL		
Steepness/Slope Cs	%	**> 900mm**
< 3%	0	0.05
3-10 %	100	0.11
10 - 30 %	0	0.20
> 30 %	0	0.30
Cs	100	0.11
Permeability Cp	%	
Very perm (Dunes)	0	0.05
Perm (light soil)	60	0.10
Semi (most soils)	40	0.20
Imperm (rock, paving)	0	0.30
Cp	100	0.14
Vegetal growth Cv	%	
Dense bush, forest	0	0.05
Cult land, sparse bush	80	0.15
Grassland	0	0.25
Bare Surface	20	0.30
Cv	100	0.18
Rural coeff	Total (Ct)	0.43

Rural coeff Ct = Cs+Cp+Cv

POST/URBAN Runoff Coefficient		
URBAN	%	
Lawn sandy<2%	0	0.08
Lawn sandy>7%	0	0.18
Lawn heavy<2%	0	0.15
Lawn heavy>7%	0	0.30
Residential single	0	0.40
Flats/dense townships	0	0.60
Industry , light	0	0.65
Paving	0	0.85
Business local	0	0.60
Business CBD	0	0.85
Streets/roofs	100	0.95
Total	100	0.95

AREA WEIGHTING FACTORS		
	%	DWA
RURAL	0	0.43
URBAN	100	0.95
LAKES	0	0.00
C_{design}	100	0.95

Durban/eThekwini region is predominantly >= 900 mm MAP

Notes	enter the % of the area satisfying each of the conditions with a total of 100%
	calculates the sum of the product of all the %'s entered and totals

Note: Where area is less than 5 000 000 m2 (ie 5 km2) then no area reduction factor (of the runoff coefficient) applies (ie. An area reduction factor for averaging rainfall intensity only applies over "larger" catchments. In such circumstances consult Catchment Manager.

RUNOFF COEFFICIENT C	
PRE	**POST**
0.43	0.95

4.5.2 Method for Specific Objective 2

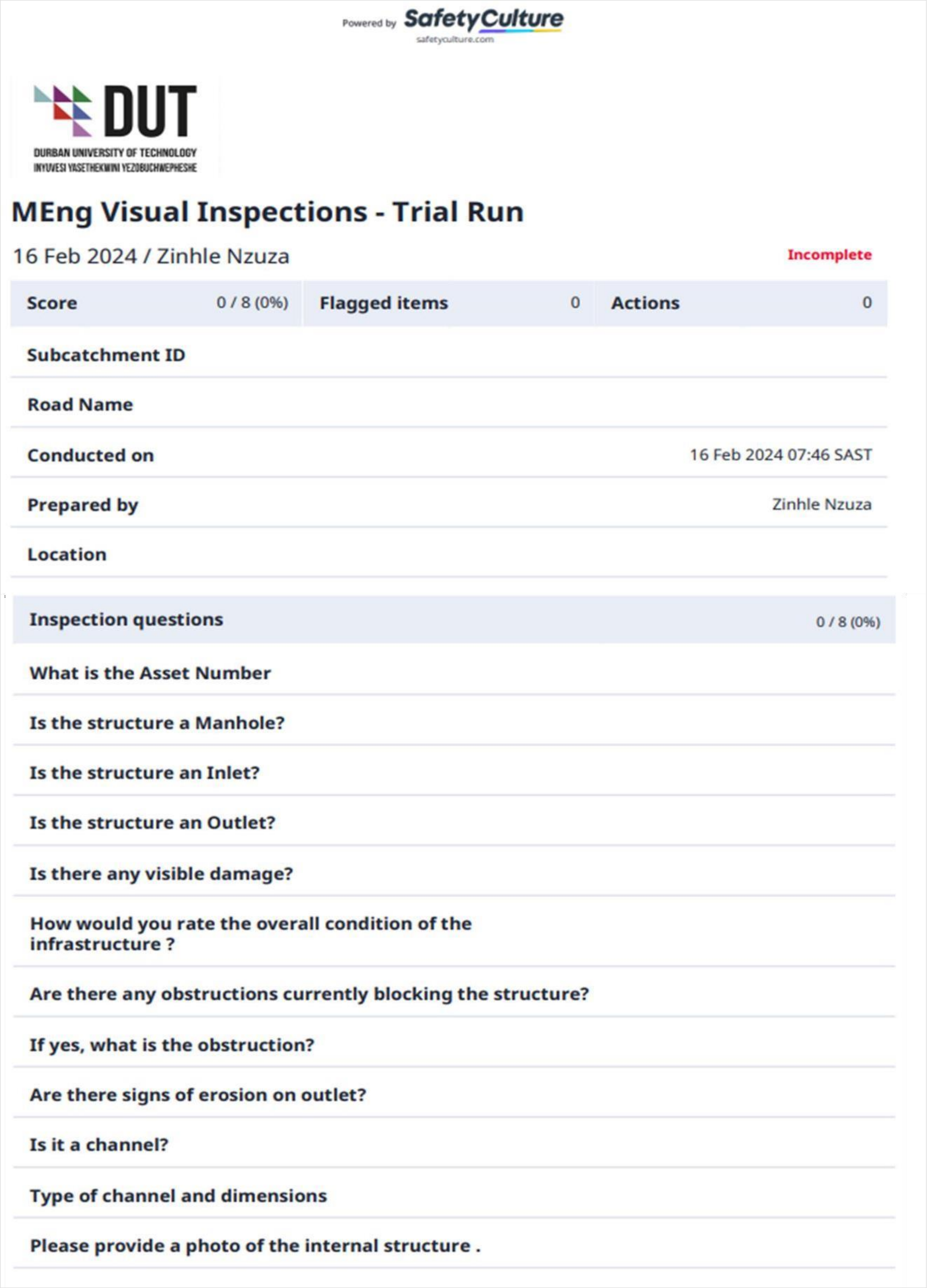
To determine the extent to which solid waste impacts the drainage system's functionality.

To assess the functionality of the stormwater networks, conditional inspections were conducted. These were inspections of manholes, inlets, discharge outlets, open channels, and culverts. An inspection photo was taken, with the completion of a visual assessment sheet on the Safety Culture App. The assessment sheet detailed the following:

1. The asset number,
2. Accessibility of the asset,
3. Obstruction observed,
4. Overall condition of structure, and
5. General comments observed by the assessor.

Field maps were produced using eThekwini Municipality stormwater GIS data 2022. This was completed to ensure that the correct asset was being inspected. The template assessment sheet is shown. Geographic information systems software, ArcMap 10.0, was used for data analysis and maps. Table 11 details the assessment sheet on the Safety Culture App.

Table 11: Infrastructure Assessment Sheet used for Inspections.



MEng Visual Inspections - Trial Run

16 Feb 2024 / Zinhle Nzuza

Incomplete

Score	0 / 8 (0%)	**Flagged items**	0	**Actions**	0

Subcatchment ID	
Road Name	
Conducted on	16 Feb 2024 07:46 SAST
Prepared by	Zinhle Nzuza
Location	

Inspection questions	0 / 8 (0%)
What is the Asset Number	
Is the structure a Manhole?	
Is the structure an Inlet?	
Is the structure an Outlet?	
Is there any visible damage?	
How would you rate the overall condition of the infrastructure ?	
Are there any obstructions currently blocking the structure?	
If yes, what is the obstruction?	
Are there signs of erosion on outlet?	
Is it a channel?	
Type of channel and dimensions	
Please provide a photo of the internal structure .	

4.5.3 Method for Specific Objective 3

To assess the performance of the existing drainage system with varying rainfall data.

A hydraulic model of each of the four sub-catchments was completed. The hydraulic models were named after the sub-catchment names, which are: Isipingo 1, Isipingo 2a, Isipingo 2b, and Isipingo 2c. Each model details which stormwater networks will flood and the severity of the flooding within the network based on a 1-hour storm simulation and the associated rainfall data. Each model was set up in six phases, which are detailed below.

Phase 1: Setting Up

Step 1: The manhole and pipe data were imported into the model as junctions and conduits.

Step 2: A LIDAR image was added to the model, including the following background layers: rivers, culverts, 2 m contours, and roads.

Step 3: All the pipe sizes were converted to meters. All profiles were checked for any missing data and attributes for manhole levels, pipe sizes, and slopes.

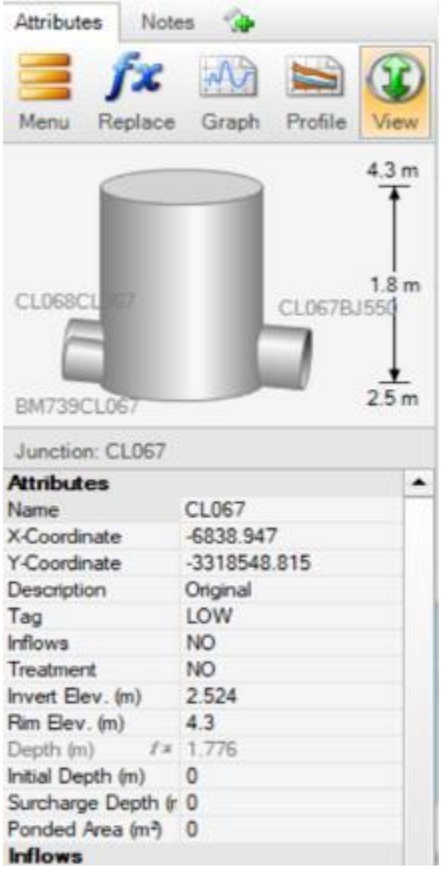
Phase 2: Manholes

Step 1: The cover levels were extracted using the LIDAR image for the manholes that do not have recorded cover levels.

Step 2: For the manholes without an invert level, an assumption was made based on the network's long section depths. A minimum cover of 1.2 m was adhered to.

Step 3: The status of orphan manholes was checked before removal. Orphan manholes are isolated structures that are not connected to a pipe or network. If the manhole was recorded as ‘live’, the pipe was assumed to connect to a manhole within the nearest network. If it was recorded as ‘abandoned’ then the manhole was removed.

Step 4: A check was conducted for manholes that were bypassed by a pipe. If a manhole was bypassed, it was checked whether it was recorded as ‘live’ or ‘abandoned’. If the manhole was recorded as ‘live’ and the pipe was described as ‘WinCan/CSCM request’, then the pipe was not split as it has been verified by a WinCan video camera inspection. If the manhole was recorded as ‘live’ and the pipe was described as ‘original’ it was split up. If the manhole was recorded as ‘abandoned’, the manhole was then removed. Figure 44 shows the manhole attribute table on PCSWMM.



Junction: CL067

Attributes	
Name	CL067
X-Coordinate	-6838.947
Y-Coordinate	-3318548.815
Description	Original
Tag	LOW
Inflows	NO
Treatment	NO
Invert Elev. (m)	2.524
Rim Elev. (m)	4.3
Depth (m) *fx*	1.776
Initial Depth (m)	0
Surcharge Depth (r	0
Ponded Area (m²)	0
Inflows	

Figure 44: Manhole attribute table on PCSWMM.
Source: PCSWMM Isipingo 2a Model

Step 5: A check was completed to ensure no manholes had a 0 m depth. Step 6: It was ensured that no high-confidence manholes were edited. The manhole data source and confidence are explained in Table 12.

Table 12: Manhole data source and confidence level

SOURCE	CONFIDENCE
GPS Survey	High (Cover + Invert)
GPS Survey	Med (Cover Only)
CSCM Request	High (Cover + Invert)
Original	Low
Wincan	Low

Step 7: The last manhole of every network was converted into an outfall. An outfall is the discharging point and structure of the network. It was ensured that the outfall did not discharge on a road, in the middle of a property, or somewhere an outfall would not be located. If there was an outfall where it did not belong, an assumption was made to determine where the network would continue and the possible location of the outfall. These assumptions were verified with visual inspections.

Step 8: If the last manhole of a network was discharging into a culvert, it was left as an outfall. It was noted as 'discharging into culvert'.

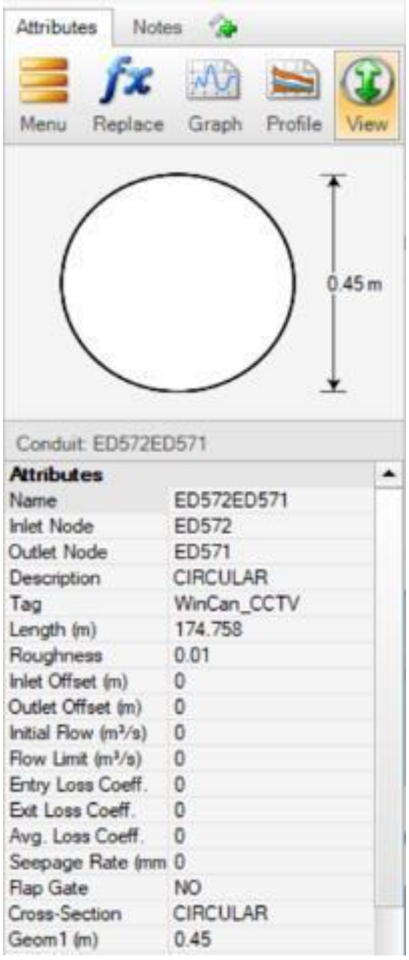
Phase 3: Pipes and Open Channels

Step 1: A check was done to see whether any larger pipes flowed into smaller pipes. This was recorded, and no changes were made.

Step 2: A check was completed for pipe sizes with a diameter of 1 m on eThekwini Municipality's open GIS viewer (eThekwini Municipality 2022c). If the pipe recorded was not 1 m, then it was changed accordingly based on the online GIS data or on the most common diameter pipe in the network that the pipe was connected to. For example, if the entire pipe network diameter was 0.375 m and one pipe was recorded with a diameter of 1 m, the 1 m diameter pipe was then assumed to be 0.375 m to ensure that it ties into the existing network. Figure 45 details the pipe attribute table on PCSWMM.

Step 3: A check was done for any adverse slopes. This was recorded.

Step 4: A check was done to ensure pipe flow from toe to toe (invert level to invert level).



Conduit: ED572ED571

Attributes	
Name	ED572ED571
Inlet Node	ED572
Outlet Node	ED571
Description	CIRCULAR
Tag	WinCan_CCTV
Length (m)	174.758
Roughness	0.01
Inlet Offset (m)	0
Outlet Offset (m)	0
Initial Flow (m^3/s)	0
Flow Limit (m^3/s)	0
Entry Loss Coeff.	0
Exit Loss Coeff.	0
Avg. Loss Coeff.	0
Seepage Rate (mm	0
Flap Gate	NO
Cross-Section	CIRCULAR
Geom1 (m)	0.45

Figure 45: Pipe attribute table on PCSWMM.
Source: PCSWMM Isipingo 2a Model

Step 5: The open channel shapefile containing all the necessary information, such as the shape, dimensions, and location of the open channels captured on site, was imported into the model.

The pipe data source and confidence are explained in Table 13.

Table 13: Pipe data source and confidence level

Source	Confidence
WinCan	High (Pipe size and attributes)
CSCM Request	High/Med (Pipe size and attributes)
Original	Low

Phase 4: Sub-catchments

Step 1: The sub-catchments based on the LIDAR image were generated using PCSWMM.

Step 2: The larger sub-catchments were split up accordingly.

Step 3: The extremely small sub-catchments were merged with a surrounding sub-catchment(s).

Step 4: The outfalls were not included in sub-catchments unless it was necessary based on how the sub-catchments had been defined.

Step 5: In areas where sub-catchments were not generated by PCSWMM, sub-catchments were added/drawn where necessary.

Step 6: The junctions (manholes) generated by PCSWMM upstream and downstream in sub-catchments were removed.

Each sub-catchment has its characteristics. However, the same factors were assigned to similar-looking characteristics in the sub-catchments in the same region. These were adjusted accordingly for all the sub-catchments. Tables, as well as a guide by

PCSWMM that provides typical characteristics and values, are available at: https://support.chiwater.com/77753/subcatchments-layer. Table 14 consist of the typical characteristics:

Table 14: Typical Sub-catchment Characteristics

Attribute	Description
Rain Gauge	5-year design rainfall, April 2019 floods and April 2022 floods
Outlet	The sub-catchment will flow into the manhole with the lowest invert.
Area	Calculated by PCSWMM
Width (m)	Calculated by PCSWMM based on flow length
Flow Length (m)	Calculated by PCSWMM after delineating the sub-catchments. After splitting up or adding new sub-catchments, the flow length was entered manually using the measure tool. A check was done to ensure the width was updated after manually adding flow length.
Slope %	Calculated by PCSWMM after delineating sub-catchments. After splitting up or adding new sub-catchments, they were manually entered. Slope = Height Difference/Flow Path.
Impervious %	Estimated by imagery
N Imprev.	0.013 * Varies per sub-catchment
N perv.	0.40 * Varies per sub-catchment
Zero Imprev	25 %
Infiltration Method	Horton Method

The Horton infiltration method was selected as the simulation method for infiltration capacity. Equation 8 details Horton's infiltration rate formula.

Equation 8

$$f = f_f + (f_0 - f_f)\ e^{-kt}$$

f_0 = the initial infiltration rate (capacity)

f_k = the final rate (almost equal to the percolation rate)

k = constant (depends on soil type and vegetation)

t = time from the beginning of the rain

The Horton technique can account for the storage volume available, maximum infiltration rate, and evapotranspiration. It also produces the best runoff behaviour results, particularly for long-term simulations of stormwater management models (Chahinian *et al.* 2005; Kim *et al.* 2021; Parnas *et al.* 2021). The infiltration parameters for each sub-catchment were based on visible basic soil characteristics and land use. The characteristic values were derived from guideline tables provided by PCSWMM (PCSWMM Support 2022). This approach was considered for each sub-catchment unless it was in close proximity to other sub-catchments with similar-looking characteristics.

Phase 5: Rainfall

Step 1: The rainfall information for the 1 in the 5-year design return period was obtained from the eThekwini Municipality rainfall data page (eThekwini Municipality 2022d).

The coordinates for the rain gauge at the centre of the Isipingo 1 sub-catchment are listed in Table 15.

Latitude Degree: 29	Latitude Minutes: 59
Longitude Degree:30	Longitude Minutes:55

Table 15: Isipingo 1 Return Period Rainfall

LATDEG	LATMIN	LONGDEG	LONGMIN	RP	M1440
29	59	30	55	2	98.9
29	59	30	55	5	**148.2**
29	59	30	55	10	186.7
29	59	30	55	20	228.7
29	59	30	55	50	291.6
29	59	30	55	100	345.9
29	59	30	55	200	407
29	59	30	55	500	500
29	59	30	55	1000	580.9

As per the rainfall spreadsheet the 1 in 5-year design rainfall = **148.2 mm/day**

The coordinates for the nearest rain gauge for Isipingo 2a and 2b sub-catchments are listed in Table 16.

Latitude Degree: 29	Latitude Minutes: 59
Longitude Degree:30	Longitude Minutes:56

Table 16: Isipingo 2a and 2b Return Period Rainfall

LATDEG	LATMIN	LONGDEG	LONGMIN	RP	M1440
29	59	30	56	2	99.6
29	59	30	56	5	**149.3**
29	59	30	56	10	188.1
29	59	30	56	20	230.4
29	59	30	56	50	293.8
29	59	30	56	100	348.5
29	59	30	56	200	410
29	59	30	56	500	503.8
29	59	30	56	1000	585.3

As per the rainfall spreadsheet the 1 in 5-year design rainfall = **149.3 mm/day**

The coordinates for the nearest rain gauge for Isipingo 2c are listed in Table 17.

Latitude Degree: 30	Latitude Minutes: 0
Longitude Degree:30	Longitude Minutes:56

Table 17: Isipingo 2c Return Period Rainfall

LATDEG	LATMIN	LONGDEG	LONGMIN	RP	M1440
30	0	30	56	2	101.2
30	0	30	56	5	**151.6**
30	0	30	56	10	191
30	0	30	56	20	234
30	0	30	56	50	298.3
30	0	30	56	100	353.9
30	0	30	56	200	416.4
30	0	30	56	500	511.6
30	0	30	56	1000	594.4

As per the rainfall spreadsheet the 1 in 5-year design rainfall = **151.6 mm/day**

Step 2: The rainfall data for the April 2019 and April 2022 floods was retrieved from the eThekwini Municipality data feeds (eThekwini Municipality 2022b). The Athlone

Park Reservoir rain gauge was chosen for the 2019 floods as it was the nearest operational gauge near the Isipingo study area during that period.

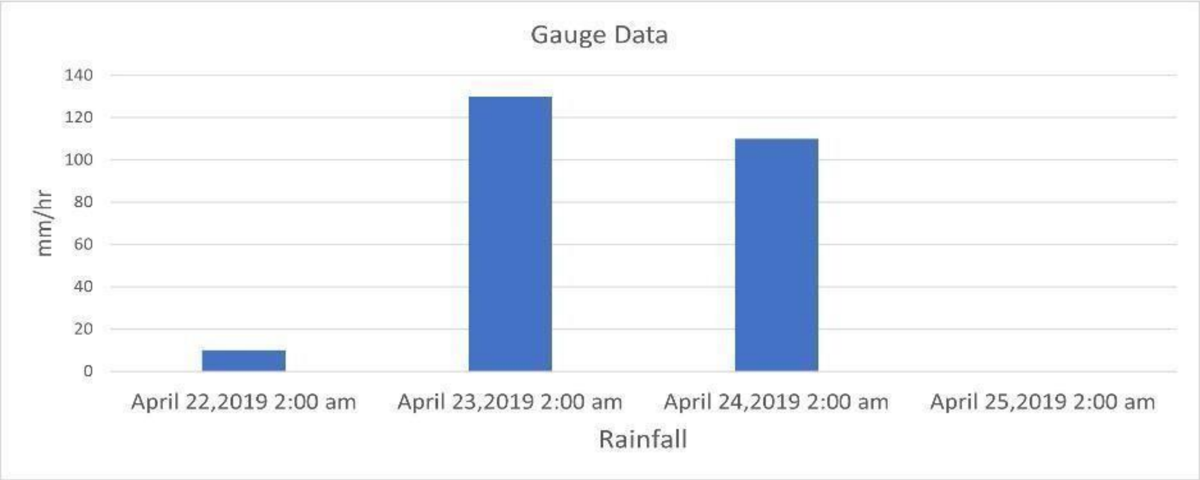


Figure 46: Rainfall Data 22 April–25 April 2019.

Source: (eThekwini Municipality 2022b)

Figure 46 shows the daily rainfall recorded during the April 2019 floods. The flood event occurred over two days, from 23–24 April 2019. 130 mm of rainfall was recorded on 23 April, and 110 mm was recorded on 24 April 2019. The total accumulated rainfall for the two days was 240 mm. No rainfall was recorded on 25 April 2019.

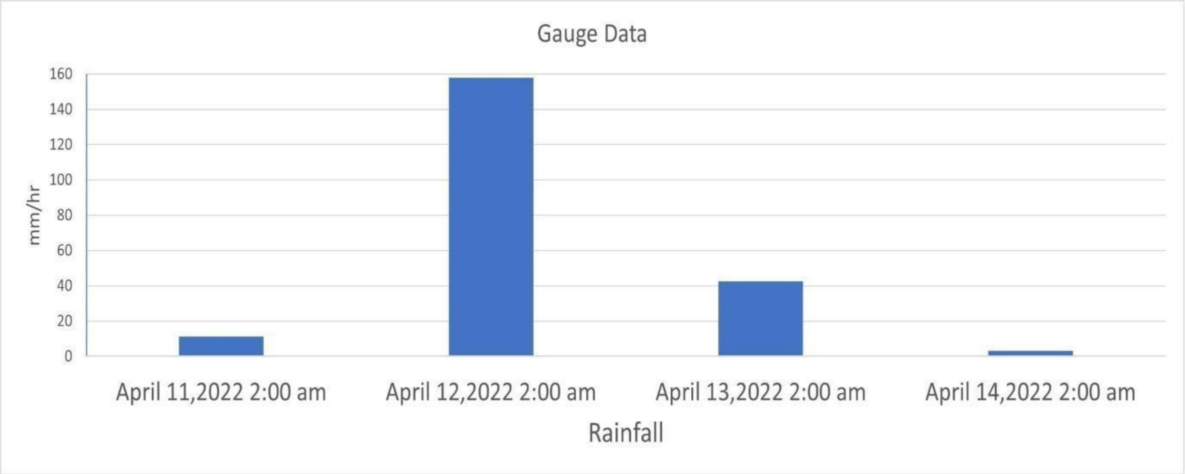


Figure 47: Rainfall data 11 April–13 April 2022

Source: (eThekwini Municipality 2022b)

The Toyota Gauge was chosen for the 2022 floods as it is located at the centre of the Lower Isipingo Catchment. During the April 2022 floods, it was the closest operational gauge. Figure 47 shows the daily rainfall recorded during the April 2022 floods. The flood event occurred over three days, from 11–13 April 2022. 11.2 mm of rainfall was recorded on 11 April, 158 mm was recorded on 12 April, and 42.4 mm was recorded on 13 April 2022. The total accumulated rainfall for the three days was 211.6 mm. Only 3.2mm of rainfall was recorded for 14 April 2022.

Step 3: A 1-hour storm at 5-minute intervals was simulated on Storm Creator South Africa (SCS) for each of the rainfall data. The output file was a unit hydrograph, which was then imported into the PCSWMM model.

Step 4: A total of three rain gauges were created based on the rainfall data. Gauge one was based on the 1 in 5-year design rainfall, Gauge two was the 23 April 2019 rainfall, and Gauge three was the 12 April 2022 rainfall. Each rain gauge was assigned a time series on PCSWMM, which was linked to the corresponding rainfall hydrograph.

Phase 6: Simulation and Running of the Model

Step 1: The rain gauge to be evaluated was assigned to the sub-catchments in the model. The model simulation time was set to one hour.

Step 2: The completed model was run. If the model failed, the errors were rectified until the model was successful.

Step 3: The junctions in the model were rendered to display the charging manholes.

Step 4: The model's final results, included junctions, pipes, channels, and sub-catchments, were exported as shapefiles for analysis on ArcMap. The model was packaged for ease of reference and accessibility to other relevant parties.

4.6 Data Analysis

The data was examined to ensure that accurate conclusions could be drawn. The pre- and post-development flows were analysed using Microsoft Excel. A spreadsheet was created for the rational method. The output peak flows from the hydrological analysis were assessed as pre- and post-hydrographs. The results of the computational data were exported to ArcMap to evaluate patterns, similarities, and differences to generate findings. The output data from infrastructure visual assessment sheets was recorded into ArcMap as a visualisation tool to generate findings. Sufficient data was obtained in terms of quantity and quality to draw reasonable conclusions.

4.6 Validity and Reliability

Validity refers to ensuring that the measurement being utilised accurately measures the variable to be assessed, while reliability ensures that the method used generates consistent results (Cook 2016). To ensure correlation between computational data and on-site data, eThekwini Municipality stormwater infrastructure GIS data 2021/2022 was used for the hydraulic model and generation of the inspection maps. The rainfall data was provided by rainfall gauges within the catchment area, which are accessible on the eThekwini Municipality data feeds website. The data is sufficient in terms of both quality and quantity to draw reasonable and reliable conclusions for the analysis.

4.7 Ethical Considerations

The study conformed with the Durban University of Technology's ethical guidelines and standards for ethics category 1, as it involved research on data or material in the public domain and the use of existing collections of data or records that contain only unspecified and unrecognisable data about human persons.

CHAPTER FIVE: RESULTS AND DISCUSSION

5.1 Results from Specific Objective 1

To evaluate the effects of urbanisation on the catchment's drainage system.

A hydrological analysis was used to compute the peak flow for pre- and post-development scenarios. This was done for each of the four sub-catchments within the Lower Isipingo Catchment. This hydrological analysis was performed using Google Earth satellite imagery to quantify the volumetric flow rate of surface water draining from the catchment area over a 20-year period. The Rational Method was followed (Equation 1 to Equation 7).

5.1.1 Isipingo 1

In 2002, the land use classifications in Isipingo 1, as shown in Figure 48, revealed a complex and multidimensional environment that mirrored the area's distinct socioeconomic dynamics and geographical characteristics. The residential zones were principally defined by rural townships, which were distinguished by a design of dispersed dwelling units located in the upper catchment region. This structure encouraged a sense of community while providing plenty of green space. The upper catchment region also included a wastewater treatment facility. This facility was critical in maintaining the catchment's sanitation and ensuring that nearby residents had access to basic services.

In contrast, the lower catchment region was dominated by single residential units with low-density development and was dominated by a variety of minor industrial activities, including a metal scrap yard. This industrial presence created job opportunities for locals and helped to boost the area's economy. The lower catchment also hosted a civic zone, which featured the Isipingo library, an important community resource that provides educational resources, activities, and a forum for public participation.

Figure 48: Isipingo 1 Pre-Development Satellite Imagery - 4 November 2002

Source: Google Earth Copernicus Land Satellite

The internal roads in the area are easily visible, forming an organised network that enables mobility and access across the catchment. The open regions around these roads, on the other hand, feature a diversified environment that includes a mix of dense bush and cultivable land. The soils in this area are semi-permeable, allowing some water infiltration, which benefits groundwater recharging. However, impermeable surfaces exist, such as paved roads and buildings, which prevent water from reaching the ground and can result in higher surface runoff during rainstorm events. The average slope is 7%, suggesting a modest slope that can affect water flow and drainage patterns. This gradient is important to the area's hydrology because it influences how water travels over the landscape and how soon it reaches water bodies.

Prior to any major development activity, the runoff coefficient for the catchment region was determined to be 0.48. This number indicates that 48% of the entire catchment area has been altered or modified in some form, resulting in alterations in natural hydrological processes. The runoff coefficient is an important parameter for determining how much rainfall will be converted to surface runoff, and a value of 0.48

indicates a significant level of development that can affect water management strategies, flood risk assessments, and environmental sustainability efforts in the region. Overall, the land use classifications in Isipingo 1 in 2002 demonstrated a well-balanced mix of residential, industrial, and civic areas, reflecting the area's development objectives and people's demands. The mix of rural townships, low-density housing, critical infrastructure, and community amenities formed a dynamic environment that supported the livelihoods and quality of life of Isipingo 1's residents. Refer to Appendix A: Calculation of Runoff Coefficient Isipingo 1.

Figure 49 depicts Isipingo 1's land use classifications, which showed substantial concentration in 2022, showing a dramatic transition in the area's urban environment. Residential neighbourhoods have gotten more crowded as a result of population growth and increased demand for homes. This density is most noticeable in suburban areas. These new buildings serve a varied clientele, giving families and individuals more alternatives for affordable living. In addition to suburban development, the construction of new low-income housing inside rural townships has been critical in meeting the requirements of economically disadvantaged inhabitants. This effort not only tackles housing shortages but also promotes community integration and improves living circumstances for people in need. The establishment of a light industrial zone near the central business district exemplifies the region's changing economic environment. This zone promotes local companies and creates job opportunities, which contributes to Isipingo 1's general economic strength.

However, the quick pace of progress has presented considerable obstacles. Internal highways, which were formerly clearly demarcated, have become more indistinguishable as a result of excessive building and a lack of effective urban planning. This has led to traffic congestion. Furthermore, the number of open spaces has decreased significantly, generating concerns about the reduction of green spaces that are critical to reducing high surface runoff volumes.

Figure 49: Isipingo 1 Post Development Satellite Imagery – 12 October 2022
Source: Google Earth Copernicus Land Satellite

The average slope has lessened as a result of the emergence of various platforms developed expressly to accommodate new home complexes. This change in the environment has resulted in an estimated runoff coefficient of 0.65, indicating that 65% of the overall catchment area has been significantly transformed as a result of these changes. This data is especially interesting since it demonstrates the level of urbanisation in the region. Furthermore, this transition has resulted in a 17% loss in accessible open space within the catchment region. This loss is directly related to the continuous and relentless process of urbanisation, which involves the conversion of previously undeveloped land into residential and commercial structures. As urbanisation progresses, the consequences for the environment and local ecosystems become more apparent, generating worries about the loss of green space, biodiversity, and general quality of life for citizens. Refer to Appendix A: Calculation of Runoff Coefficient Isipingo 1. Table 18 details the summary results of the Rational Method for Isipingo 1.

In conclusion, while Isipingo 1's land use zones have expanded and evolved significantly over time, this transition has resulted in a complex collection of difficulties. Rapid land use changes have resulted in increasing population density, increase in infrastructure and development, and environmental degradation. These difficulties need a thorough examination of the present urban landscape, taking into consideration the community's different needs, the conservation of natural resources, and the incorporation of sustainable practices.

Table 18: Summary of Rational Method for Isipingo 1

RUNOFF COEFFICIENT							
PRE				POST			
0.48				0.65			
RUNOFF – Q							
PRE				POST			
	TIME	*Q(m^3/s)*	*Q(ℓ/s)*		*TIME*	*Q(m^3/s)*	*Q(ℓ/s)*
START	0	0.00	0.00	START	0	0.00	0.00
PEAK	15	0.00008	0.08	PEAK	10	0.00012	0.12
END	30	0.00	0.00	END	20	0.00	0.00

From 2002 to 2022, the flow rate increased significantly, going from 0.08 ℓ/s to 0.12 ℓ/s. This adjustment significantly increases runoff flow, mirroring a trend in urban growth. Minor changes in the density of residential units in Isipingo 1 have contributed to the increased flow rate. These alterations have had a cumulative impact, resulting in an enhanced flow of 0.04 ℓ/s. This shows that as residential areas have become more densely populated, surface runoff flow rates have increased. Figure 50 is the hydrograph that exhibits this data.

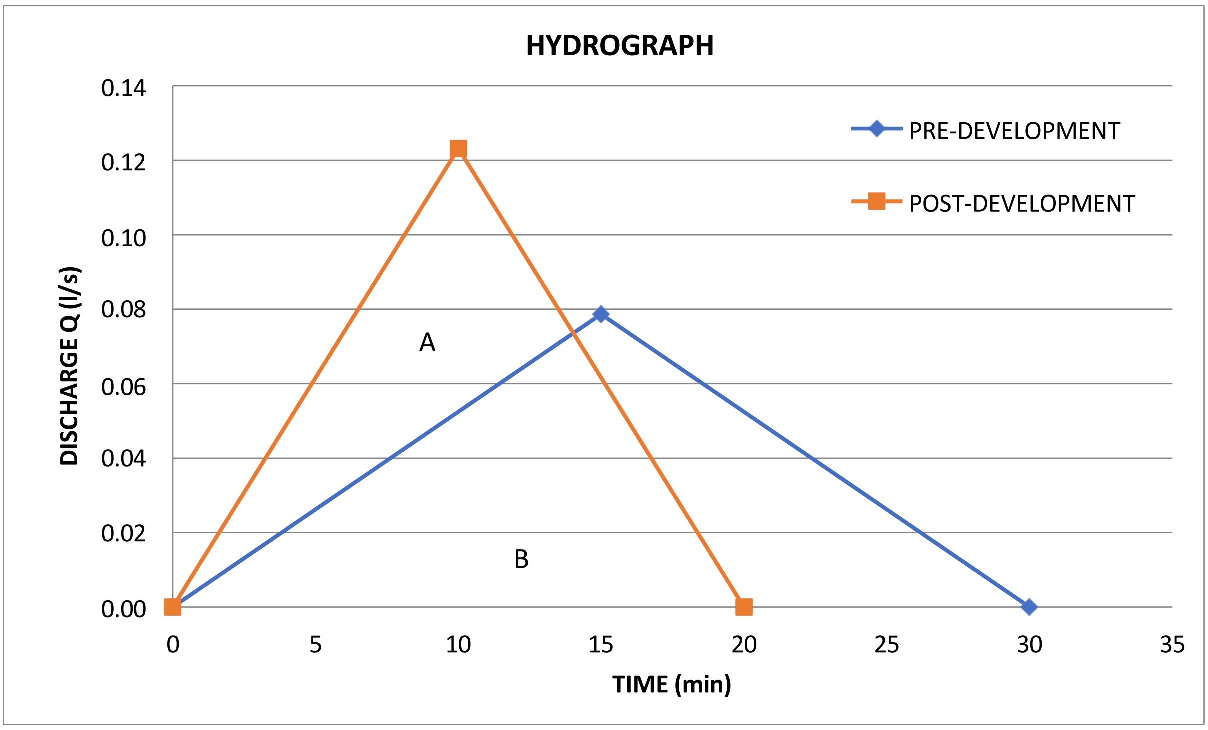


Figure 50: Isipingo 1 Hydrograph.

Figure 50 is the hydrograph which shows how the flow rate changed throughout the assessed 20-year period. This graph is an excellent tool for understanding the link between urbanisation and surface runoff flow dynamics. This graph not only shows the increased trend in runoff flow rates, but it indicates the reduction in concentration time. By evaluating the hydrograph, one can obtain insight into how urban development density affects catchments, which can be used to drive future planning and management methods for sustainable urban growth.

The method utilised for estimating the approximate storage involved a detailed analysis of the hydrograph in Figure 50, which represents both pre-development and post-development conditions. The following method was used to calculate the approximate storage: area under post-development hydrograph (area A) - area under pre-development hydrograph (area B). This analysis revealed that the storage capacity pre-development was 44.13 litres. In contrast, with post-development, the storage capacity expanded dramatically to 73.90 litres. This modification resulted in net runoff storage of 29.77 litres, indicating a significant increase in surface runoff.

5.1.2 Isipingo 2a

In 2002, the land use classifications in Isipingo 2a are as shown in Figure 51. The residential zones were primarily defined by township units situated in the upper catchment region. Such township units are often housing structures that offer necessary shelter for low- to middle-income households. In contrast, the central region of Isipingo 2a was characterised by suburban single-family dwellings, indicating a different demography and lifestyle. Furthermore, the upper catchment area was not only residential; it also housed two major educational institutions. Mangosuthu University of Technology, a well-known higher education school, providing a variety of technical and vocational programs. In addition to the university, Umlazi Comtech High School served as a vital educational facility for secondary education, catering to the youth of Isipingo 2a and surrounding areas.

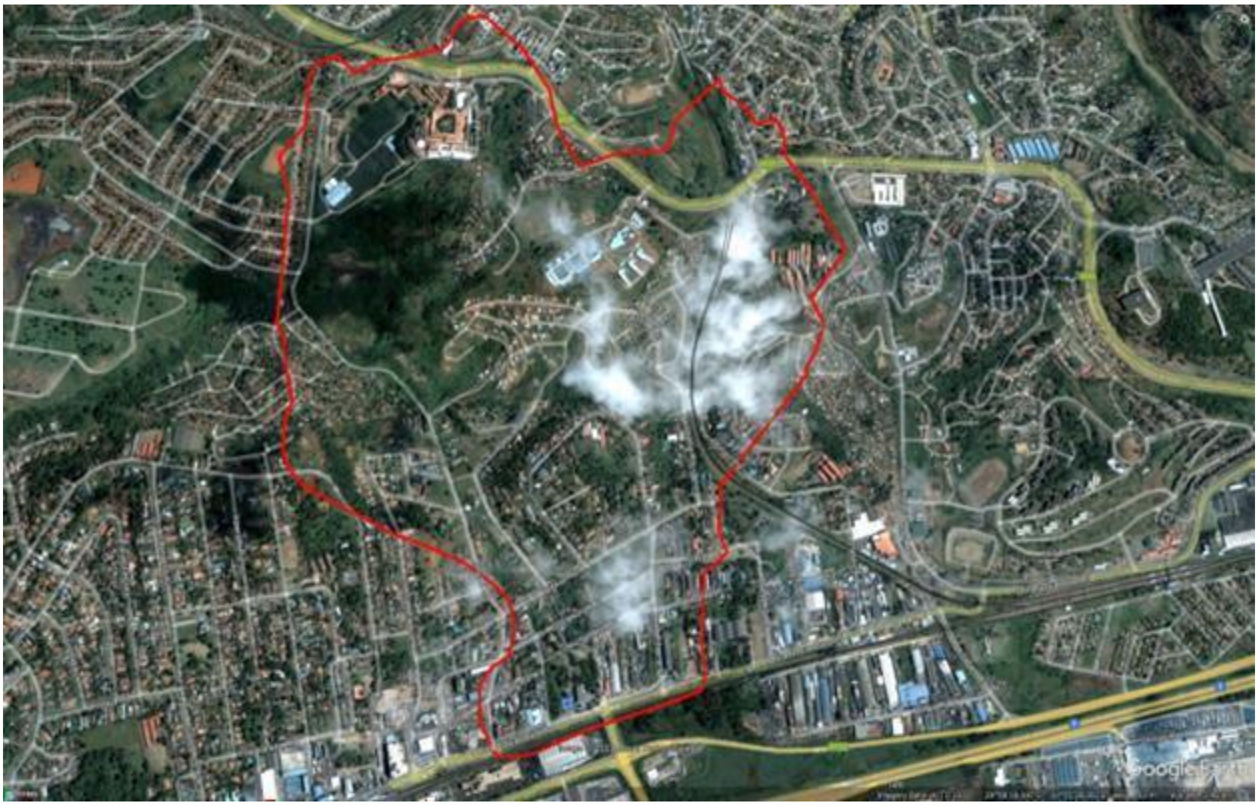


Figure 51: Isipingo 2a Pre-Development Satellite Imagery - 4 November 2002
Source: Google Earth Copernicus Land Satellite

The commercial district was strategically positioned in the lower catchment area, acting as a centre for a broad mix of businesses, offices, shops and retail enterprises catering to the requirements of the local population of Isipingo 2a and adjacent areas. The open areas that surrounded the commercial zone stood out against the undeveloped land.

These regions consisted of a mix of dense bush and cultivable land. The soils in this area were mostly permeable and semi-permeable, which allowed for efficient soil infiltration and drainage. However, there were certain portions of impermeable pavement, notably in the commercial zone, that reduced infiltration and increased surface runoff.

The developed area was minimal, while there was a vast amount of open area. The average gradient within the catchment was 7%, suggesting a mild slope. The runoff coefficient was calculated as 0.50. This indicated that 50% of the catchment area had been developed. The runoff coefficient is an important metric in hydrology because it measures the fraction of rainfall that becomes surface runoff. A value of 0.50 suggested a moderate amount of impermeable surfaces, which would have influenced the catchment's hydrological dynamics.

Figure 55 depicts a complete overview of the land use zones in Isipingo 2a, indicating a significant concentration of varied land uses. Residential neighbourhoods in this region have seen significant growth in population density, indicating an increasing need for housing. This increase in housing units mirrors larger urbanisation trends, as more individuals and families seek homes in suburban areas, resulting in a more economically active area. Informal settlements have been increasingly prevalent, particularly in the area between Mangosuthu University, Comtech High School, the rural township, and the surrounding light industrial zone near the CBD. These informal settlements are frequently formed in response to an urgent demand for inexpensive housing, and their concentration in this particular region indicates a considerable inflow of inhabitants seeking closeness to educational institutions and job prospects. This phenomenon highlights the issues that come with urban growth, such as the need for enough infrastructure and services to sustain the growing population.

Figure 52: Isipingo 2a Post Development Satellite Imagery – 12 October 2022
Source: Google Earth Copernicus Land Satellite

As immense development has occurred over time, the area's internal roads have become more difficult to distinguish. The growth of urban development has resulted in a significant decrease in open areas. As a result of this development, the land's average gradient has dropped to 6%. This shift is mostly due to the development of additional platforms and structures to meet the expanding demands of the urban environment. Furthermore, the area's hydrological features have changed dramatically. The estimated runoff coefficient, which measures the fraction of rainfall that becomes surface runoff, was calculated to be 0.60. This statistic indicates that 60% of the catchment area has been developed, implying that a significant percentage of the land has been converted from its natural condition to impermeable surfaces such as roads, and buildings. This shift has resulted in a 10% loss in open space within the catchment, demonstrating the continued influence of urbanisation on the environment. Refer to Appendix A: calculation of runoff coefficient Isipingo 2a. Table 19 details the results summary of the Rational Method for Isipingo 2a.

Table 19: Summary of Rational Method for Isipingo 2a

RUNOFF COEFFICIENT							
PRE				POST			
0.50				0.60			
RUNOFF – Q							
PRE				POST			
	TIME	*Q(m^3/s)*	*Q(ℓ/s)*		*TIME*	*Q(m^3/s)*	*Q(ℓ/s)*
START	0	0.00	0.00	START	0	0.00	0.00
PEAK	15	0.00006	0.06	PEAK	10	0.00008	0.08
END	30	0.00	0.00	END	20	0.00	0.00

The flow has increased from 0.06 ℓ/s to 0.08 ℓ/s in 20 years from 2002 to 2022. This shift reflects an increase of 0.02 ℓ/s, which is attributable to a variety of urbanisation variables that have impacted the catchment. Changes in residential unit density are a substantial contributor to this increase. As the area's population has risen, the number of residential units has gradually increased. In addition to residential development, there have been advances in the business sector. The opening of new businesses and commercial facilities has also contributed to the higher flow rate. The hydrograph is shown on Figure 53 which illustrates this data.

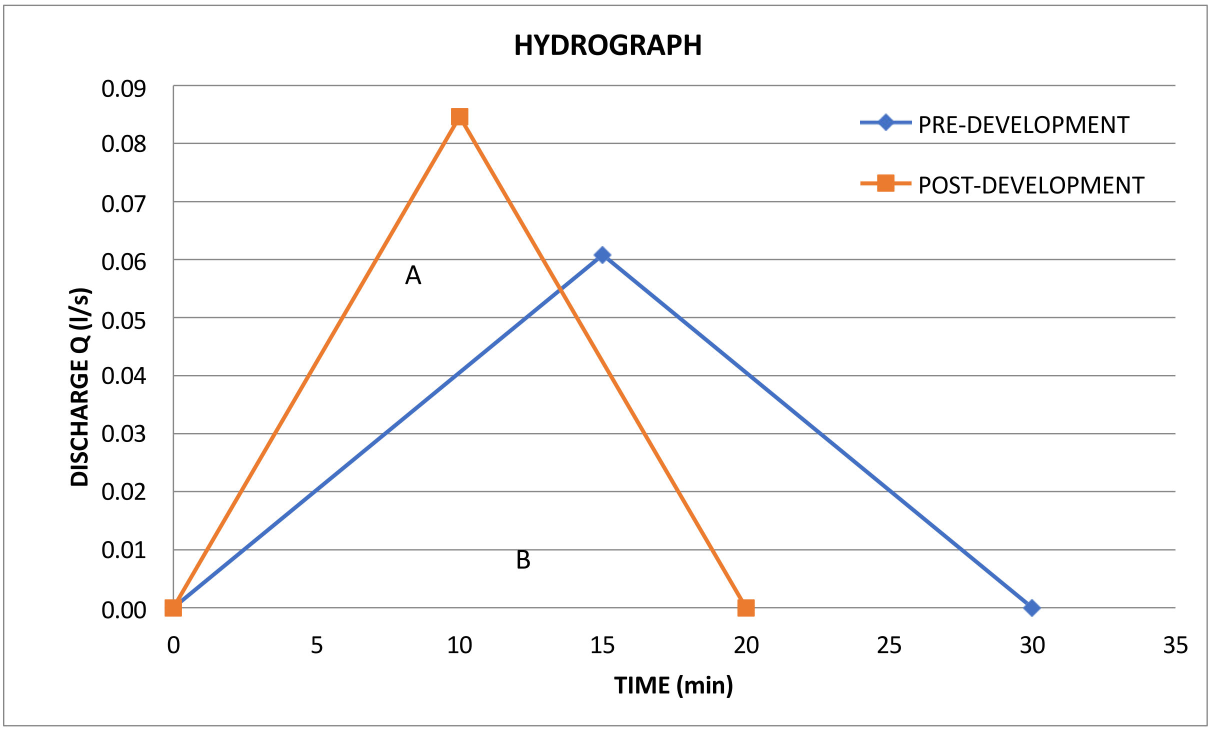


Figure 53: Isipingo 2a Hydrograph.

Figure 53 is the hydrograph which shows how the flow rate varies during the pre- and post-development years. This graph not only shows the increased trend in surface runoff flow rate but also depicts the reduction in concentration time. By examining the hydrograph, one may acquire insights into the link between population increase, business expansion, and surface runoff flow dynamics. The following method was used to calculate the approximate storage: area under post-development hydrograph (area A) - area under pre-development hydrograph (area B). Therefore, the approximate pre-development storage taken from the graph is = 32.90 litres and the post-development storage is 50.79 litres, which is a runoff storage increase of 17.89 litres. This increase is the result of urban growth which causes more surface runoff.

5.1.3 Isipingo 2b

Figure 54 depicts the land use zones in Isipingo 2b in 2002, which reflect a diversified urban landscape. The catchment included a suburban residential zone. A small CBD development is near the residential zone, strategically positioned along the railway line at the area's lower end. This CBD operated as a focus for local businesses and services, giving inhabitants easy access to stores, businesses, and other necessities.

Internal streets in the suburban area were well-demarcated. These roads were intended to handle both automobile and pedestrian traffic, including walkways to promote safe and active commuting.

In addition to residential and commercial sectors, Isipingo 2b was supplemented with green spaces, which were filled with lush vegetation, such as trees, bushes, and manicured gardens. The availability of parks and natural spaces allowed for runoff infiltration.

Figure 54: Isipingo 2b Pre-Development Satellite Imagery - 4 November 2002
Source: Google Earth Copernicus Land Satellite

Overall, the land use zones in Isipingo 2b in 2002 exhibited a balanced approach to urban planning, combining residential, commercial, and green spaces to foster a lively and sustainable community. The size of the developed region corresponds to the amount of undeveloped land, demonstrating a clear link between development and the remaining natural environment. The average gradient within the catchment is 5%, which has a substantial impact on surface runoff and drainage patterns. This gradient is mostly due to the existence of residential and commercial structures, which modify the natural terrain and influence how infiltration and diverted in the region.

The catchment's pre-development runoff coefficient was calculated to be 0.59. This coefficient is an important statistic in hydrology since it represents the percentage of rainfall that becomes surface runoff. A runoff coefficient of 0.59 implies that about 59% of the catchment area contributes to surface runoff. This statistic indicates that a portion of the catchment was still in its natural form, allowing for infiltration of stormwater.

The land use zones of Isipingo 2b, as shown in Figure 55, were significantly concentrated in 2022, demonstrating the area's urban growth. Residential areas have seen a significant rise in population density, owing to a spike in housing units in the suburbs. This increase may be ascribed to a variety of causes, including an inflow of new people looking for affordable housing and the expansion of local facilities, which make the region more appealing to both families and individuals. In addition to the residential development, there has been a significant surge in development in the central business area through the growth of new business establishments, office spaces, and retail stores, resulting in a thriving economic climate. The expansion of the CBD not only created job possibilities but also improved the general accessibility of services for residents.

The internal roads within Isipingo 2b are now plainly visible as a result of the dense construction and continuous urban growth. Increased traffic flow and connectivity across zones have made transportation simpler for both residents and companies. However, this expansion has resulted in a significant reduction of open green areas, which were formerly a distinguishing characteristic of the catchment in 2002.

Figure 55: Isipingo 2b Post Development Satellite Imagery – 12 October 2022. Source: Google Earth Copernicus Land Satellite

The calculated post-development runoff coefficient for the Isipingo 2b catchment is 0.69. This statistic indicates that 69% of the catchment area has been developed, which has important consequences for hydrological behaviour. Increased impermeable surfaces, such as roads, buildings, and other infrastructure, result in more runoff during rainfall events due to reduced soil infiltration. This urban development has resulted in a 10% loss in open space within the catchment. Open places, such as parks, fields, and other green spaces, are critical for absorbing stormwater and decreasing runoff. The loss of these places due to urban development can heighten flooding hazards. Appendix A: Calculation of Runoff Coefficient Isipingo 2b provides a thorough overview of how the runoff coefficient was calculated. Table 20 also includes a summary of the Rational Method's results for the Isipingo 2b catchment. This table summarises critical factors, such as peak flow rates, and time of concentration.

Table 20: Summary of Rational Method for Isipingo 2b

RUNOFF COEFFICIENT							
PRE				POST			
0.59				0.69			
RUNOFF – Q							
PRE				POST			
	TIME	*Q(m³/s)*	*Q(ℓ/s)*		*TIME*	*Q(m³/s)*	*Q(ℓ/s)*
START	0	0.00	0.00	START	0	0.00	0.00
PEAK	15	0.00003	0.03	PEAK	10	0.00004	0.04
END	30	0.00	0.00	END	20	0.00	0.00

The flow has increased from 0.03 ℓ/s to 0.04 ℓ/s in a 20-year period from 2002 to 2022. Minimal developmental changes have seen an increase in the flow of only 0.01ℓ/s, revealing underlying changes in the catchment characteristics. The rise is mostly due to developmental changes in the density of residential units in the catchment. Furthermore, the expansion of the CBD has contributed to this increase. Figure 56 is the hydrograph that represents this data, which shows how the flow varies during 2002 and 2022.

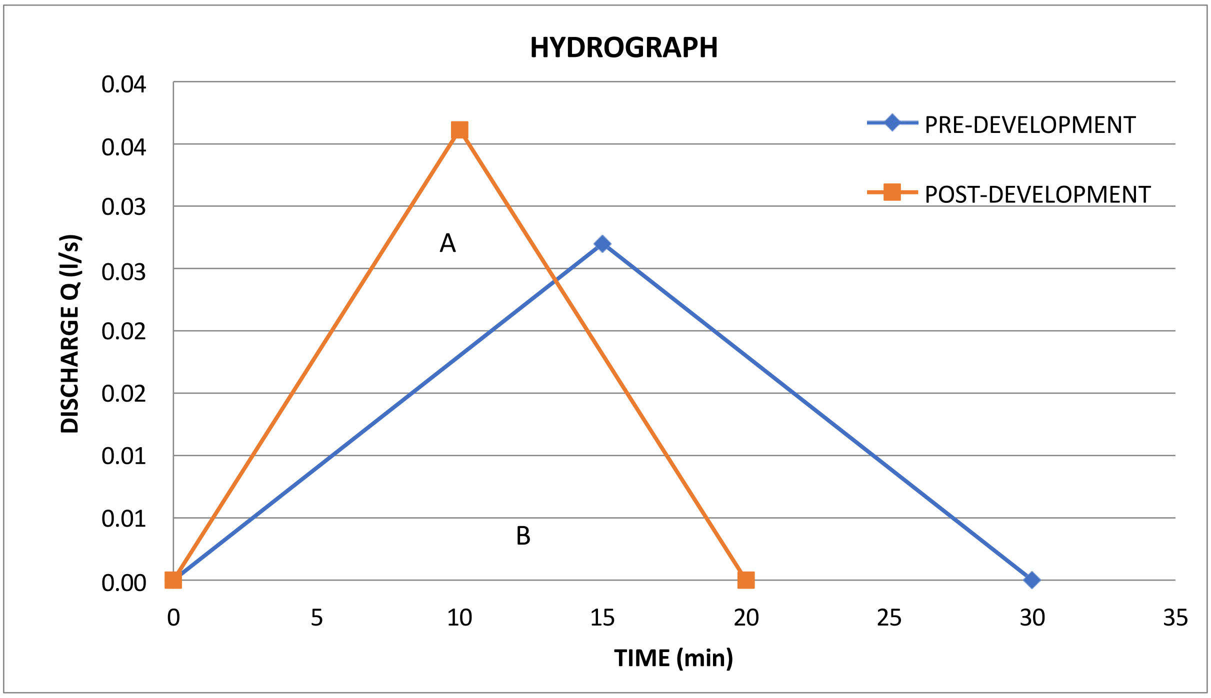


Figure 56: Isipingo 2b Hydrograph.

This graph not only shows the rise in flow over 20 years but also acts as a useful tool for understanding the larger effects of urban growth on surface runoff flow. This graph not only shows the increased trend in runoff flow rates, but it indicates the reduction in concentration time. In 2002, the catchment was well-developed, resulting in an insignificant flow differential of 0.01 ℓ/s. The following method was used to calculate the approximate storage: area under post-development hydrograph (area A) - area under pre-development hydrograph (area B). Therefore, the approximate pre-development storage from the graph is = 14.42 litres and the post-development storage is 21.69 litres which is a runoff storage increase of 7.27 litres, this is due to the slight increase in urban development and hardened areas.

5.1.4 Isipingo 2c

Figure 57 depicts Isipingo 2c's land usage in 2002, which revealed a complex and multidimensional environment reflecting the area's socioeconomic dynamics. The catchment has a designated light and heavy industrial sector that acts as a hub for a variety of manufacturing and production operations. This industrial zone consisted of factories, warehouses, and logistical facilities that boosted the local economy and provided locals with job opportunities and a suburban residential zone that the lagoon. The residential had single-family homes, townhouses, and apartment buildings, resulting in a community-oriented setting. The proximity to the lagoon increased the residential zone's visual and recreational value.

In addition to the established industrial and residential zone, Isipingo 2c witnessed the formation of an informal settlement near the suburban residential zone. This informal community was made up of informal dwellings and reflected the larger socioeconomic challenge such as a lack of access to permanent housing, and inadequate infrastructure. The presence of this informal community underlined the area's continuing urbanisation and demographic transitions, as well as the need for improved housing options and social services to serve the rising population.


Figure 57: Isipingo 2c Pre- Development Satellite Imagery - 4 November 2002
Source: Google Earth Copernicus Land Satellite

The industrial zone at the centre of the catchment is highly concentrated with very minimal green spaces. The N2 is identifiable, as are the internal roads in the industrial zone and residential area. The vegetal growth is composed of cultivable land and sparse bush around the estuary area. The catchment is highly developed. Due to the extensive impervious surfaces at the centre of the catchment, the slope is only 2%. This can also be attributed to the historic wetland topography and the Isipingo estuary in the lower catchment. The pre-development runoff coefficient calculated is 0.66, which implies that 66% of the catchment area was developed in 2002.

The industrial zone in the heart of the catchment has a high density of development, with a primarily urbanised environment and few accessible open spaces accessible. This concentration of industrial activity is heightened by the presence of the N2 highway, a key transportation artery that aids the flow of products and people, effectively connecting the industrial sector to larger regional networks. In addition to the N2, a network of internal roads weaves through both the industrial and residential sectors, providing vital access.

The vegetation in this intensively developed area is mostly made up of cultivable land, as well as sparse bushes along the estuary. This low vegetation cover demonstrates the influence of urbanisation on the natural environment since the catchment has seen substantial development over time, altering what was previously a more diversified biological landscape. The central section of the catchment is noted for its predominance of impermeable surfaces, such as roads, houses, and other structures, which drastically affect the area's natural hydrology. The low slope of only 2% in this location adds to the difficulties connected with water drainage and runoff control. This relatively flat terrain may be traced back to the area's former wetland ecosystem, notably the Isipingo estuary at the catchment's lower end.

In terms of hydrological impact, the pre-development runoff coefficient for the catchment region was calculated to be 0.66. This shows that by 2002, nearly 66% of the watershed area had been developed. The high runoff coefficient represents the higher amount of surface runoff caused by the large impervious surfaces, which can worsen floods and degrade water quality in the estuary and nearby water bodies. Overall, the catchment area's transition from a more natural wetland to a more built environment highlights the region's intricate interplay of urbanisation, hydrology, and ecology.

In 2022, the land use of Isipingo 2c, as depicted in Figure 58, has been a significant surge in development in the industrial area through the growth of new factories, warehouses, and establishments, resulting in a thriving economic climate. The expansion of the industrial zone not only created job possibilities but also increased the need for development which led to heavily concentrated suburban residential zones and informal settlements. The N2 highway is a major transportation artery and the internal roads in the industrial zone and residential area are still clearly visible.

Figure 58: Isipingo 2c Post Development Satellite Imagery – 12 October 2022. Source: Google Earth Copernicus Land Satellite

The existence of green open areas inside the industrial zone has grown more concealed as a result of continued industrial growth. As industries and warehouses expand, previously visible pockets of greenery are consumed by concrete, bricks and steel, reducing the natural environment that formerly defined the area. This tendency is not unique; it is replicated in the nearby informal settlement, where green spaces that originally served as a barrier and recreational space for people have considerably decreased. As the settlement's population grew, so did the number of informal dwelling units, resulting in a congested and more urbanised atmosphere that encroached on any remaining open spaces.

The calculations found that the post-development runoff coefficient for this catchment was 0.73. This graphic shows that 73% of the catchment area has been developed, demonstrating how the landscapes have been turned into urban infrastructure. This transition has not been without costs; it has resulted in a 7% reduction in the quantity of open space accessible within the catchment. This loss of green space is directly related to the relentless process of urbanisation, which emphasizes growth and expansion over the preservation of natural landscapes. Refer to Appendix A: Calculation of Runoff

Coefficient Isipingo 2c. Table 21 summarises critical factors, such as peak flow rates, and time of concentration.

Table 21: Summary of Rational Method for Isipingo 2c

RUNOFF COEFFICIENT							
PRE				POST			
0.66				0.70			
RUNOFF – Q							
PRE				POST			
	TIME	*Q(m^3/s)*	*Q(ℓ/s)*		*TIME*	*Q(m^3/s)*	*Q(ℓ/s)*
START	0	0.00	0.00	START	0	0.00	0.00
PEAK	15	0.0002	0.24	PEAK	10	0.00030	0.30
END	30	0.00	0.00	END	20	0.00	0.00

The flow has increased from 0.24 ℓ/s to 0.30 ℓ/s in 20 years from 2002 to 2022. This shift reflects an increase of 0.06 ℓ/s, which is attributable to a variety of urbanisation variables that have impacted the catchment. Changes in the industrial zone and residential density are substantial contributors to this increase. As the area's population has risen, the number of residential units has gradually increased. In addition to residential development, there have been advances in the industrial sector. The opening of new factories and manufacturing facilities has also contributed to the higher flow rate. The hydrograph is shown on Figure 59 which illustrates this data.

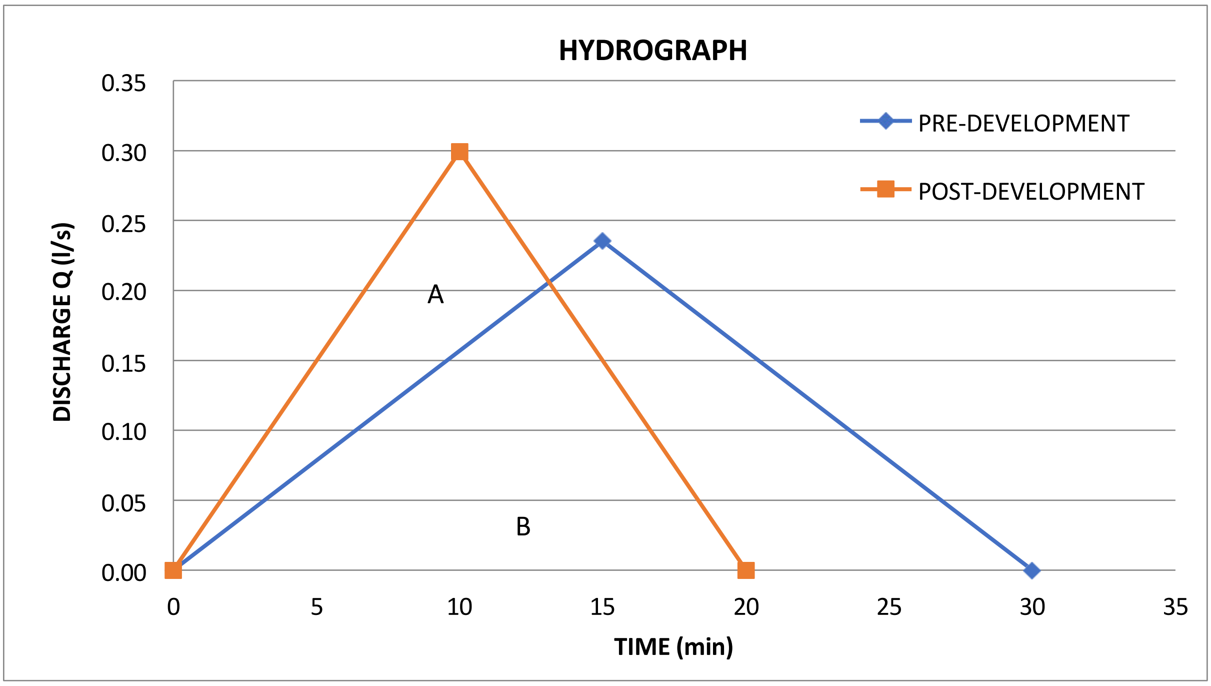


Figure 59: Isipingo 2c Hydrograph.

The method used to determine the estimated storage was an approach that evaluated the hydrograph showing both pre-development and post-development circumstances. The following method was used to calculate the approximate storage: area under post-development hydrograph (area A) - area under pre-development hydrograph (area B). Therefore, the approximate pre-development storage from the graph is = 123.44 litres and the post-development storage is 179.53 litres, which is a runoff storage increase of 56.09 litres. The contrast between these pre- and post-development results shows clearly how urban growth affects runoff storage capacity. This depicts the amount of water that would have been retained or absorbed in natural landscapes.

5.1.5 Discussion

The results from objective 1 are summarised on Table 22.The flow (Q) percentage increase detailed on Table 22 was determined using Equation 9.

Equation 9

$$Q\ increase = \left(\frac{Post\ Development\ Q - Pre\ Development\ Q}{Pre\ Development\ Q}\right) x\ 100$$

Table 22: Summary of Rational Method Results

Catchment	Pre Dev Coefficient	Post Dev Coefficient	Pre Dev Q (ℓ/s)	Post Dev Q (ℓ/s)	Q Increase (%)
Isipingo 1	0.48	0.65	0.08	0.12	50
Isipingo 2a	0.50	0.60	0.06	0.08	33
Isipingo 2b	0.59	0.69	0.03	0.04	33
Isipingo 2c	0.66	0.70	0.24	0.30	25

Isipingo 1 has undergone the highest urbanisation due to the highest increase in runoff flow over the assessed 20-year period from 2002 to 2022, going from 0.08 ℓ/s to 0.12 ℓ/s as shown in Table 21 and illustrated in Figure 48 and Figure 49. This is caused by the establishment of a light industrial zone near the central business causing an increase in population resulting in denser residential neighbourhoods in the suburbs, and new low-income housing inside rural townships. This exemplifies the catchment economic growth necessitating the need for development. However, the number of open spaces has decreased significantly ultimately increasing surface runoff volumes.

Isipingo 2a and Isipingo 2b have undergone moderate urbanisation with a 33% increase, the major noted variation within the catchment characteristics is the increase in density in the residential zones. In Isipingo 2a the flow has increased from 0.06 ℓ/s to 0.08 ℓ/s in 20 years from 2002 to 2022. This shift reflects an increase of 0.02 ℓ/s as shown in Table 21 and illustrated in Figure 51and Figure 51. There are extremely dense residential zones with additional units in the suburban area and concentrated informal settlements between Mangosuthu University and Comtech High School. Both the rural township and surrounding light industrial zone near the CBD have also become highly concentrated in both catchments.

In Isipingo 2b the flow has increased from 0.03 ℓ/s to 0.04 ℓ/s in a 20-year period from 2002 to 2022. Minimal developmental changes in the CBD and significant increase in suburban residential areas have seen an increase in the flow of only 0.01ℓ/s shown in Table 21 and illustrated in Figure 51 and Figure 51. In comparison to Isipingo 2a, the CBD zone in Isipingo 2b was already well established by 2002, and there was not any significant developmental area increase in this zone. This urban shift has resulted in a loss of open green spaces within both Isipingo 2a and 2b catchments, leading to an increase in surface runoff. This demonstrates the continued influence of urbanisation on the natural hydrological processes and the environment.

Isipingo 2c stands out as the region's most developed catchment area, with remarkable flow values reported in both pre-and post-development scenarios as shown in Figure 57 and Figure 57. Despite its great flow capacity, it has the smallest increase in runoff compared to the other catchments. The flow has increased from 0.24 ℓ/s to 0.30 ℓ/s in 20 years from 2002 to 2022 as shown in Table 21. This remarkable phenomenon may be primarily attributed to Prospecton's tremendous expansion of the heavy industrial sector, which began in the 1960s. As industrial facilities were built, they not only changed the terrain but also the hydrological dynamics of the catchment area. Prospecton's industrial growth has had a significant impact on the local environment and community. Furthermore, the increase in population density in the surrounding informal community has exacerbated the problem. As more people moved to the region in quest of job opportunities in the growing industrial sector, the demand for housing increased. This resulted in the spread of informal dwelling units, which encroached on green open spaces along the shore.

The results highlight the trend as noted by Zhang (2016) that raises issues that come with urban growth, as the need for enough infrastructure and services to sustain the growing population caused by the region's changing economic environment. The observed rise in runoff storage in all sub-catchments is directly related to urban development activities, namely the extension of impermeable surfaces like roads, buildings, and parking lots. These impermeable regions prevent water from penetrating the soil, resulting in increased surface runoff during rainy events. As a result, the natural hydrological cycle changes, as mentioned by Chen *et al. (*2021). Urbanised catchments allow more surface runoff to flow straight into drainage systems rather than reducing peak flows by allowing absorption for groundwater recharge (Kauffman *et al.* 2009; Salvadore *et al.* 2015).

The results also support research shown by USEPA (1983) by using hydrographs to provide insights into the link between urban growth, and surface runoff dynamics. For this study, it can be concluded that an increase in urban development increases the surface runoff in urban catchments, which subsequently increases the peak discharges as shown in the hydrographs for each sub-catchment. This highlights that drainage systems cannot be based on stationary data as land use and cover characteristics vary with time as in recent studies by Kleidorfer *et al. (*2014) and Hussain (2022). Their studies have found that drainage systems that were constructed using historic patterns of rainfall are often underperforming due to climate change and a constant increase in urban areas.

This implies that drainage systems need to be upgraded at certain intervals to align with the rate of urbanisation in urban catchments. Further restrictions need to be placed on catchment developed and undeveloped area percentages, which can reduce the constant need to upgrade drainage systems as this can be costly. This can also be used as a strategy to ensure catchment sustainability.

5.2 Results from Specific Objective 2

To determine the extent to which solid waste impacts the drainage system's functionality.

To assess the functionality of the stormwater networks, conditional inspections were conducted on the manholes, inlets, discharge outlets, open channels, and culverts. An inspection photo was taken, with the completion of a visual assessment sheet on the

Safety Culture App. The assessment sheet detailed the following: asset number, accessibility of the asset, any obstructions observed, overall condition of the structure, and general comments observed by the assessor.

Geographic information systems software, ArcMap 10.0, was used for data analysis and maps. The functionality of the structures was categorised as functional, partly functional, and not functional. Functional structures are fully functional without any obstruction, while structures, while structures that appear to obstruct stormwater flow are considered partially functional. Not functional structures are completely blocked with no flow of stormwater. The type of obstruction observed was recorded. The overall condition of structures was marked as good, fair, and poor. Good structures were considered damage-free, and fair structures have visible defects but do not impact the flow of stormwater. Poor structures were completely damaged and impacted the flow of stormwater.

5.2.1 Isipingo 1

Isipingo 1 as shown on Figure 60 and Figure 61 has a total of 403 structures; 229 structures were assessed, while 174 structures were inaccessible. Several variables, including location, type of structure, manhole cover, and the structure's material type, prevented access to the 174 structures. No culverts, canals, or open channels were observed in this catchment.

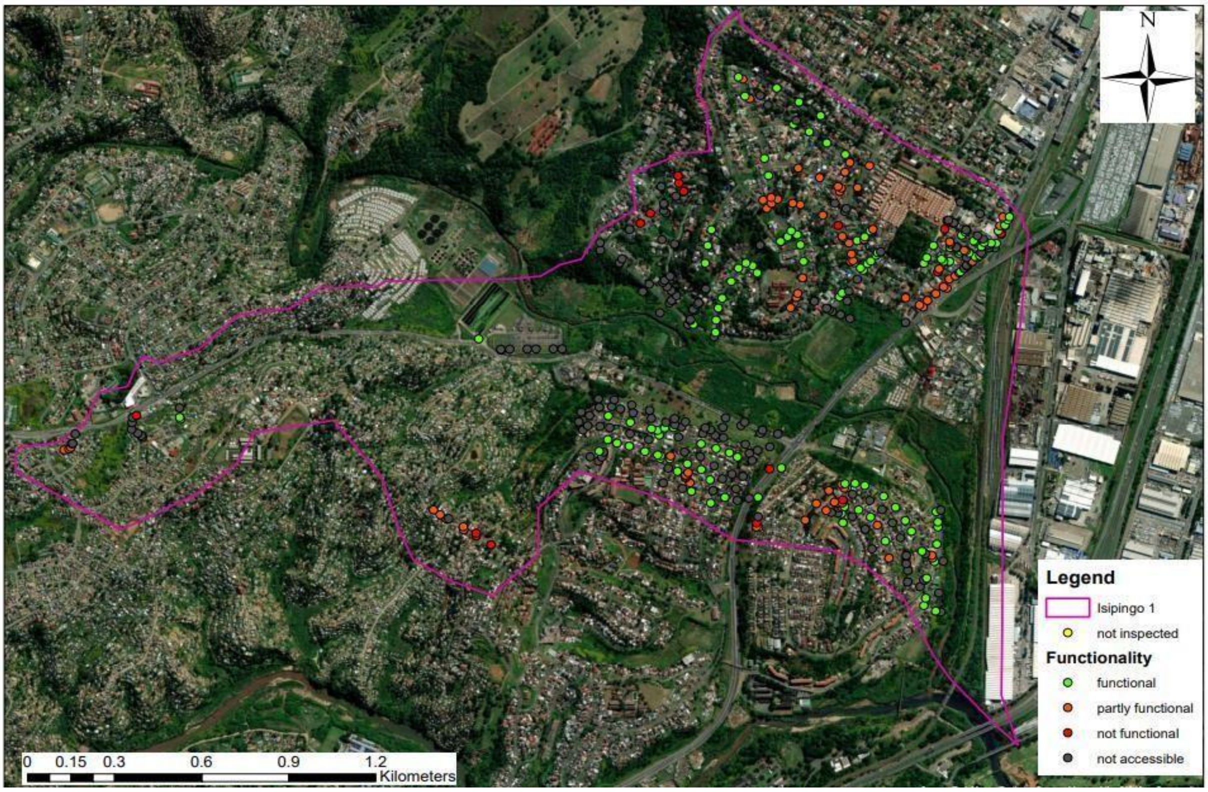


Figure 60: Isipingo 1 functional structures.

Source: (ESRI) ArcMap 10.0 with eThekwini Municipality shapefiles.

The upper catchment's vulnerable areas are in Malukazi Township Road 1 and Asihlenge Place, where structures are partially functioning and hindered by waste and silt. In the Oriental Hills area, partly functioning structures, all of which are silted, were found on Oriental Drive, Strawberry Avenue, and Nertum Road. In the Isipingo CBD residential area, partly functional and blocked structures with waste and silt were located on Sucrose Road, Platt Drive, Marigold Avenue, Protea Road, and Wistaira Road. Conversely, 24 structures in the Malukazi Township and the Isipingo CBD residential area and surroundings were defective and require replacement. Figure 61 details the type of obstruction observed in the structures.

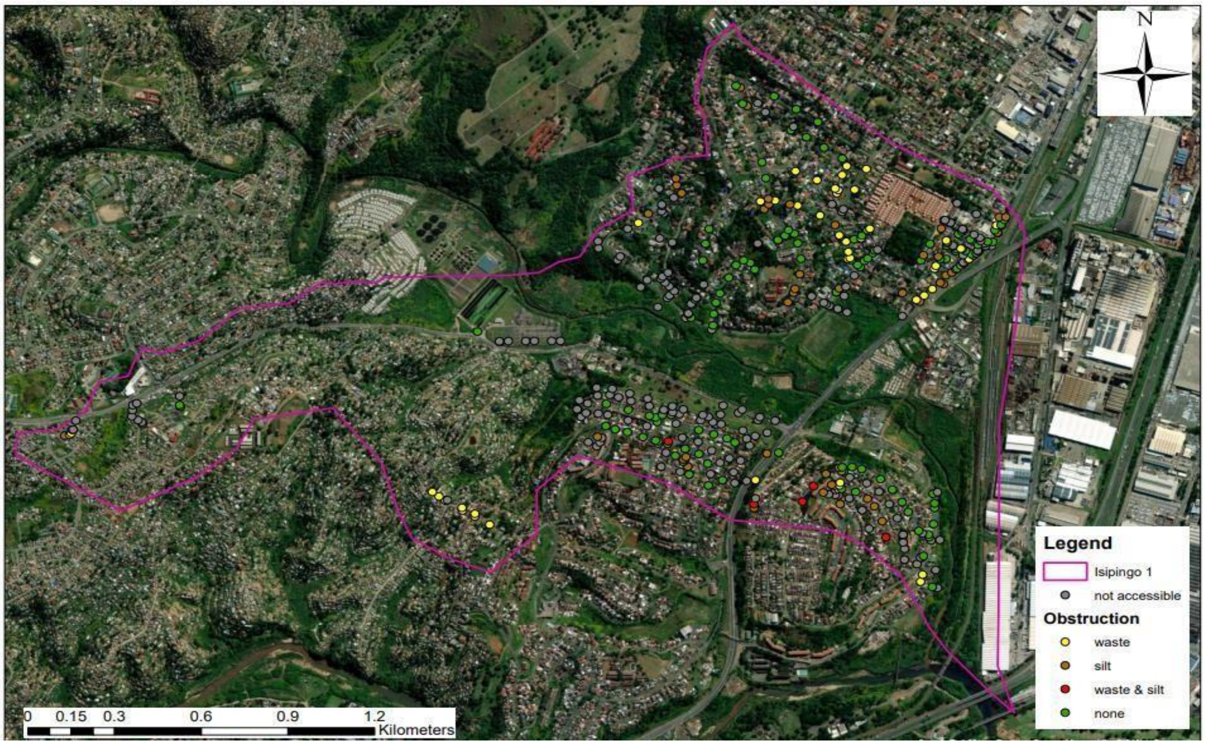


Figure 61: Isipingo 1 obstruction type.

Source: (ESRI) ArcMap 10.0 with eThekwini Municipality shapefiles.

Table 23 presents a thorough summary of the inspection results for Isipingo 1, emphasising the functional condition and structural integrity of the examined structures. A vast majority of the structures assessed, precisely 57%, were classed as functional, suggesting that they are working efficiently and serving their original purpose. In contrast, 35% of the structures were classified as partially functional, implying that, while they may still serve some operational purpose, they are not working optimally and may require maintenance or repairs to improve their usefulness. Alarmingly, only eight percent of the structures were designated as non-functional, indicating that they are now unable to perform their original purpose and may pose safety or operational problems.

The inspection also revealed critical insights into the primary obstructions affecting the functionality of these structures. Waste was identified as the leading obstruction, accounting for 22% of the issues observed. This indicates a significant accumulation of debris that could hinder the proper operation of the structures. Silt was another major concern, representing 23% of the obstructions, which suggests that sediment buildup is also a prevalent issue that could affect drainage and overall structural performance.

Additionally, a combination of waste and silt was noted in 2% of the cases, highlighting instances where both factors are contributing to the functional impairments.

When evaluating the structural condition of the inspected sites, the findings were relatively positive. A majority of 58% of the structures were rated as being in good condition, which implies that they are well-maintained and capable of functioning effectively. Meanwhile, 32% of the structures were assessed as fair, indicating that while they are still operational, they may require some attention to prevent deterioration. However, a concerning 10% of the structures were found to be in poor condition, which raises alarms about their safety and functionality. These structures may necessitate replacement or significant repairs to ensure they can meet safety standards and operational requirements.

Table 23: Isipingo 1 site inspection results

Accessibility		%
Accessible	229	57
Not accessible	174	43
Functionality		%
Functional	131	57
Partly functional	81	35
Not functional	17	8
Obstruction		%
Waste	51	22
Silt	53	23
Waste and silt	5	2
Vegetation	1	0
None	119	52
Condition of structure		%
Good	134	58
Fair	74	32
Poor	24	10

5.2.2 Isipingo 2a

Isipingo 2a on Figure 62 and Figure 63 has a total of 192 structures; 164 structures were assessed, while 28 structures were inaccessible. Several culverts and open channels were observed in this catchment.

Figure 62: Isipingo 2a functional structures.

Source: (ESRI) ArcMap 10.0 with eThekwini Municipality shapefiles.

The upper catchment's vulnerable areas were found at 109406 Street, and 109405 Street in Umlazi, where structures were partially functioning and hindered by waste. Structures located at Sulangeni Road, Ramsunder Road, and Gokul Road in the central catchment were partially functional due to waste. Structures on Ramdas Road are not functional due to silt. Phila Ndwandwe Road, Clarke Road, and Inwabi Road in the Isipingo CBD area were partially functional and blocked with waste and silt. These structures were also defective and need to be replaced. Figure 63 details the type of obstruction observed in the structures.

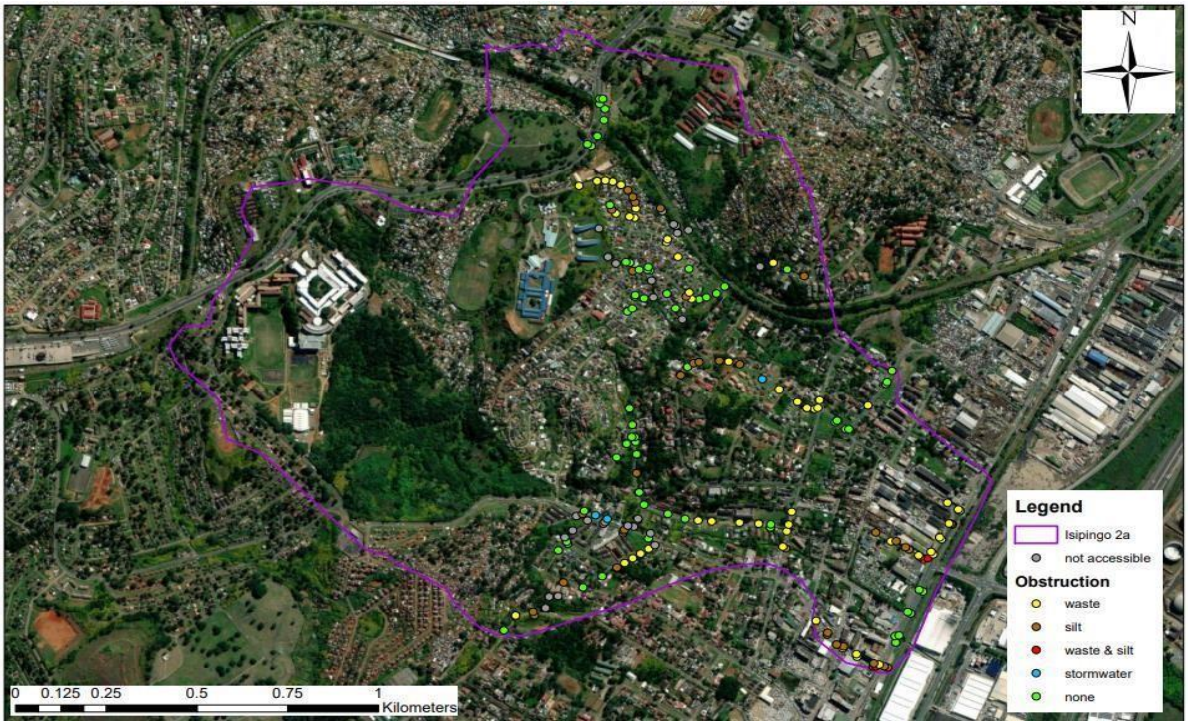


Figure 63: Isipingo 2a obstruction type.

Source: (ESRI) ArcMap 10.0 with eThekwini Municipality shapefiles.

Table 24 summarises the findings from the site assessment at Isipingo 2a. The examination focused on numerous structures in the region, indicating that a sizable proportion, particularly 51%, were considered functioning. This suggests that slightly more than half of the structures are functioning properly, which is a favourable conclusion in terms of infrastructure functionality evaluation. However, the inspection revealed many serious problems that impact the structures' functionality. Waste was the most significant obstruction observed, accounting for 34% of functional difficulties. This indicates that waste accumulation is an important concern that must be addressed in order to improve the general functionality of the structures.

Following waste, silt was recognised as the second biggest obstruction, accounting for 20%. The presence of both waste and silt contributed an extra 2% to the blockages, demonstrating that combined causes have an impact on the structures' functionality. Furthermore, the inspection discovered that only three structures had stagnant stormwater, accounting for barely 1% of the sub-catchment area. While this proportion is low, stagnant water can cause further difficulties, such as structural damage, and should not be ignored.

In terms of the overall condition of the assessed structures, the results were favorable. The majority, 64%, were rated as being in good condition, implying that the infrastructure is well-maintained and functioning at its designed capacity. However, there are still a significant number of structures that require repair. Specifically, 21% were classified as fair, suggesting that while functioning, they may require maintenance or modifications to avoid deterioration. Alarmingly, 18% of the structures were found to be in poor condition, requiring replacement to ensure safety and functionality.

Table 24: Isipingo 2a site inspection results

Accessibility		%
Accessible	164	85
Not accessible	28	15
Functionality		%
Functional	84	51
Partly functional	64	39
Not functional	16	10
Obstruction		%
Waste	55	34
Silt	32	20
Waste and silt	4	2
Stormwater	3	1
None	70	43
Condition of structure		%
Good	106	64
Fair	35	21
Poor	29	18

In conclusion, while the assessment of Isipingo 2a found that the bulk of the structures are operational and in excellent condition, considerable issues remain, notably concerning waste and silt blockages. Addressing these concerns is critical to ensuring the integrity and efficacy of the area's infrastructure.

5.2.3 Isipingo 2b

Isipingo 2b on

Figure 64 and Figure 65 has a total of 279 structures; 220 structures were assessed, while 59 structures were inaccessible. No culverts, canals, or open channels were observed in this catchment.

Figure 64: Isipingo 2b functional structures.

Source: (ESRI) ArcMap 10.0 with eThekwini Municipality shapefiles

The most vulnerable areas with no functional structures were located in Isipingo CBD and surrounding areas at Phila Ndwandwe Road, Police Station Road, Watson Road, Alexandra Avenue, Jadwat Street, Kajee Road, Pardy Road, Church Lane and Thomas Lane. These structures were blocked with waste, silt, and stormwater, they were also in poor condition and required replacement. In the residential area, partly functioning structures were found on Saunders Avenue, James Avenue, Dahlia Place, Jadwat Street, Lotus Road, and Pardy Road, which were either silted or blocked with waste.

Isipingo 2b is the centre of Isipingo CBD, which contains the main shops, offices, financial institutions and public transportation. As a result, there is a high volume of traffic and people in the immediate area which can contribute to increased waste accumulation and degraded structures. Figure 65 details the type of obstruction observed in the structures.

Figure 65: Isipingo 2b obstruction type.

Source: (ESRI) ArcMap 10.0 with eThekwini Municipality shapefiles

Table 25 summarises the findings from the site assessment at Isipingo 2b. The study found a concerning status of the structures assessed, with only 22% deemed functioning. This suggests that the vast majority of the structures are fully functional. Specifically, 45% of the structures were classified as partially functional, implying that, while they may still be functional, they are not performing at full capacity. Alarmingly, 33% of the structures were found to be non-functional, indicating the crucial need for intervention.

The inspection also revealed several obstructions that contributed to the structures' degraded operation. Waste was the most common concern, affecting 53% of the structures assessed. This indicates a large collection of debris or litter that prevents appropriate operation. Silt was another significant obstruction, affecting 22% of the structures, possibly leading to drainage concerns and additional degradation. In a smaller sample, 4% of the structures had a mix of waste and silt, indicating a complication that might worsen the overall state of the structures. Furthermore, stagnant stormwater was found to block 17% of the structures, potentially causing further structural damage. Positively, 17% of the structures were found to be unobstructed, indicating that certain portions are still working and may require less urgent maintenance.

When assessing the overall state of the evaluated structures, the results were similarly concerning. Only 22% of the structures were classified as being in good condition, showing that a small number of structures are well-maintained and functional. In contrast, 40% were rated as fair, indicating that, while still functional, they require attention to avoid future deterioration. The concern is that 38% of the structures were determined to be in bad condition and required replacement. This underscores the urgent need for action to address the deteriorating status of the infrastructure at Isipingo 2b, as a large number of the structures are either in danger of failing or are beyond repair. Overall, the findings highlight the crucial need for a planned waste management strategy, improved drainage, and investments in the upkeep or replacement of impacted infrastructure to maintain the area's safety and functionality.

Table 25: Isipingo 2b site inspection results

Accessibility		%
Accessible	220	79
Not accessible	59	21
Functionality		%
Functional	48	22
Partly functional	100	45
Not functional	72	33
Obstruction		%
Waste	117	53
Silt	49	22
Waste and silt	8	4
Stormwater	8	4
None	38	17
Condition of structure		%
Good	49	22
Fair	87	40
Poor	84	38

5.2.4 Isipingo 2c

Isipingo 2c on Figure 66 and Figure 67 has a total of 591 structures; 375 structures were assessed, while 216 structures were inaccessible. Several variables, including location, kind of structure, manhole cover and material of the structure, prevented access to 216 structures. Several culverts, canals and open channels were observed and inspected in this catchment.

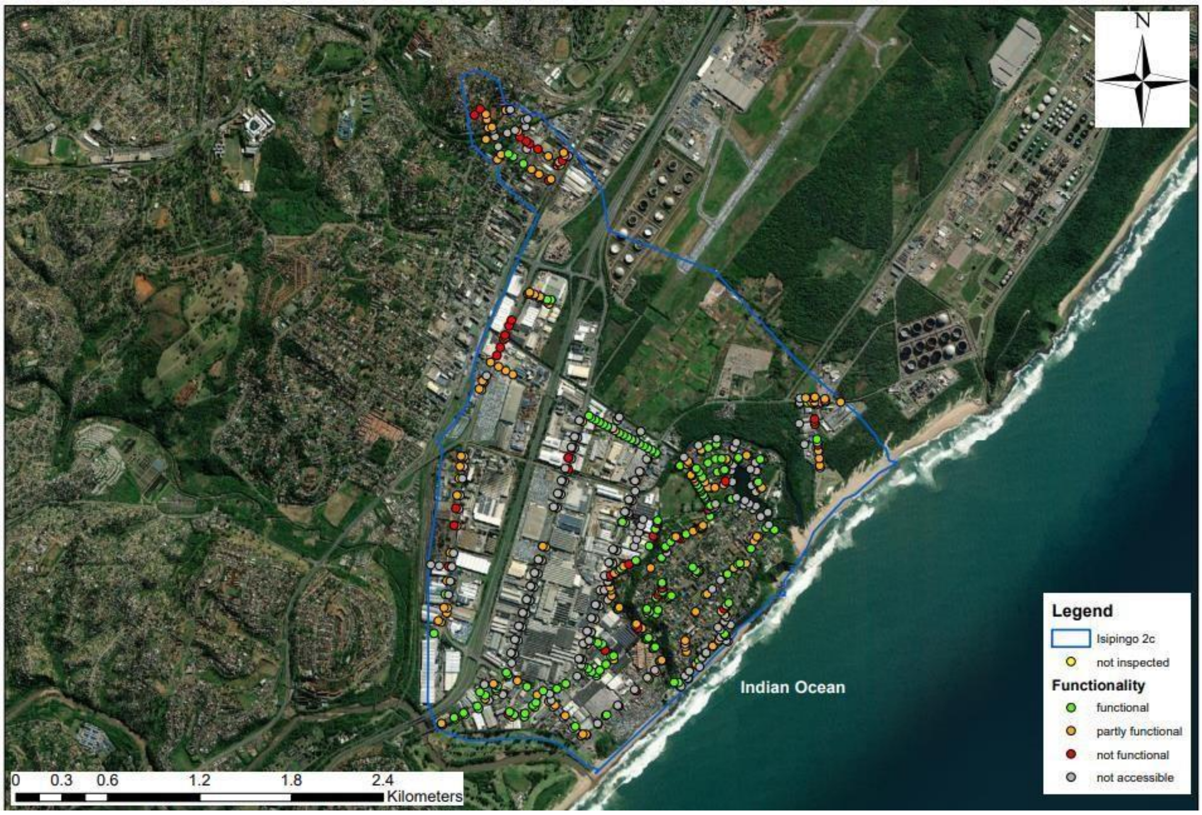


Figure 66: Isipingo 2c functional structures.

Source: (ESRI) ArcMap 10.0 with eThekwini Municipality shapefiles

Structures within the industrial area along Prospecton Road and Joyner Road were all locked and inaccessible due to the critical industrial business along these roads. Structures within the industrial area that were accessible and inspected were functional and partly functional due to silt are located on Willcox Road, Baltex Avenue, Jeffels Road, Orient Road and Mack Road. Given the frequent traffic around the industrial region, structures on Willcox Road, Baltex Avenue, and Jeffels were in dire condition and required replacement. Vulnerable areas around the residential area with none and partially functional structures blocked with waste and silt were located at Inner Circuit Road, Outer Circuit Road, Delta Road, Duiker Road, and Remora Road. Figure 67 details the type of obstruction observed in the structures.

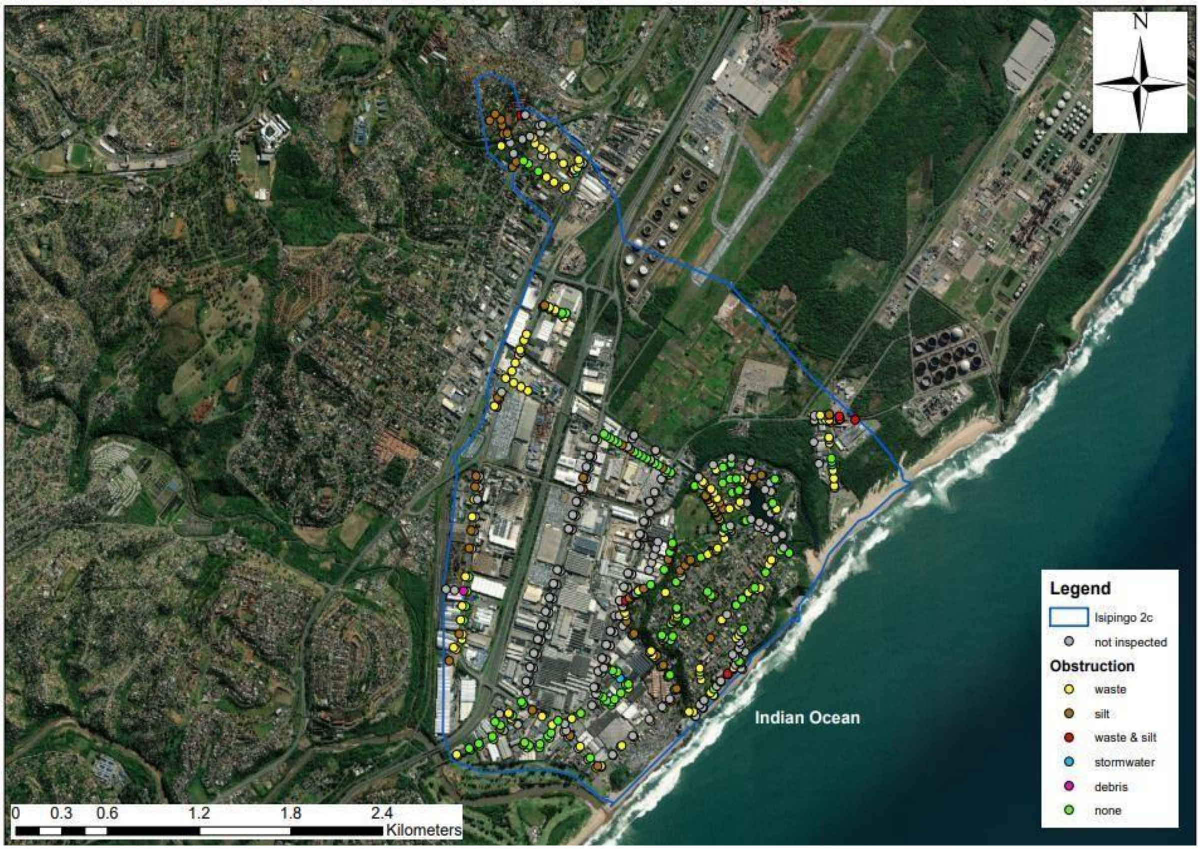


Figure 67: Isipingo 2c obstruction type.
Source: (ESRI) ArcMap 10.0 with eThekwini Municipality shapefiles

Table 26 summarises the findings from the site assessment at Isipingo 2c. The assessments included a variety of structures and revealed a wide range of results. Specifically, 44% of the structures were classed as functional, suggesting that they were functioning well and serving at their full capacity. In contrast, another 44% were classified as somewhat functional, implying that while these structures were functioning to some extent, they may require maintenance or repairs to regain full functionality. Alarmingly, 12% of the structures were classified as non-functional, indicating a considerable concern about their functionality.

Several blockages were discovered during the examination, which hampered the structure's operation. Waste was the most common obstruction, affecting 41% of the assessed structures. This implies a serious problem with waste management in the region, which may pose health and environmental dangers. Following waste, silt was identified as a substantial blockage, affecting 18% of the structures. The presence of silt can cause drainage concerns and worsen the degradation of structures.

Furthermore, a mix of waste and silt was found in 3% of the instances. Other obstructions were stagnant stormwater, which appeared in 1% of the structures. Positively, 36% of the assessed structures were found to be free of blockages, implying that a component of the infrastructure is operating without major blockages.

In terms of the general state of the structures, the data provide a mixed picture. The majority, 53%, were discovered to be in good condition, suggesting that these structures are well-maintained and functioning efficiently. However, 31% of the structures were classified as fair, indicating that, while still operable, they may require maintenance to avoid future degradation. In contrast, 16% of the structures were found to be in poor condition, raising concerns about their safety and functionality, indicating an immediate need for replacement or extensive repairs to guarantee they can continue to serve the community efficiently. Overall, the findings from the Isipingo 2c site assessment highlight the significance of removing the observed obstructions and upgrading the structural condition to improve functioning and durability.

Table 26: Isipingo 2c site inspection results

Accessibility		%
Accessible	375	79
Not accessible	216	21
Functionality		%
Functional	166	44
Partly functional	166	44
Not functional	43	12
Obstruction		%
Waste	155	41
Silt	69	18
Waste and silt	10	3
Stormwater	4	1
Debris	1	1
None	136	36
Condition of structure		%
Good	200	53
Fair	114	31
Poor	61	16

5.2.5 Discussion

The Lower Isipingo Catchment has a total of 1465 identified stormwater assets, including the 988 structures that were accessible and inspected on site. This means that the visual evaluations conducted on these assets represent a considerable 67% of the total number of stormwater structures within the catchment area. However, it is vital to remember that a large number of structures were not accessible for assessment. The causes for this inaccessibility include several significant elements. Many inaccessible structures are located on private properties, limiting access owing to property rights and privacy concerns.

Furthermore, certain assets are placed in servitudes, which are places designated for specific uses, such as civil services, and where entry is restricted or controlled. The location of certain structures near high-traffic roads such as the N2, also represented a difficulty. Inspections are challenging due to the safety concerns connected with accessing these areas, as well as the possibility of disrupting traffic flow. Additionally, extensive vegetation in some areas blocked access to several stormwater assets, especially outlet structures. Limiting the inspection procedure.

Other logistical difficulties also led to the inability to evaluate certain structures. For example, locked manhole covers were a substantial obstacle since they restricted inspectors from accessing for inspection. Similarly, metal coverings and gratings are difficult to remove or need specialised skills, which hindered access even further. The nature of the structures themselves, such as headwalls, also impeded inspection attempts owing to their design and placement. In summary, while a substantial portion of the stormwater assets in the Lower Isipingo Catchment were inspected, a notable number remain unassessed due to a combination of accessibility issues related to property rights, safety concerns, environmental factors, and structural characteristics.

According to the site assessments, waste is the most prevalent type of obstruction in the drainage system in Isipingo 1, 2a, 2b and 2c. This is shown on Table 23 to Table 26. This waste can consist of a number of elements, including litter, debris, and organic matter, which collect over time and clog the channels through which stormwater is intended to flow. Following waste, silt was shown to be another typical obstruction, frequently collecting in regions where water flow is restricted. In several cases, both waste and silt were present, exacerbating the situation and impeding water flow. Furthermore, stagnant stormwater was found in some structures, which might be ascribed to downstream bottlenecks or negative slopes in the pipe system. When water cannot move freely through the network, it might accumulate in some regions, posing safety risks and increasing the risk of localised flooding. This stagnation not only endangers the nearby environment but may also deteriorate the infrastructure itself since standing water can cause corrosion.

The findings regarding the culverts at Isipingo 2a and 2c were especially concerning. These structures were found to be insufficiently maintained, raising major concerns about their ability to withstand expected stormwater flows and volumes. Proper maintenance is required to guarantee that these culverts can successfully divert water away from residential areas while preventing overflow during severe rain events.

Isipingo 2b and 2c have the highest quantity of partly- and non-functional structures as shown in Table 25 and Table 26. Several structures in these locations are in critical condition, suggesting that they must be replaced immediately to maintain their safety and operation. The issues that these structures encounter are strongly related to the services provided in their particular catchment regions, which have a significant impact on their general condition and use. Figure 66 and Figure 67 show that Isipingo 2b is strategically located in Isipingo's major business center. This ideal position not only serves as a business hub but also attracts a lot of vehicular and pedestrian traffic. The huge volume of people and vehicles causes wear and tear on the infrastructure, complicating the maintenance and operation of the structures in this region.

Figure 68

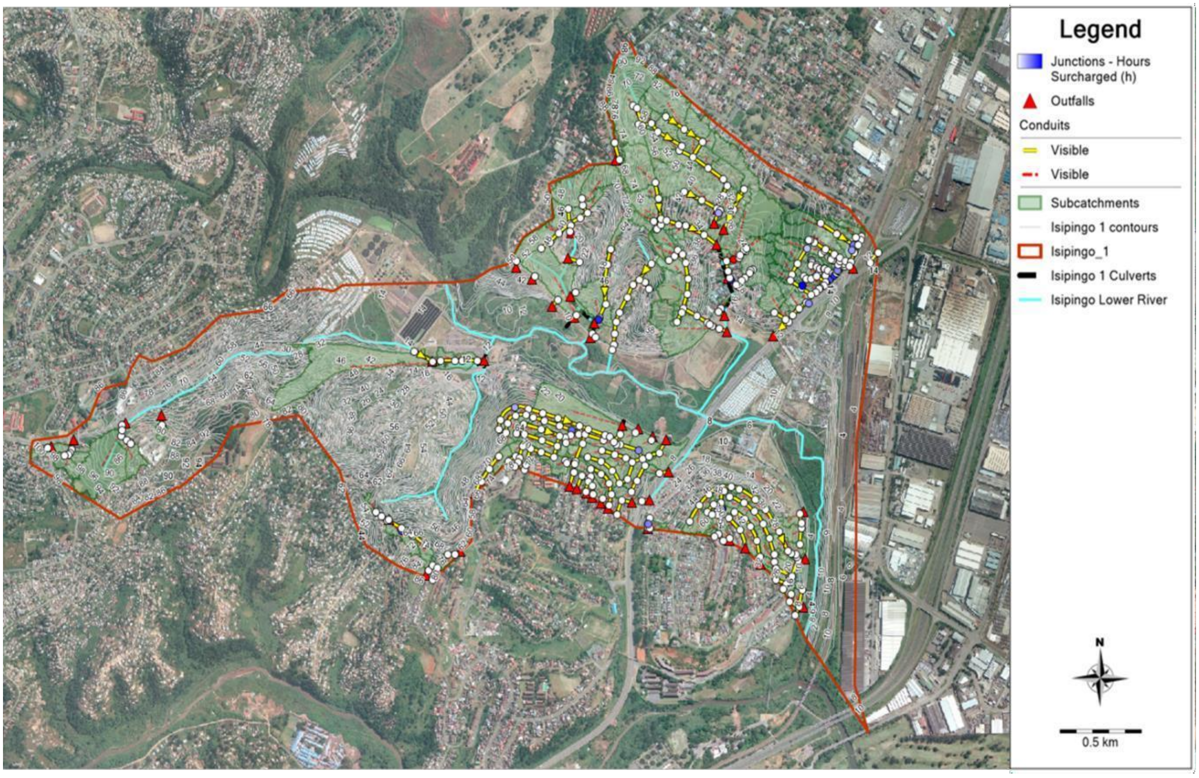


Figure 69 show that Isipingo 2c is located within Prospecton's industrial zone. This catchment is distinguished by its industrial businesses, which draw a large amount of pedestrian and vehicular traffic. The economic activity in these sites emphasizes their importance, but it also highlights the vulnerabilities these communities confront, particularly in terms of infrastructural resilience. Both Isipingo 2b and 2c are particularly vulnerable to flooding, a danger exacerbated by the inadequate stormwater management systems in place. These systems are now not performing at their full capacity, owing to obstacles that prevent effective drainage. This problem can be intensified during periods of severe rainfall when the risk of flooding increases significantly. The combination of heavy traffic, critical infrastructure conditions, and ineffective stormwater management creates a precarious situation for both areas, necessitating immediate attention and action to reduce flooding risks and improve the overall structural integrity of the structures within these catchment zones.

The results support the claims noted by Erasmus (2019) that eThekwini Municipality officials observed that flooding within the city is worsened by waste caused by widespread littering, which is the main cause of blockage of drainage systems. Obstructions and maintenance problems not only reduce the ability of stormwater networks to prevent floods but also increase the danger of flooding occurrences. This can cause considerable damage to infrastructure and property, resulting in expensive repairs and community disturbances. Addressing these findings through prompt maintenance and repair activities is critical to restoring stormwater system performance and protecting surrounding areas from flood damage.

5.3 Results from Specific Objective 3

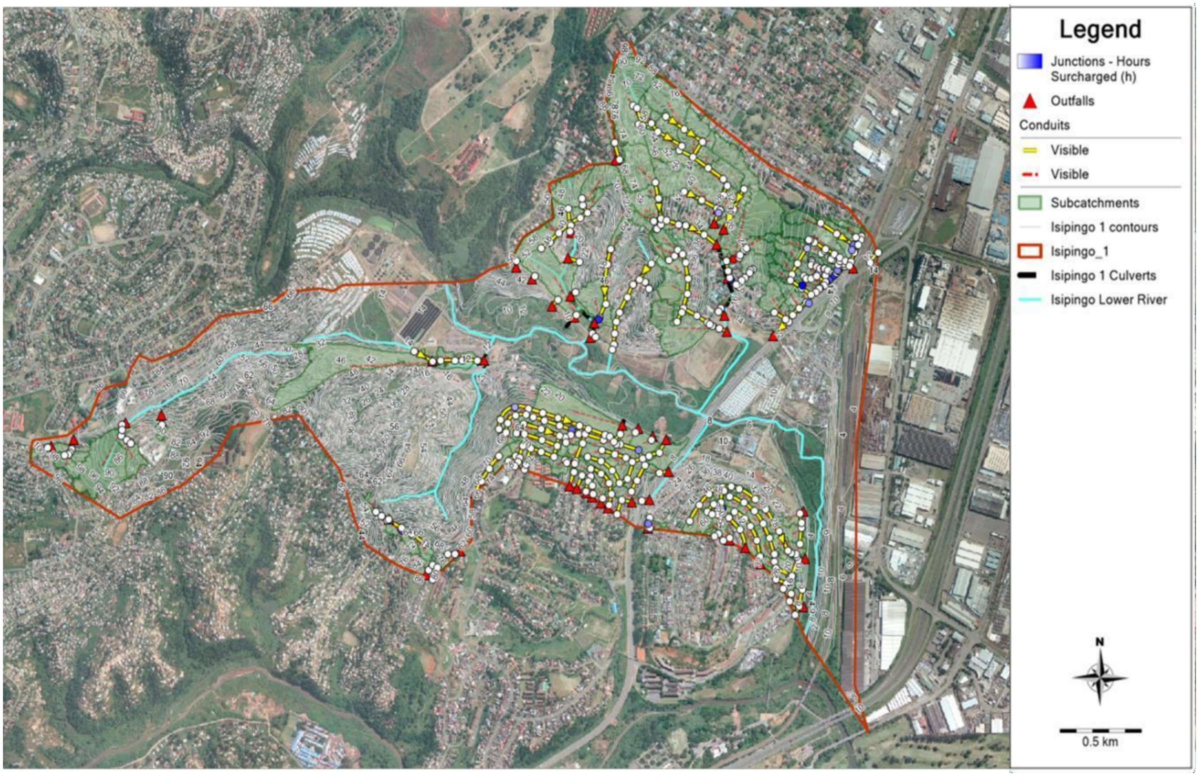
To assess the performance of the existing drainage system with varying rainfall data.

A hydraulic model of each of the four sub-catchments—Isipingo 1, Isipingo 2a, Isipingo 2b, and Isipingo 2c—was completed. Each model details which stormwater networks are flooding and the severity of the flooding within the network based on a 1-hour storm simulation and the associated rainfall data.

5.3.1 Isipingo 1

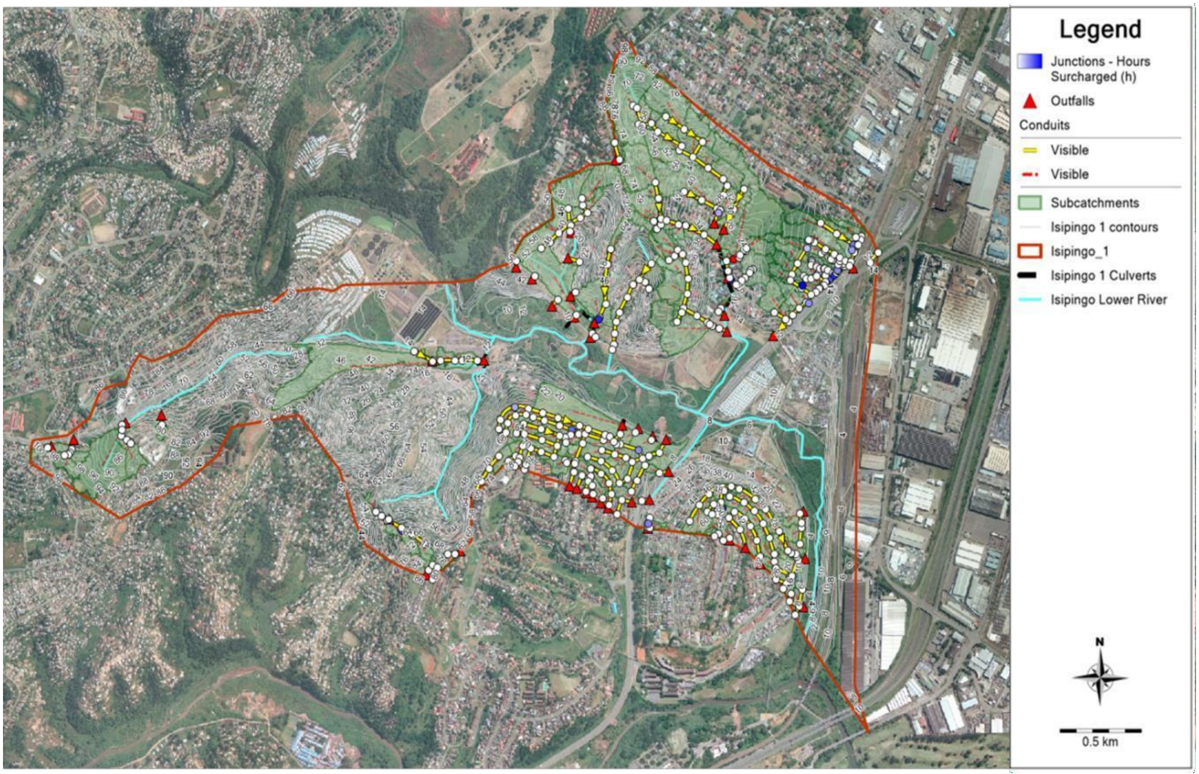
The manholes were rendered to display hours surcharged (h) with a blue gradient spectrum. The colour white can be regarded as being clear, whereas deeper blue can be viewed as extreme surcharging and subsequent flooding. Surcharging occurs when water rises to the top of the highest pipe as the rate of water entry exceeds the outlet's capacity. Flooding refers to all the water that overflows a manhole, whether it ponds or not.

In Isipingo 1 there are 21 surcharging structures with nine flooding structures. The model results shown on Figure 68, Figure 69, and Figure 70 have demonstrated that there are more clear/white manholes with isolated areas with varying shades of blue. The prevalence of clean or white manholes indicates that the drainage system is relatively clear of obstructions, allowing for the effective flow of water. This is critical during seasons of high rainfall because it allows runoff to be adequately directed away from urban areas, lowering the danger of floods. While the existence of nine flooding structures indicates possible issue regions, it does not detract from the system's overall efficacy.



This means that the drainage infrastructure in Isipingo 1 is functioning satisfactorily, indicating that the system has sufficient capacity to mitigate stormwater runoff with all three rain gauges, 148.2 mm, 130 mm, and 158 mm rainfall. These results show that, even during heavy rainfall events, the system can handle the surge of stormwater runoff without being overwhelmed. The drainage system's capacity to manage such rainfall volumes without serious flooding demonstrates the sufficient design and implementation of the drainage system in this area.

Figure 68 indicates the model results with the 148.2 mm rainfall April 2019 floods. The model has sufficient capacity to mitigate stormwater runoff with 148.2 mm rainfall as there are more clear/white structures and few isolated surcharging/flooding areas which indicates good operation. Therefore, the drainage infrastructure is functioning satisfactorily. The results of the model are similar to Figure 69 and Figure 70 despite the differing rainfall gauges, due to the same problematic regions produced by negative pipe slope, inaccurate cover level, incorrect invert elevations, and varying pipe sizes along the networks.



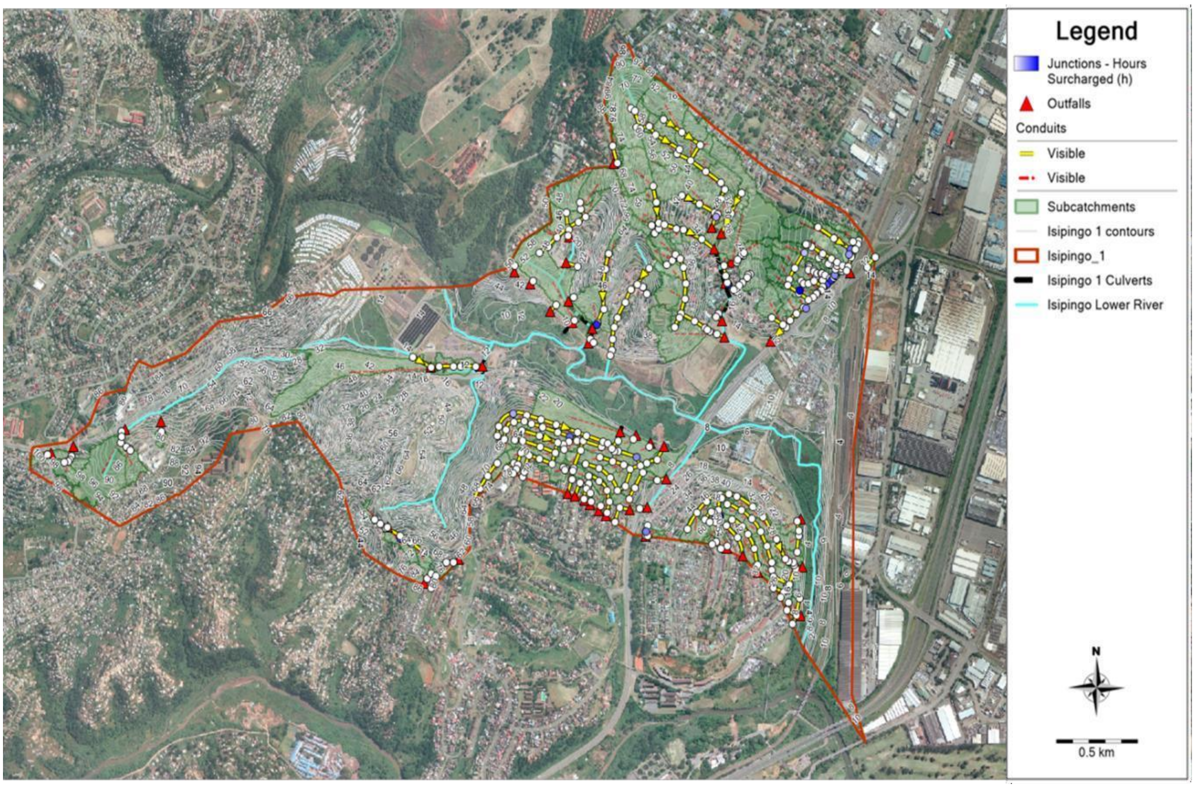


Figure 68: 148.2 mm 1 in 5-year design rainfall.

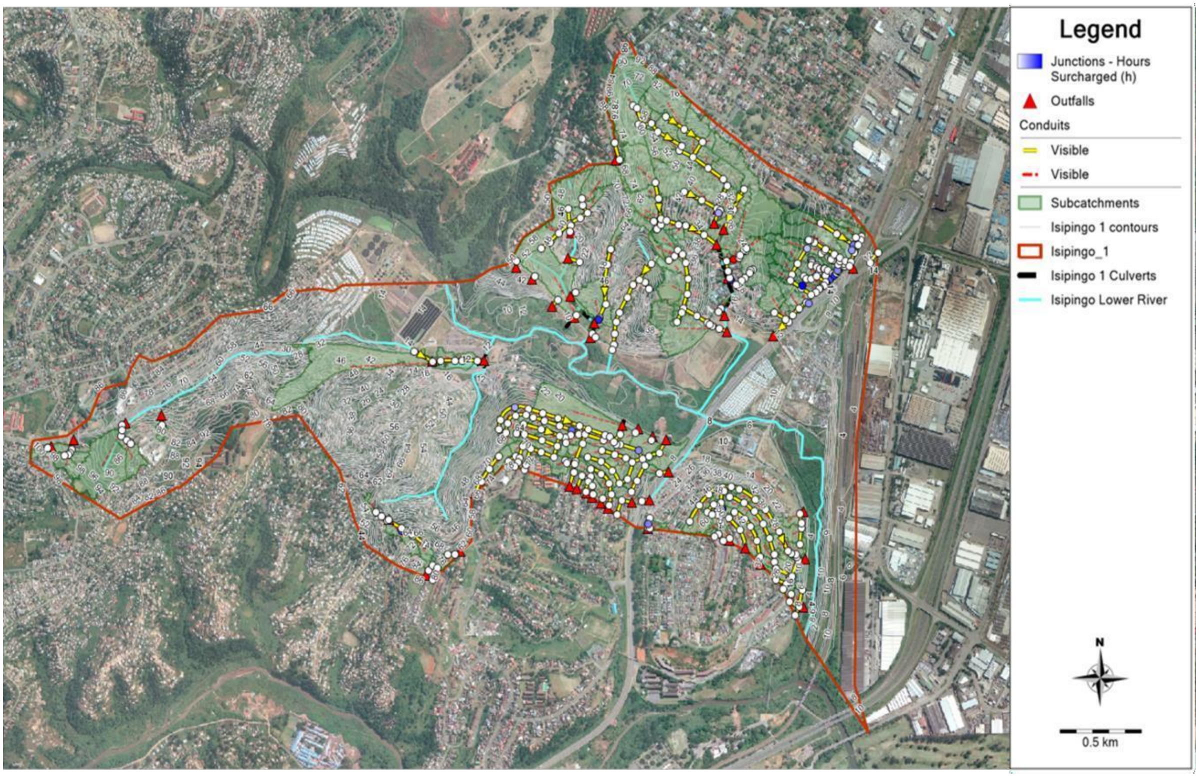


Figure 69 indicates the model results for Isipingo 1 with the 130 mm April 2019 flood rainfall. The model has sufficient capacity to mitigate stormwater runoff as the drainage infrastructure is functioning adequately with few isolated surcharging/flooding areas.

The results of the model are similar to Figure 68 and Figure 70 regardless of the different rainfall gauges due to the same problematic areas caused by the negative pipe slope, inaccurate cover level, incorrect invert elevations, and varying pipe sizes along the networks.

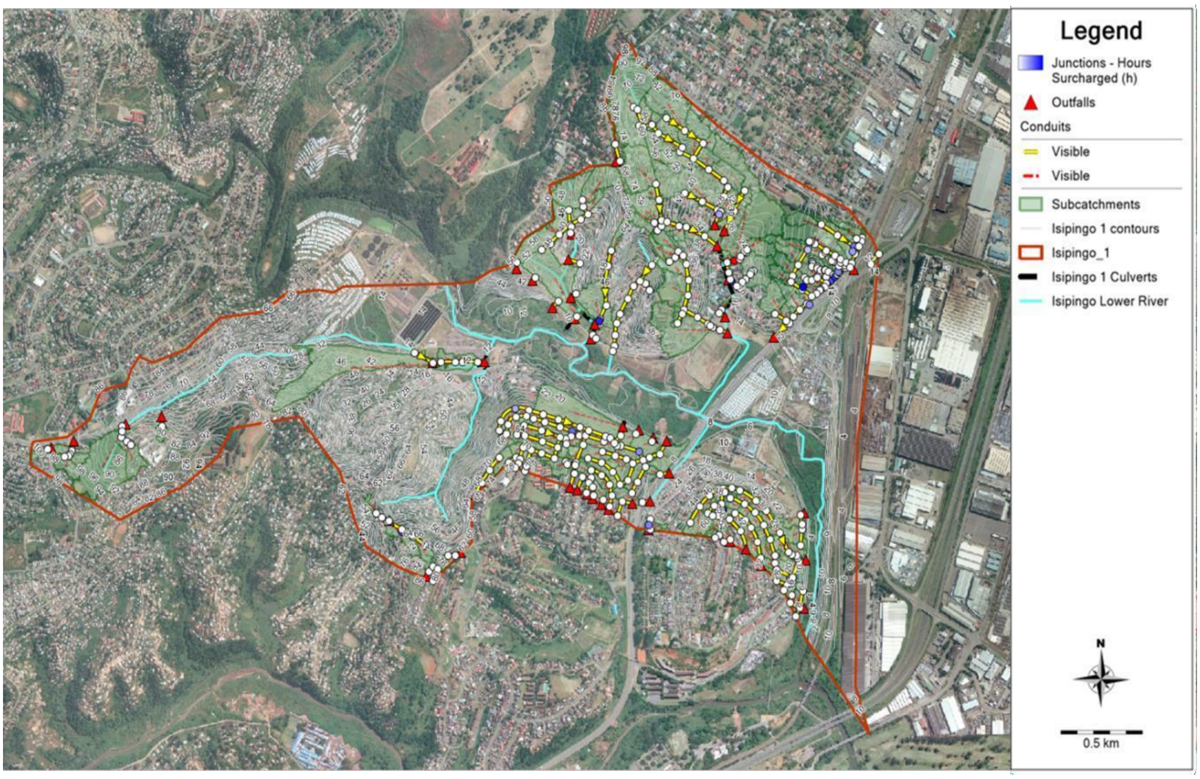


Figure 69: 130 mm rainfall April 2019 floods.

Figure 70 indicates the model results for Isipingo 1 with the 158 mm April 2022 flood rainfall. The results of the model in Figure 68,

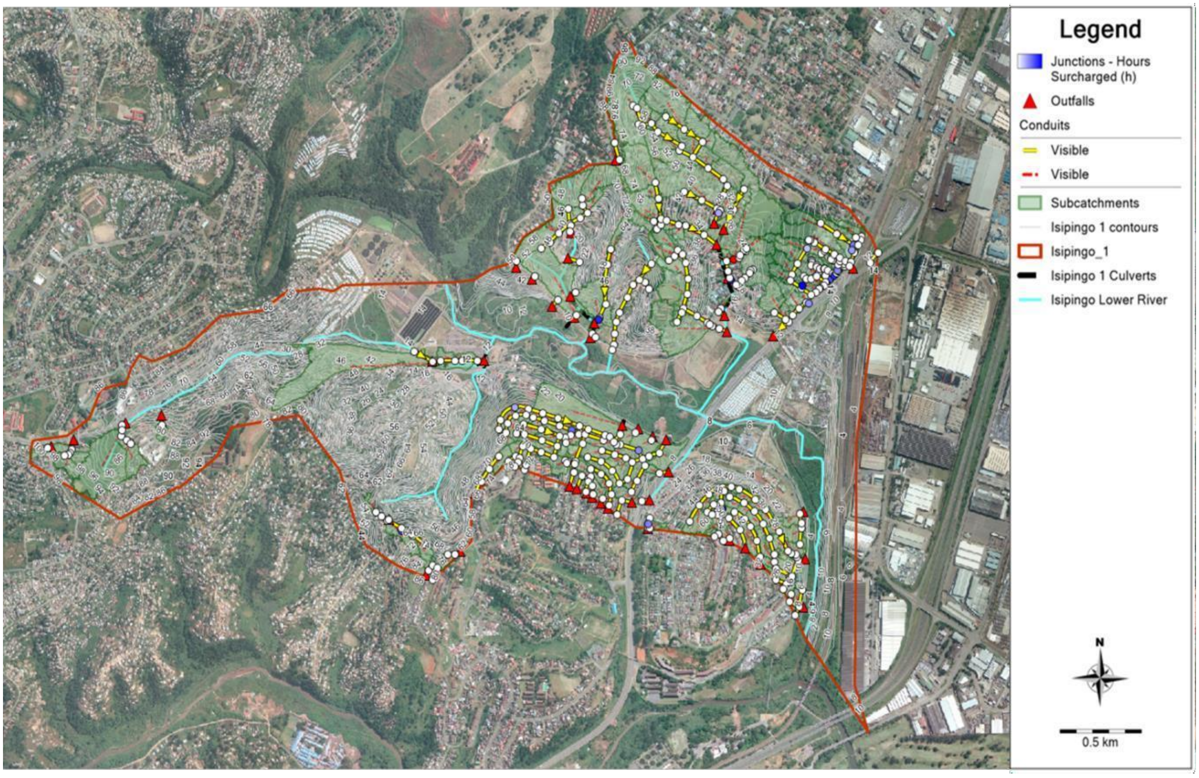


Figure 69, and Figure 70 are relatively similar regardless of the different rainfall gauges due to the same problematic areas caused by negative pipe slope, inaccurate cover, incorrect invert elevations and varying pipe sizes along the networks. This ultimately causes certain structures to surcharge or to flood along the network. The different rain gauges only change the shade of the blue along the network which is regarded as the degree of surcharging and subsequent flooding.

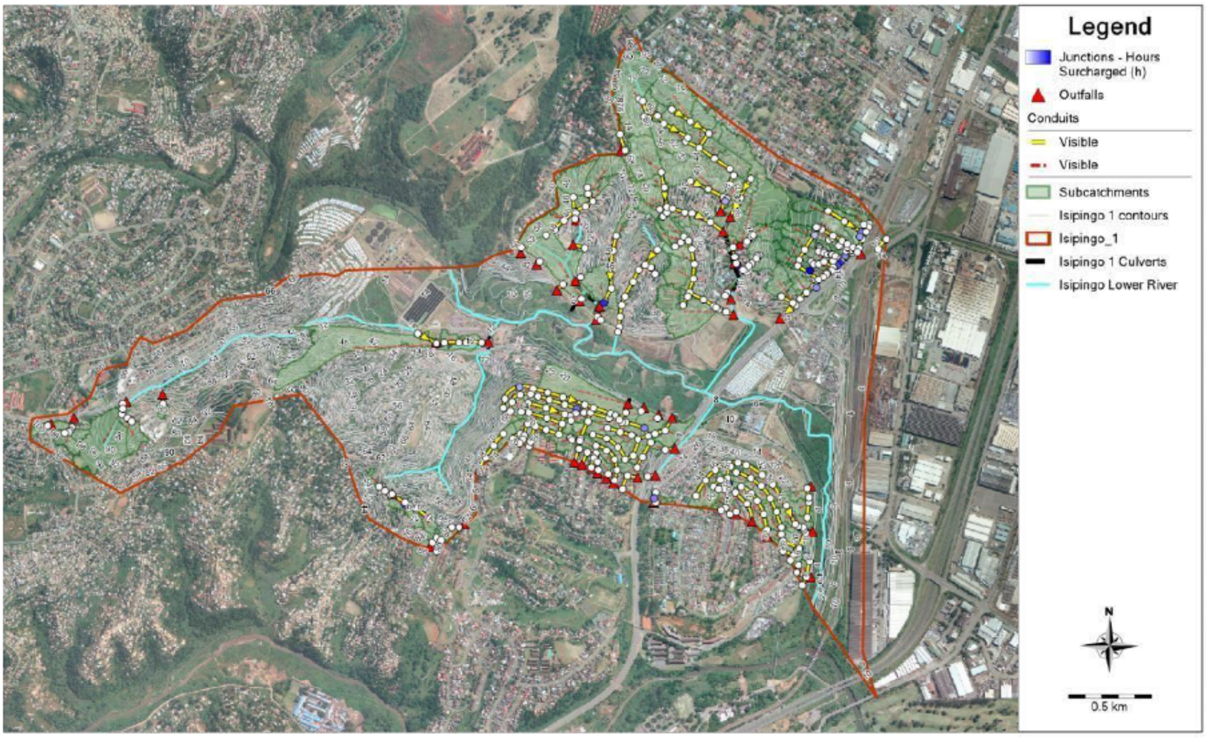


Figure 70: 158 mm rainfall April 2022 floods.

The hydraulic capacity of drainage systems is crucial for sustainable water management, especially in urban areas. However, in the Isipingo 1 model, this potential is hampered by several causes. One major difficulty is the occurrence of negative pipe slopes, which can cause water to flow in the wrong direction or stagnate and obstruct the flow of water. This poor alignment can cause obstructions and lower flow rates, increasing drainage issues. Inadequate manhole cover, incorrect invert elevations and pipe sizes were noted which can disrupt the intended flow of water, leading to areas of ponding and increased risk of overflow. As a result, the drainage networks experience surcharging and subsequent flooding in these areas.

The vulnerable areas in this sub-catchment include Pepperberry Road, Sucrose Road, Nilgiri Road, Platt Road, and Delhoo Road. This is shown in the longsections on Figure 71, Figure 72, Figure 73, Figure 74, Figure 75, and Figure 76.

Figure 71 illustrates a longsection along Pepperberry Road. The negative slope of pipe ED440ZC011 is caused by the inaccurate cover and invert elevation of ZC011, leading ED440 to surcharge. This has caused a backlog in the flow of stormwater in the network causing ED440 and ED395 vulnerable to possible flooding.

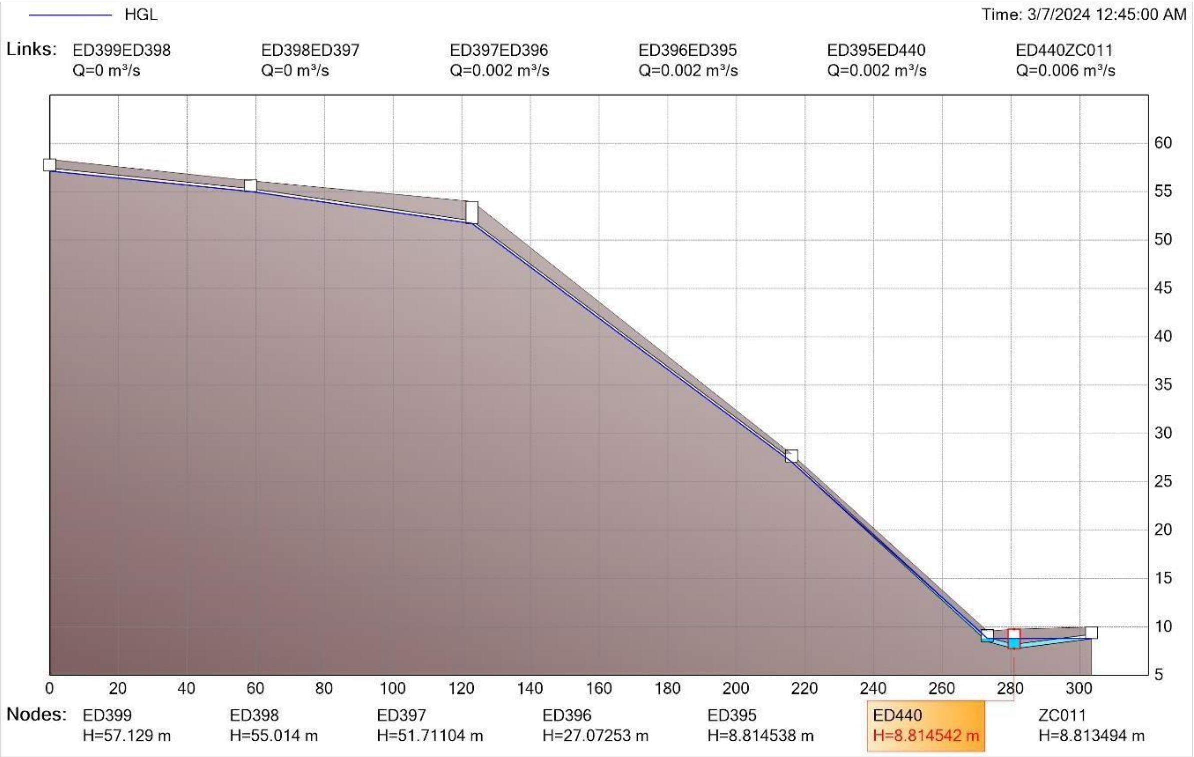


Figure 71: ED399ZC011 Longsection (Pepperberry Road)

Figure 72 illustrates a longsection along Sucrose Road. The negative slope of pipe ED352ED322 has led to surcharging of ED352 and hindering the flow of water downstream in the network. The negative slope of pipe ED337ED338 has caused a backlog in the flow of stormwater upstream making ED304, and ED301 to surcharge, causing ED337 to flood.

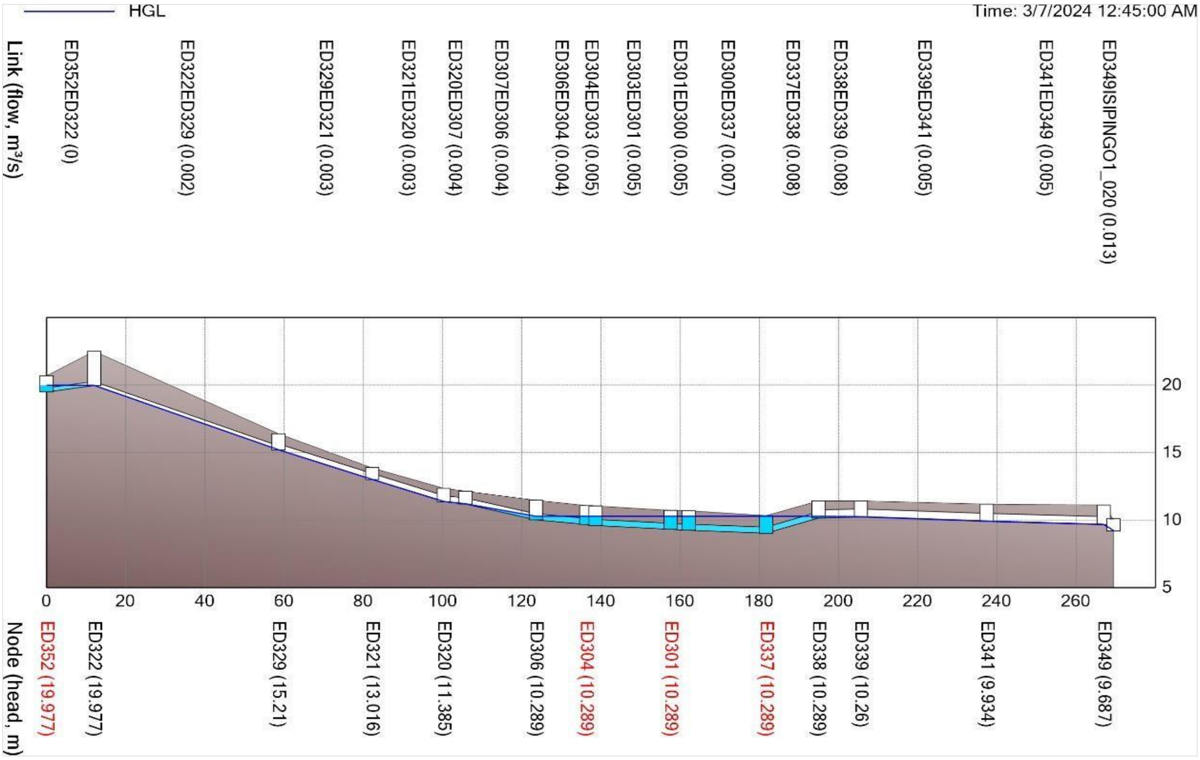


Figure 72: ED352ED349 Longsection (Sucrose Road)

Figure 73 illustrates a longsection along the intersection of Delhoo and Sucrose Road. The negative slope of pipe ED507ED508 is created by the incorrect invert level of ED507, ED508 and ZC020. This has hindered the flow of water downstream in the network causing a backlog in the flow of stormwater upstream leading ZC020 to surcharge and the flooding of ED506.

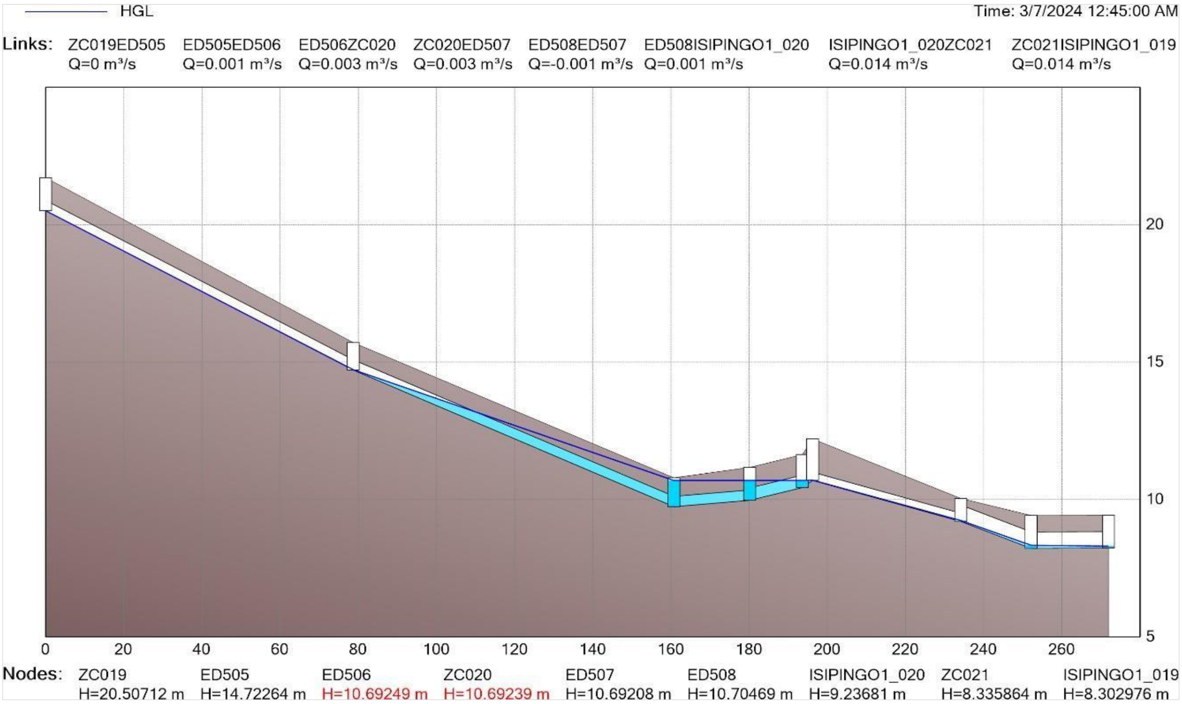


Figure 73: ED505ISIPINGO1_019 Longsection (Delhoo and Sucrose Road)

Figure 74 illustrates a longsection along Platt Road. The incorrect cover and invert level of outfall ED277 have caused a negative slope on pipes ED275ED276 and ED276ED277. This has hindered the flow of stormwater downstream to the outfall and has caused a backlog in the flow of stormwater upstream leading ED275 to flood. Inconsistent pipe diameters, ED275ED276 with Ø375 and ED276ED277 with Ø225, reduce hydraulic capacity as larger pipe sizes cannot discharge into smaller pipes.

It is important to highlight that improper pipe diameters can significantly reduce the system's ability to mitigate predicted runoff volumes. The undersized pipes for the projected flow can become overloaded, resulting in surcharging. This leads to backflow and increases the risk of flooding, especially after high rainfall or storm events.

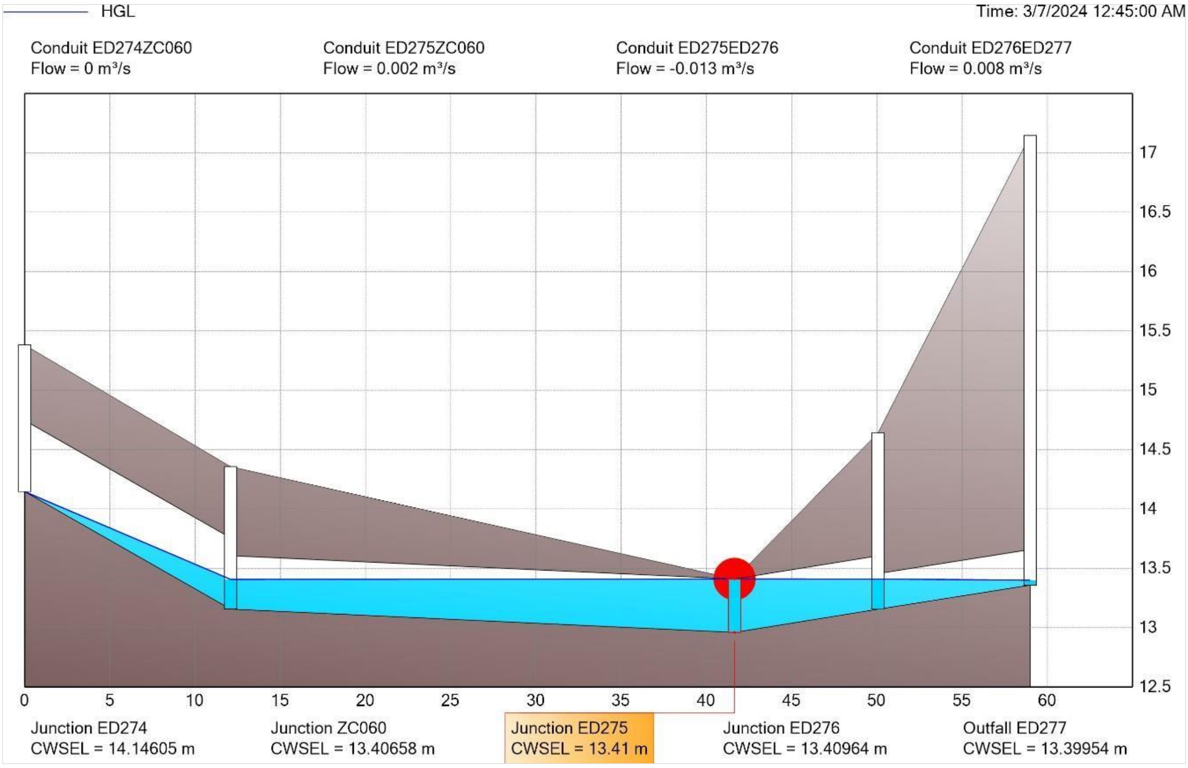


Figure 74: ED274ED277 Longsection (Platt Road)

Figure 75 is a longsection along Nilgiri Road. The incorrect invert level of ED284 has led to the surcharging of ED278. The incorrect cover and invert level of ED277 have led to the surcharging of ED276 and have hindered the flow of stormwater to outfall ED277.

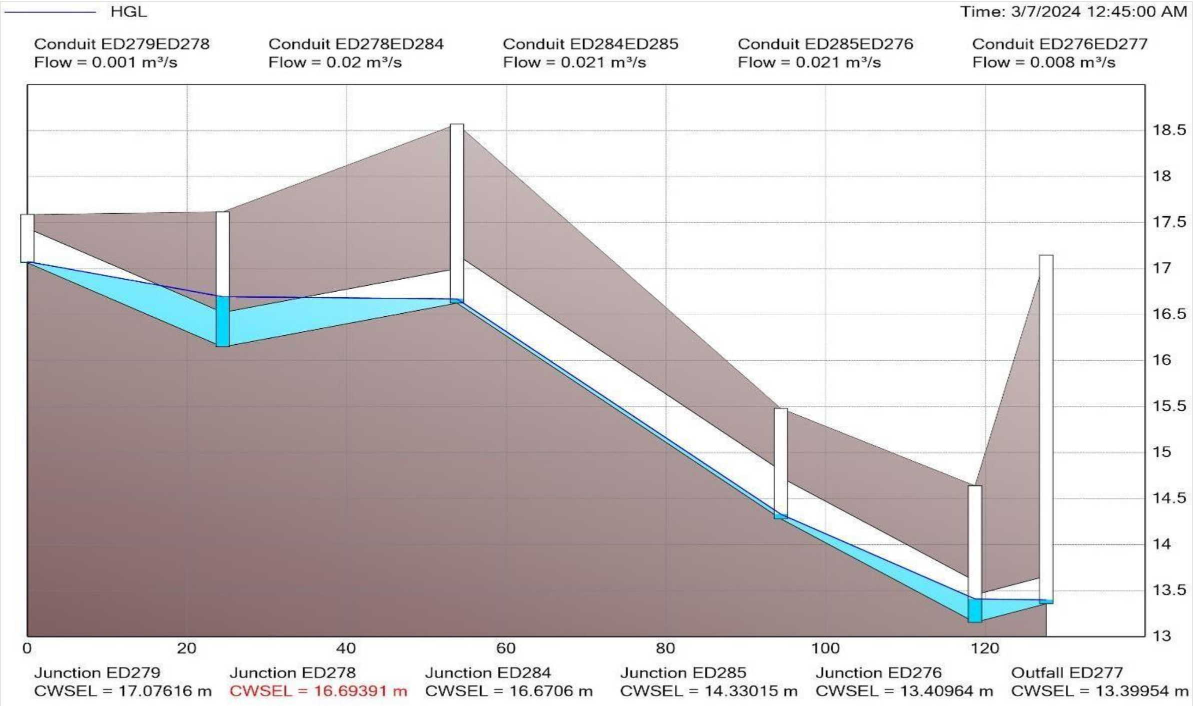


Figure 75: ED279ED277 Longsection (Nilgiri Road)

Figure 76 illustrates a longsection along Wanda Cele Road. The incorrect invert level of M04365 and M0369 has created a negative pipe slope on M0429M0365 causing M0429 to flood. This has hindered the flow of stormwater to outfall M0369.

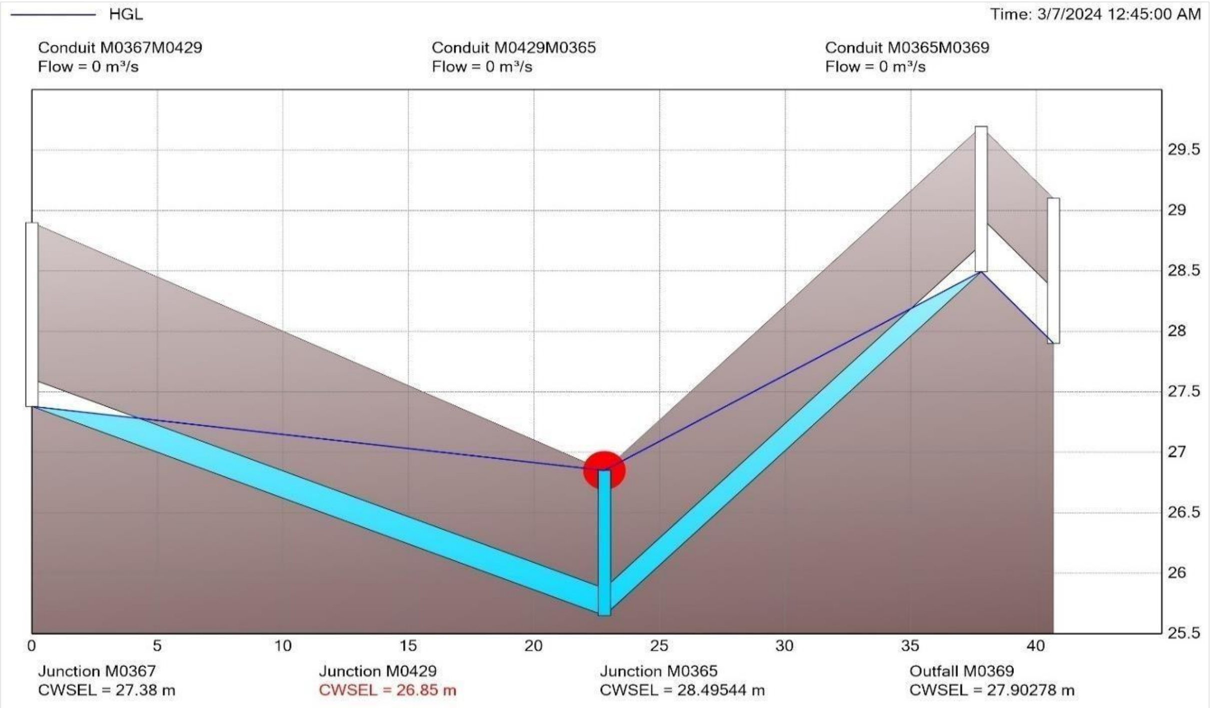
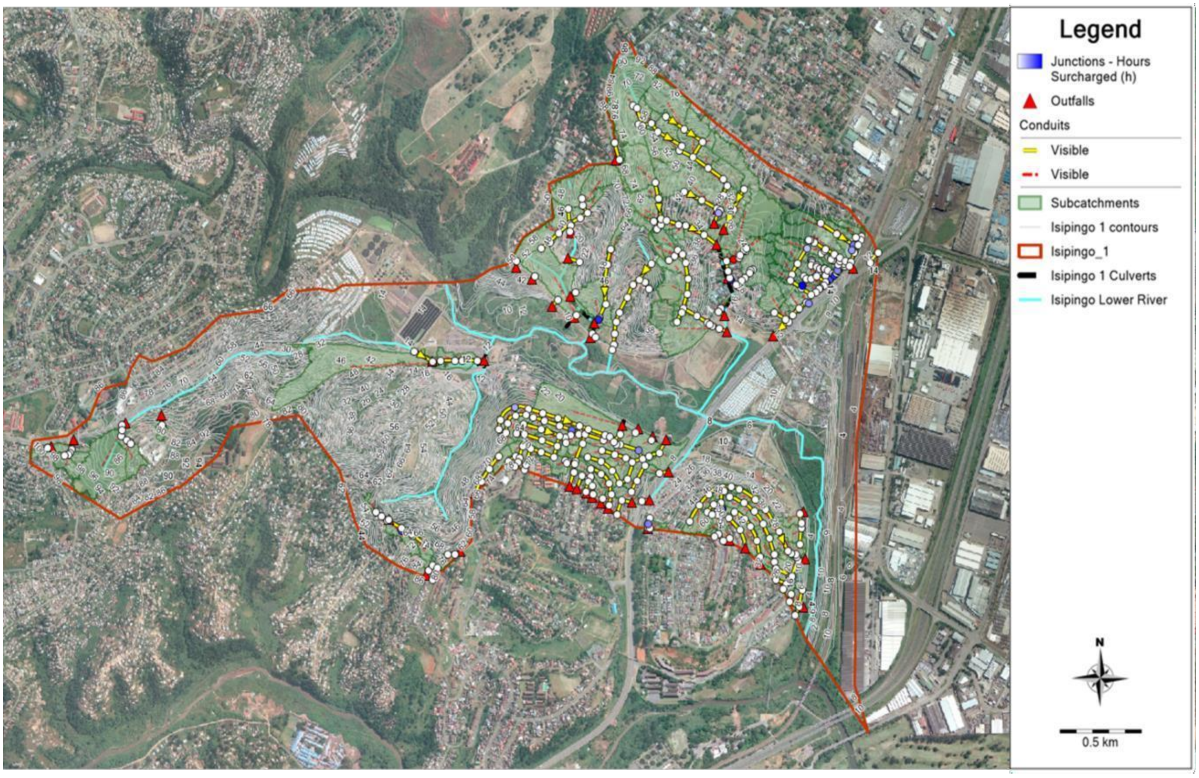


Figure 76: M0367M0369 Longsection (Wanda Cele Road)

5.3.2 Isipingo 2a

The manholes were rendered to display hours surcharged (h) with a blue gradient spectrum. The colour white can be regarded as being clear, whereas deeper blue can be regarded as extreme surcharging and subsequent flooding. Surcharging occurs when water rises to the top of the highest pipe as the rate of water entry exceeds the outlet's capacity. Flooding refers to all the water that overflows a manhole, whether it ponds or not.

In Isipingo 2a there are 14 surcharging structures with three flooding structures. The models shown on Figure 68, Figure 69, and Figure 70 have demonstrated that there are more clear/white manholes with isolated areas with light shades of blue. The white manholes show good operation, while the reported rainfall volumes demonstrate the drainage infrastructure's ability to handle heavy precipitation events with minor overflowing or failing reflecting its capacity. This resilience is critical in reducing the hazards connected with floods, especially in places prone to severe rainfall.



This means that the drainage infrastructure in Isipingo 2a is functioning adequately, indicating that the system has sufficient capacity to mitigate stormwater runoff with all three rain gauges 149.3 mm, 130 mm and 158 mm rainfall.

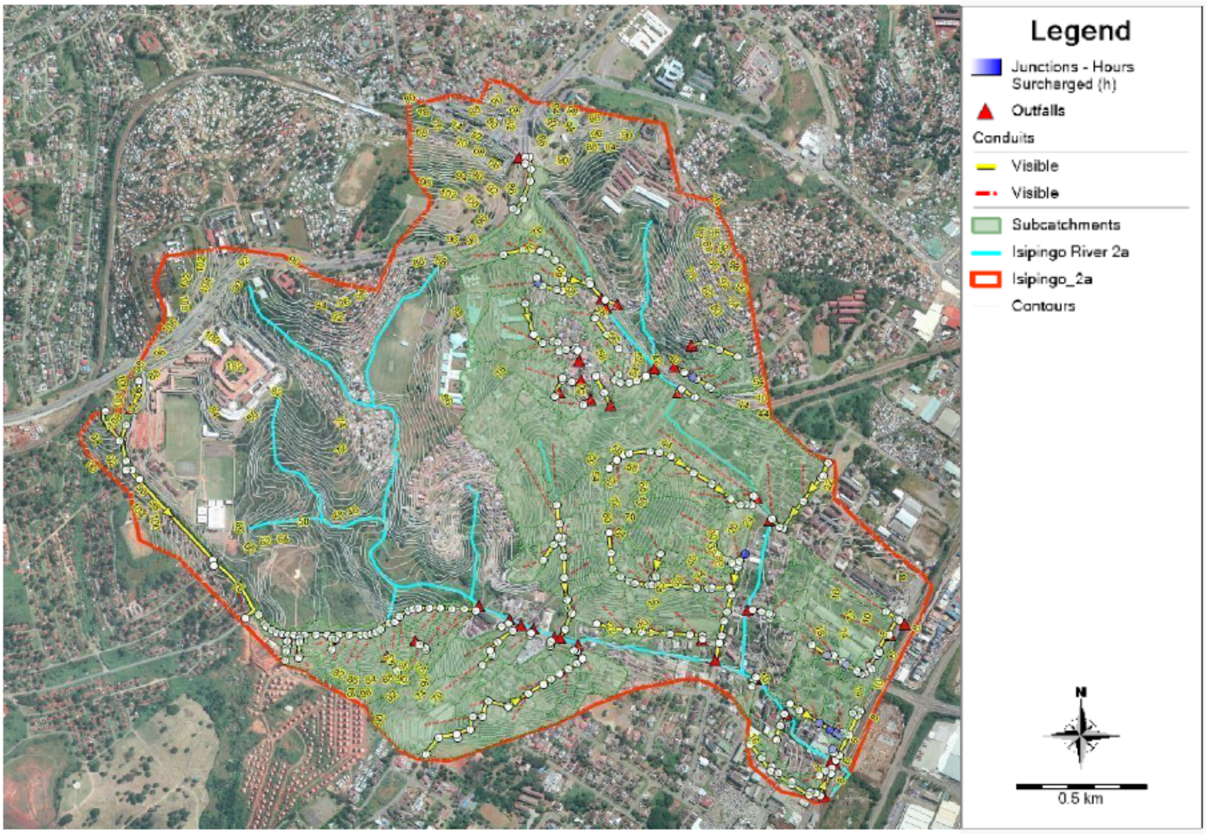


Figure 77: 149.3 mm 1 in 5-year design rainfall.

Figure 77 illustrates the Isipingo 2a model results with the 149.3 mm 1 in 5-year design rainfall. The model has sufficient capacity to mitigate stormwater runoff as the drainage infrastructure is functioning adequately with few isolated surcharging/flooding areas downstream. The results of the model are similar to Figure 78 and Figure 79 regardless of the different rainfall gauges due to the same problematic areas caused by the negative pipe slope, inaccurate cover level, and incorrect invert elevations.

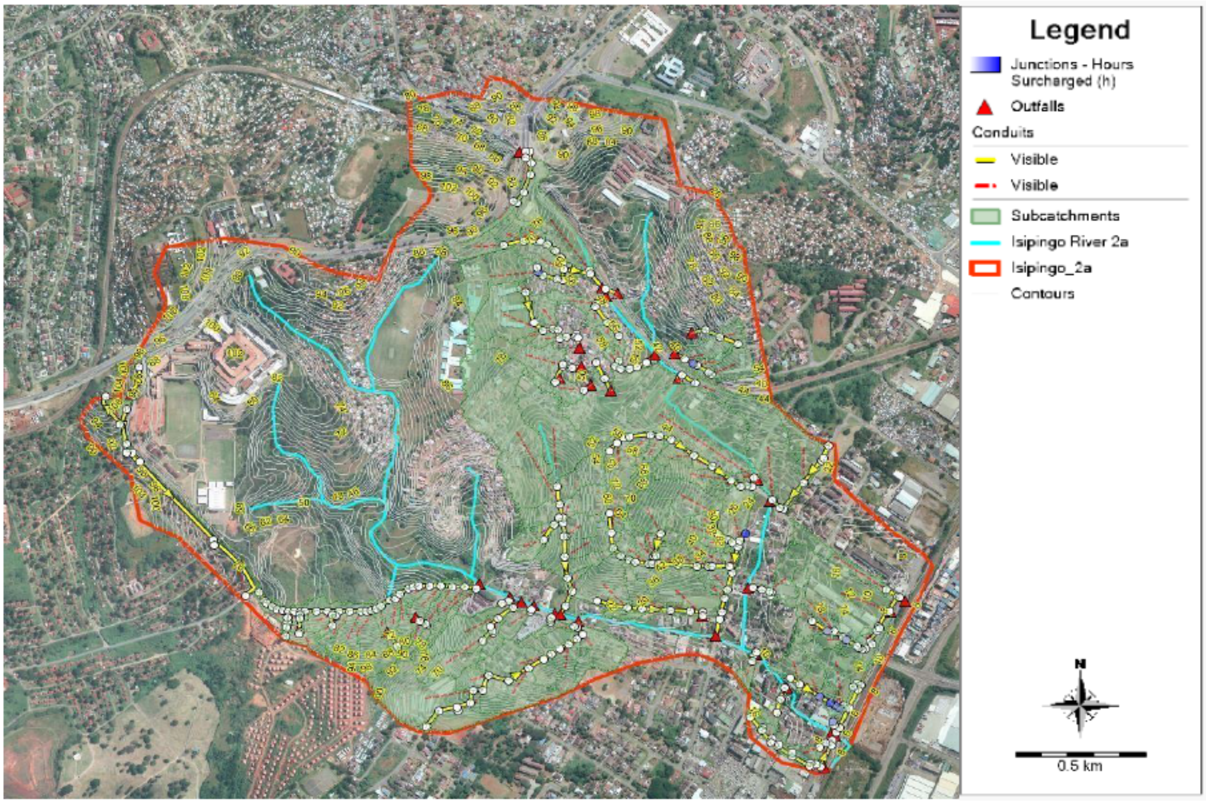


Figure 78: 130 mm of rainfall April 2019 floods.

Figure 78 is the Isipingo 2a model results with the 130 mm rainfall April 2019 floods. The model has sufficient capacity to mitigate stormwater runoff with 130 mm rainfall as there are more clear/white structures and less isolated surcharging/flooding areas. Therefore, the drainage infrastructure is functioning adequately. The results of the model are similar to Figure 77 and Figure 79 regardless of the different rainfall gauges due to the same problematic areas caused by the negative pipe slope, inaccurate cover level, and incorrect invert elevations.

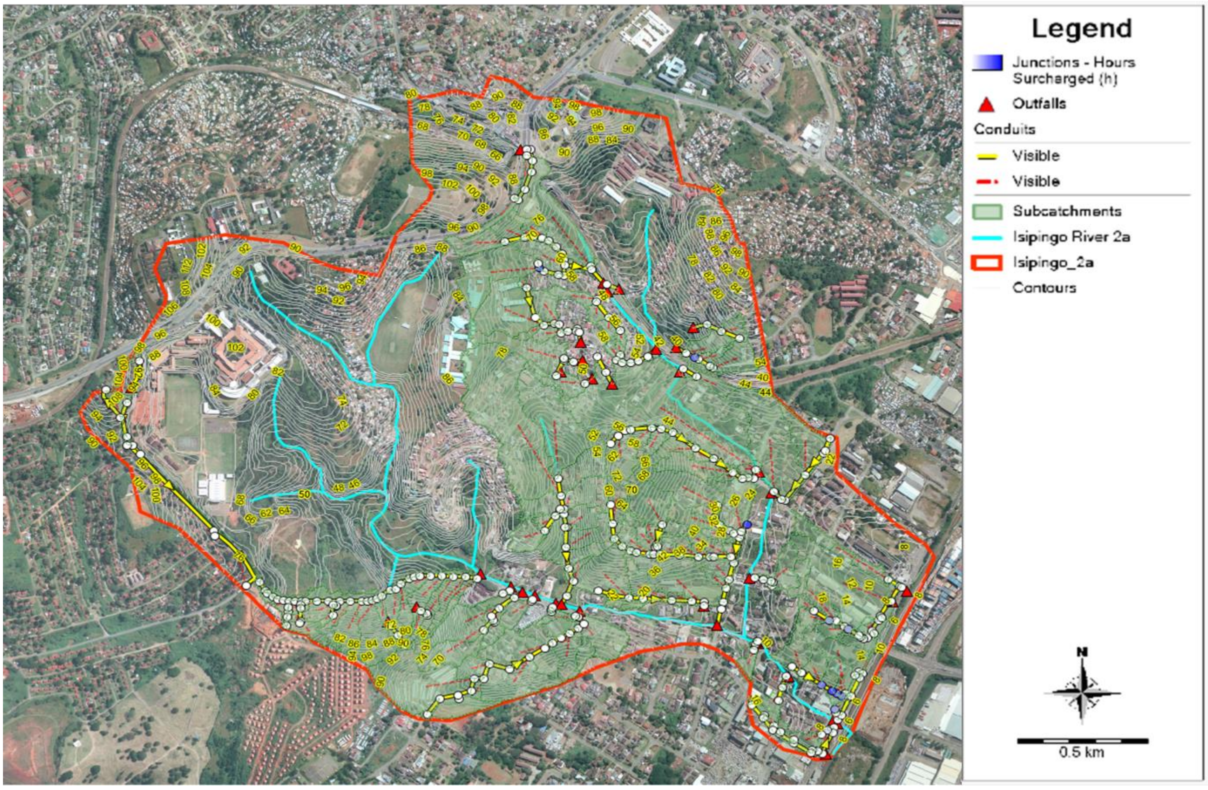


Figure 79: 158 mm rainfall April 2022 floods.

Figure 79 is the Isipingo 2a model results with the 158 mm rainfall April 2022 floods. The model in Figure 77, Figure 78, and Figure 79 have produced fairly similar results regardless of the different rainfall gauges due to the same problematic areas caused by constant negative pipe slope, inaccurate cover, incorrect invert elevations, and insufficient pipe capacity. This ultimately causes certain structures to surcharge or to flood along the network. The different rain gauges only change the shade of the blue along the network which is regarded as the degree of surcharging and subsequent flooding.

The hydraulic capacity is compromised in certain areas due to negative pipe slope, inaccurate cover, and invert elevations. As a result, the drainage networks experience surcharging and subsequent flooding in these areas. The vulnerable areas in this sub-catchment include Clark Road, Phila Ndwandwe Road, Gokul Road, Mohan Road, and Road ID08054. This is shown in the longsections on Figure 80, Figure 81, Figure 82, Figure 83, Figure 84.

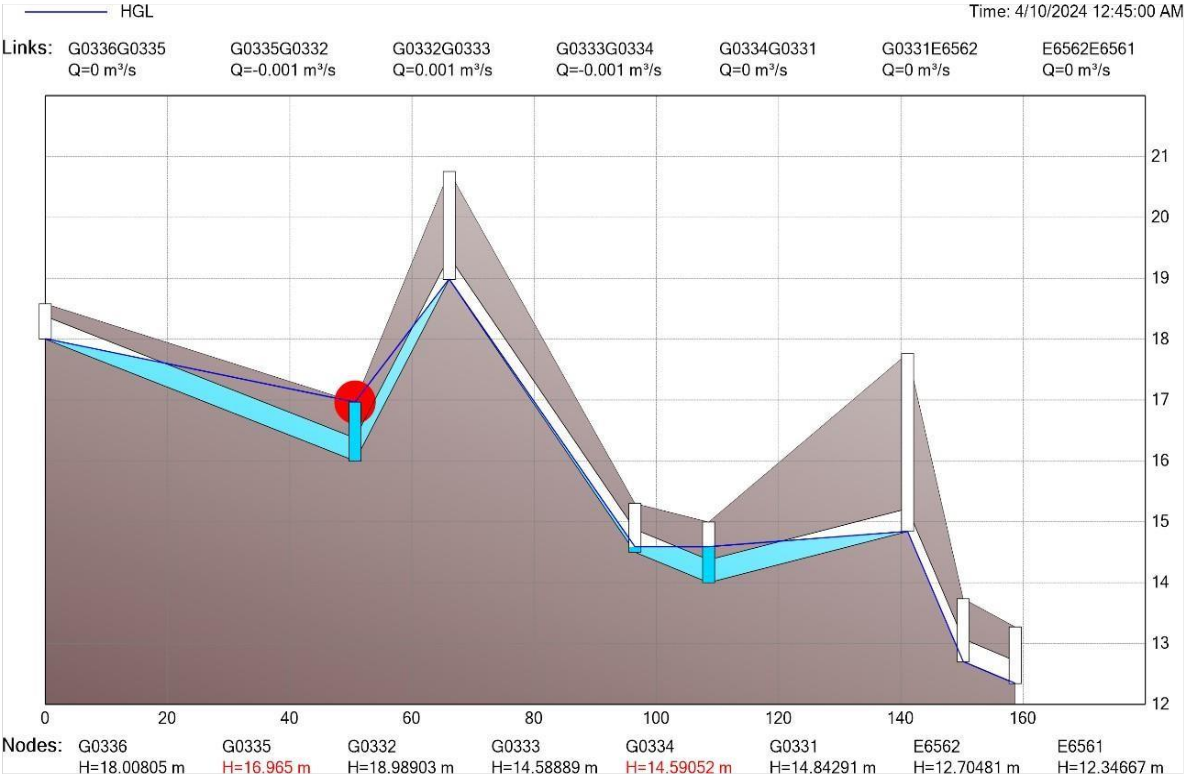


Figure 80: G0336E6561 Longsection (Clark Road)

Figure 80 illustrates a longsection along Clark Road. The negative slope of pipe G0335G0332 is caused by the inaccurate cover and invert elevation of G0332, leading G0335 to flood. The negative slope of pipe G0334G0331 is caused by the inaccurate cover and invert elevation of G0331, leading G0334 to surcharge. This has caused a backlog in the flow of stormwater in the network causing G0334 vulnerable to possible flooding.

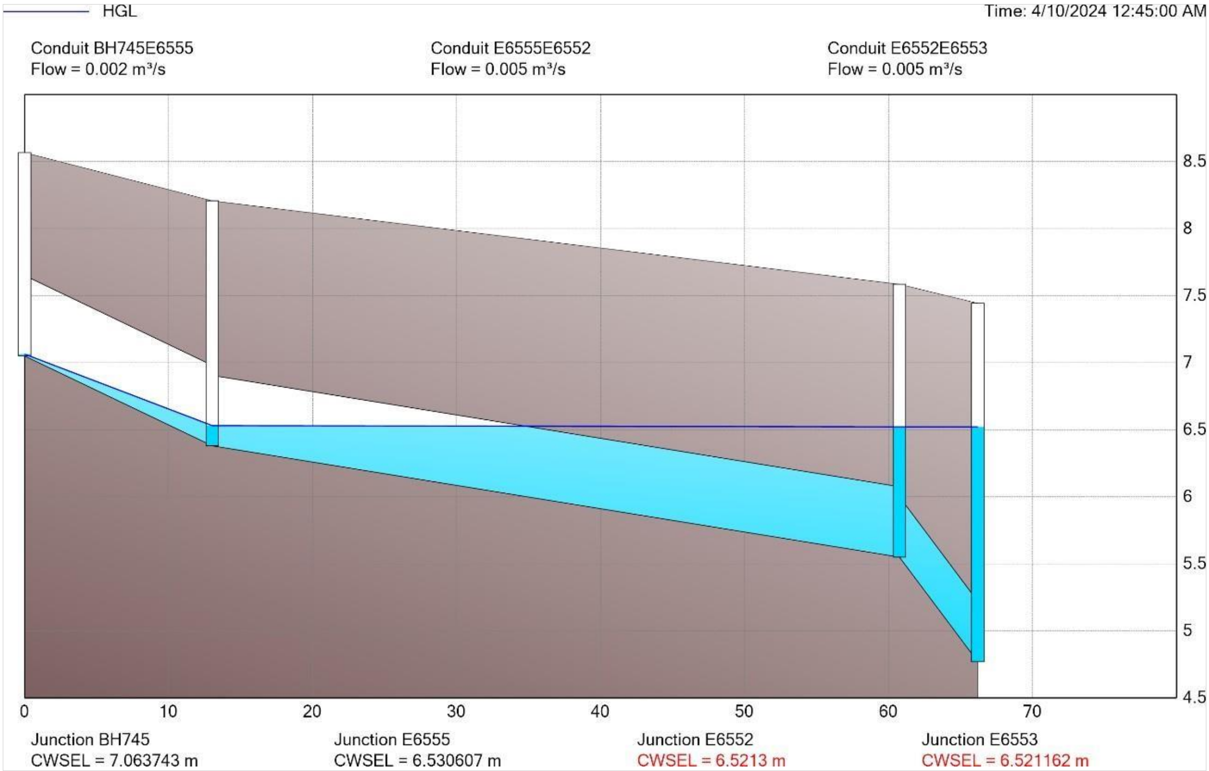


Figure 81:BH745E6553 Longsection (Phila Ndwandwe Road)

Figure 81 illustrates a longsection along Phila Ndwandwe Road. ED6552 and E6553 are surcharging due to insufficient pipe capacity. Pipes E6555E6552, and E6552E6553 must be upgraded to a higher pipe diameter from Ø450.

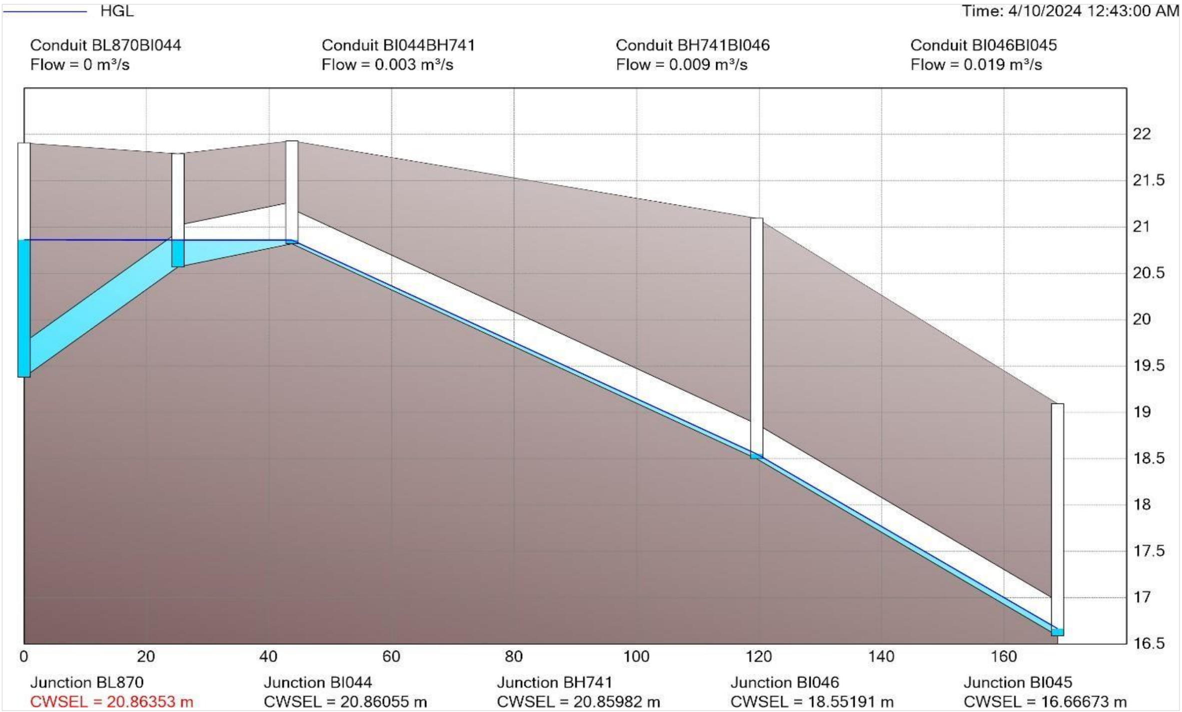


Figure 82: 74: BL870BI045 Longsection (Gokul Road)

Figure 82 is a longsection along Gokul Road. The negative slope of pipe BL870BI044 is caused by the inaccurate cover and invert elevation of BI044, leading BL870 to surcharge. This has caused a backlog in the flow of stormwater upstream in the network causing BL870 vulnerable to possible flooding.

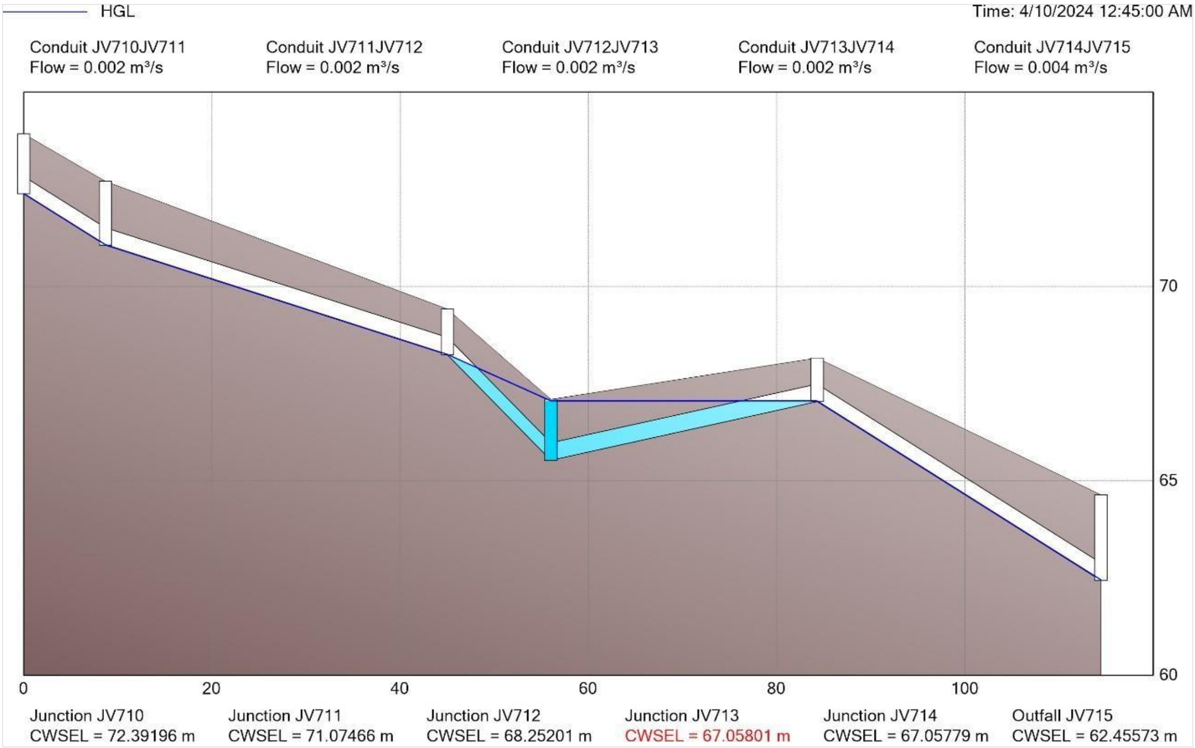


Figure 83: JV710JV15 Longsection (Mohan Road)

Figure 83 is a longsection along Mohan Road. The negative slope of pipe JV713JV714 is caused by the incorrect invert elevation of JV714, leading JV713 to flood. This has caused a backlog in the flow of stormwater in the network.

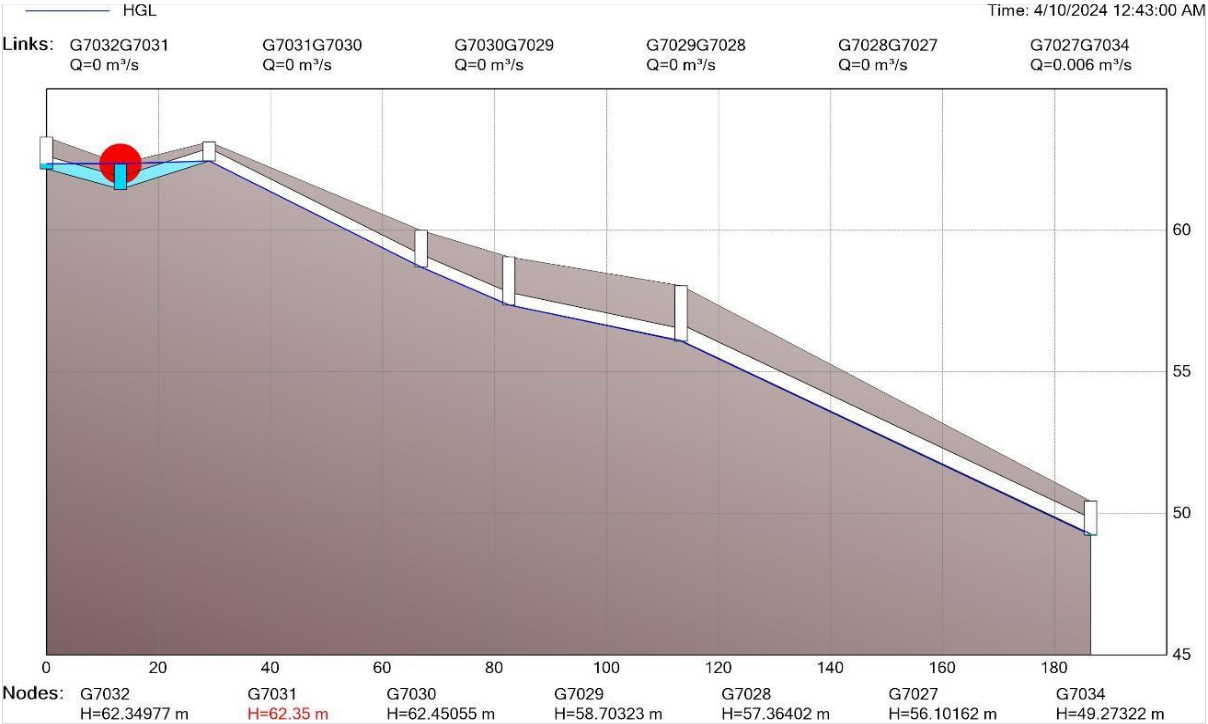


Figure 84: G7032G7034 Longsection (Road ID108054)

Figure 84 is a longsection along Road ID108054. The negative slope of pipe G7031G7030 is caused by the incorrect invert elevation of G7030, leading G7031 to flood. This has caused a backlog in the flow of stormwater upstream in the network.

5.3.3 Isipingo 2b

The manholes were rendered to display hours surcharged (h) with a blue gradient spectrum. The colour white can be regarded as being clear, whereas deeper blue can be regarded as extreme surcharging and subsequent flooding. Surcharging occurs when water rises to the top of the highest pipe as the rate of water entry exceeds the outlet's capacity. Flooding refers to all the water that overflows a manhole, whether it ponds or not.

In Isipingo 2b there are 15 surcharging structures with two flooding structures. The model shown in Figure 68,

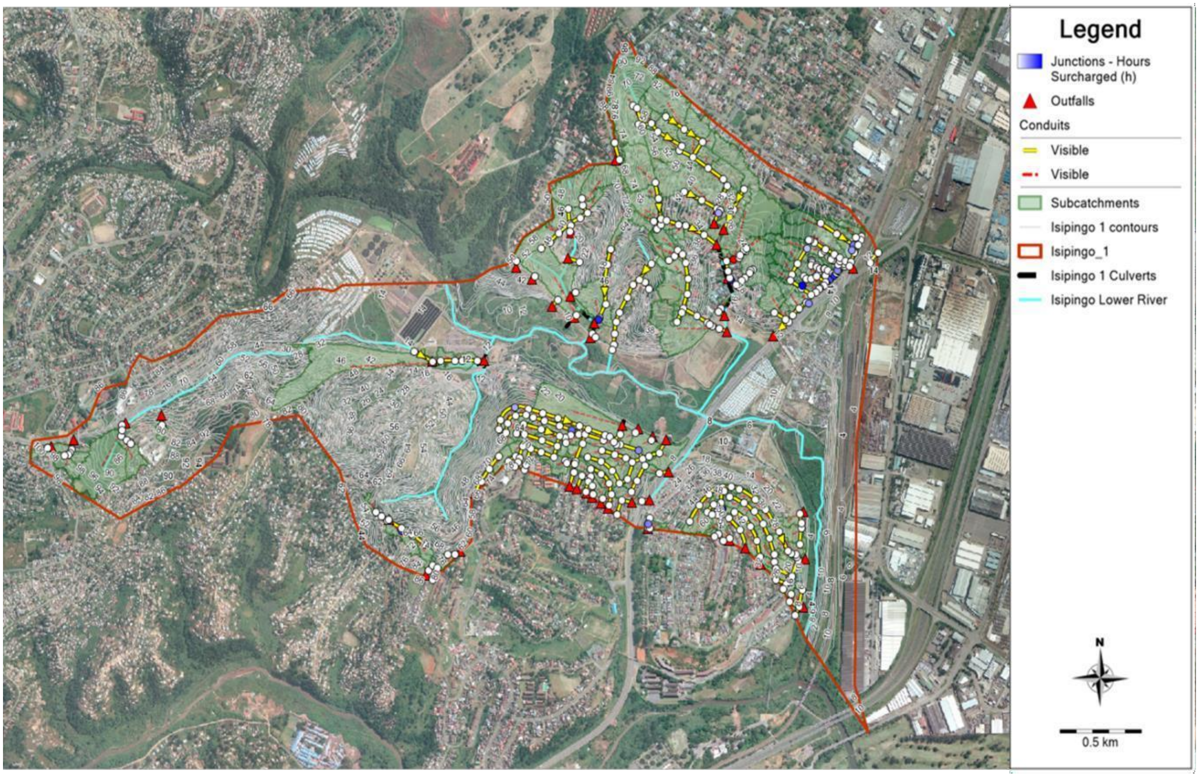


Figure 69, and Figure 70 have demonstrated that there are more clear/white manholes with isolated areas with varying shades of blue in the lower catchment. This means that the drainage infrastructure in Isipingo 2a is functioning sufficiently, indicating that the system has sufficient capacity to mitigate stormwater runoff with all three rain gauges 149.3 mm, 130 mm and 158 mm rainfall. Figure 77 indicates the model results for Isipingo 2a with the 149.3 mm 1 in 5-year design rainfall.

Figure 85: 149.3 mm 1 in 5-year design rainfall.

Figure 85 shows the Isipingo 2b model results with the 149.3 mm 1 in 5-year design rainfall. The model has sufficient capacity to mitigate stormwater runoff with 149.3 mm rainfall due to more clear/white structures and isolated surcharging/flooding areas in downstream networks. The results of the model are similar to Figure 86 and Figure 87 regardless of the different rainfall gauges due to the same problematic areas caused by the negative pipe slope, inaccurate cover level, and incorrect invert elevations.

Figure 86: 130 mm rainfall April 2019 floods.

Figure 86 shows the model results with the 130 mm rainfall April 2019 floods. The model has sufficient capacity to mitigate stormwater runoff with 130 mm rainfall due to more clear/white structures and isolated surcharging/flooding areas in downstream networks. The results of the model are similar to Figure 86 and Figure 87 regardless of the different rainfall gauges due to the same problematic areas caused by the negative pipe slope, inaccurate cover level, and incorrect invert elevations.

Figure 87: 158 mm rainfall April 2022 floods.

Figure 87 shows the model results with the 158 mm rainfall April 2022 floods. The model in Figure 85, Figure 86, and Figure 87 have produced fairly similar results regardless of the different rainfall gauges due to the same problematic areas caused by negative pipe slope, inaccurate cover, and incorrect invert elevations. This has ultimately caused certain structures to surcharge or to flood along the network. The different rain gauges only change the shade of the blue along the network which is regarded as the degree of surcharging and subsequent flooding.

The hydraulic capacity is compromised in certain areas due to negative pipe slope, inaccurate cover, and invert elevations. As a result, the drainage networks experience surcharging and subsequent flooding in these areas. The vulnerable areas in this sub-catchment include Phila Ndwandwe Road, Hillview Place, Lotus Road and Pardy Road. This is shown in the longsections on Figure 88, Figure 89, Figure 90, and Figure 91.

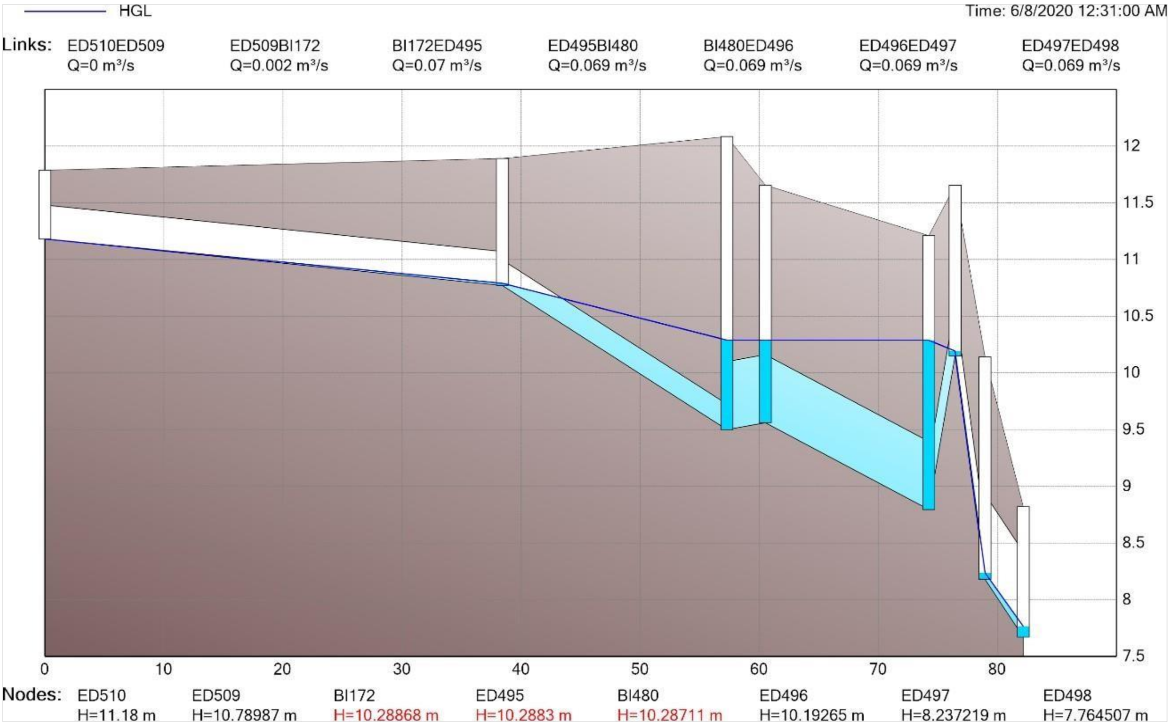


Figure 88: ED510ED498 Longsection (Phila Ndwandwe Road)

Figure 88 is a longsection along Phila Ndwandwe Road. The negative slope of pipe BI172ED495 is caused by the incorrect invert elevation of ED495, leading BI172 to surcharge. The negative slope of pipe BI480ED496 is caused by the incorrect invert elevation of ED496, leading BI480 to surcharge. This has restricted the flow of stormwater in the network causing BI172, ED495, and BI480 vulnerable to possible flooding.

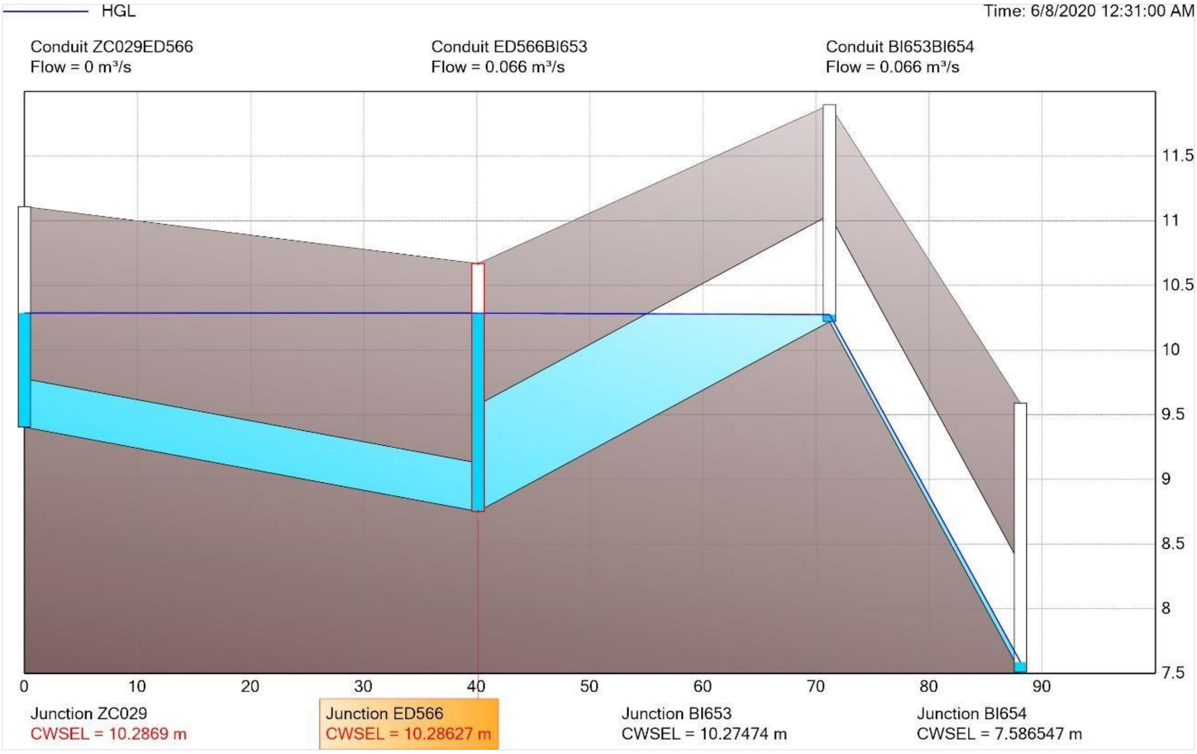


Figure 89: ZC029BI654 Longsection (Hillview Place)

Figure 89 illustrates a longsection along Hillview Place. The negative slope of pipe ED566BI653 is caused by the incorrect invert elevation of ED566, leading ZC029 and ED566 to surcharge. This has restricted the flow of stormwater downstream in the network causing ZC029, and ED566 vulnerable to possible flooding.

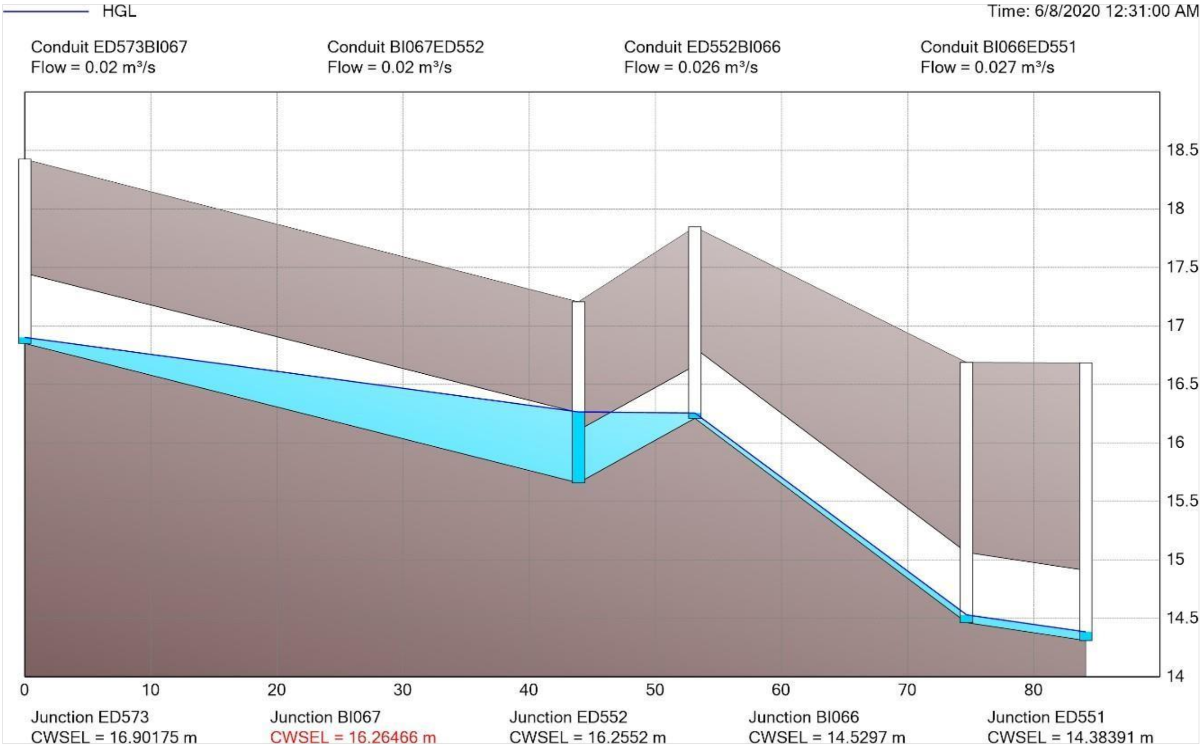


Figure 90: ED573ED551 Longsection (Lotus Road)

Figure 90 illustrates a longsection along Lotus Road. The negative slope of pipe BI067ED552 is caused by the incorrect invert elevation of ED552, leading BI067 to surcharge. This has restricted the flow of stormwater downstream in the network causing BI067 vulnerable to possible flooding.

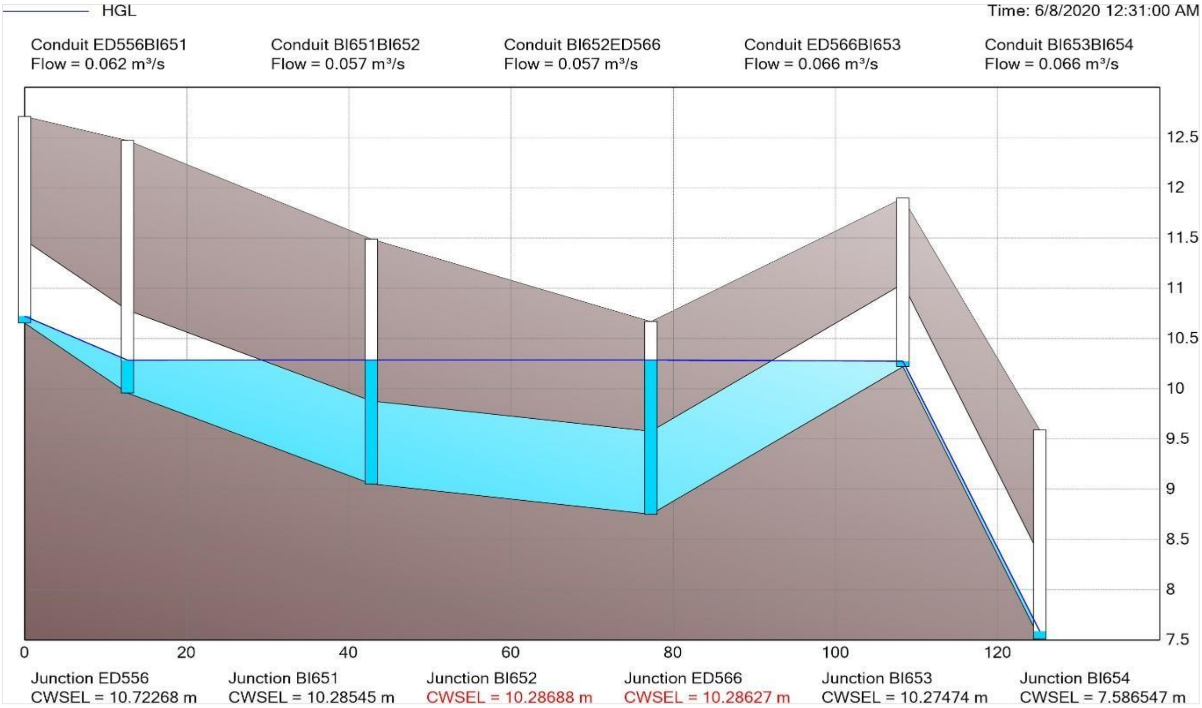


Figure 91: ED556BI654 Longsection (Pardy Road)

Figure 91 illustrates a longsection along Pardy Road. The negative slope of pipe ED566BI653 is caused by the incorrect invert elevation of BI653, leading ED566, and BI651 to surcharge. This has restricted the flow of stormwater downstream in the network causing BI652 and ED556 vulnerable to possible flooding.

5.3.4 Isipingo 2c

The manholes were rendered to display hours surcharged (h) with a blue gradient spectrum. The colour white can be regarded as being clear, whereas deeper blue can be regarded as extreme surcharging and subsequent flooding. Surcharging occurs when water rises to the top of the highest pipe as the rate of water entry exceeds the outlet's capacity. Flooding refers to all the water that overflows a manhole, whether it ponds or not.

In Isipingo 2c there are 41 surcharging structures with five flooding structures. The model shown in Figure 92, Figure 93, and Figure 94 have demonstrated that there are more isolated areas with varying shades of blue along the networks. This means that the drainage infrastructure in Isipingo 2c is not functioning adequately, indicating that the system is sufficient but with limited capacity to mitigate stormwater runoff with all three rain gauges 148.2 mm, 130 mm and 158 mm rainfall.

Figure 92: 151.6 mm 1 in 5-year design rainfall.

Figure 92 demonstrates the model results for Isipingo 2c with the 151.6 mm 1 in 5-year design rainfall. The model has limited capacity to mitigate stormwater runoff with 151.6 mm rainfall due to various surcharging/flooding areas. The results of the model are similar to Figure 93 and Figure 94 regardless of the different rainfall gauges due to the same problematic areas caused by the negative pipe slope, inaccurate cover level, and incorrect invert elevations.

Figure 93: 130 mm April 2019 floods.

Figure 93 is the Isipingo 2c model results with the 130 mm rainfall April 2019 floods. The model has limited capacity to mitigate stormwater runoff with 130 mm rainfall due to more surcharging/flooding areas at various networks. The results of the model are similar to Figure 92 and Figure 94 regardless of the different rainfall gauges due to the same problematic areas caused by the negative pipe slope, inaccurate cover level, and incorrect invert elevations.

Figure 94: 158 mm rainfall April 2022 floods.

Figure 94 is the Isipingo 2c model results with the 158 mm rainfall April 2022 floods. The model in Figure 92, Figure 93, and Figure 94 have produced fairly similar results regardless of the different rainfall gauges due to the same problematic areas caused by negative pipe slope, inaccurate cover level, and incorrect invert elevations. This ultimately causes certain structures to surcharge or to flood along the network. The different rain gauges only change the shade of the blue along the network which is regarded as the degree of surcharging and subsequent flooding.

The hydraulic capacity is compromised in certain areas due to negative pipe slope and inaccurate cover and inlet elevations. As a result, the drainage networks experience surcharging and subsequent flooding in these areas. The vulnerable areas in this sub-catchment include Inner Circuit Road, Delta Road, Duiker Road, Prospecton Road and Phila Ndwandwe Road. This is shown in the longsections on Figure 95, Figure 96, Figure 97, Figure 98, and Figure 99.

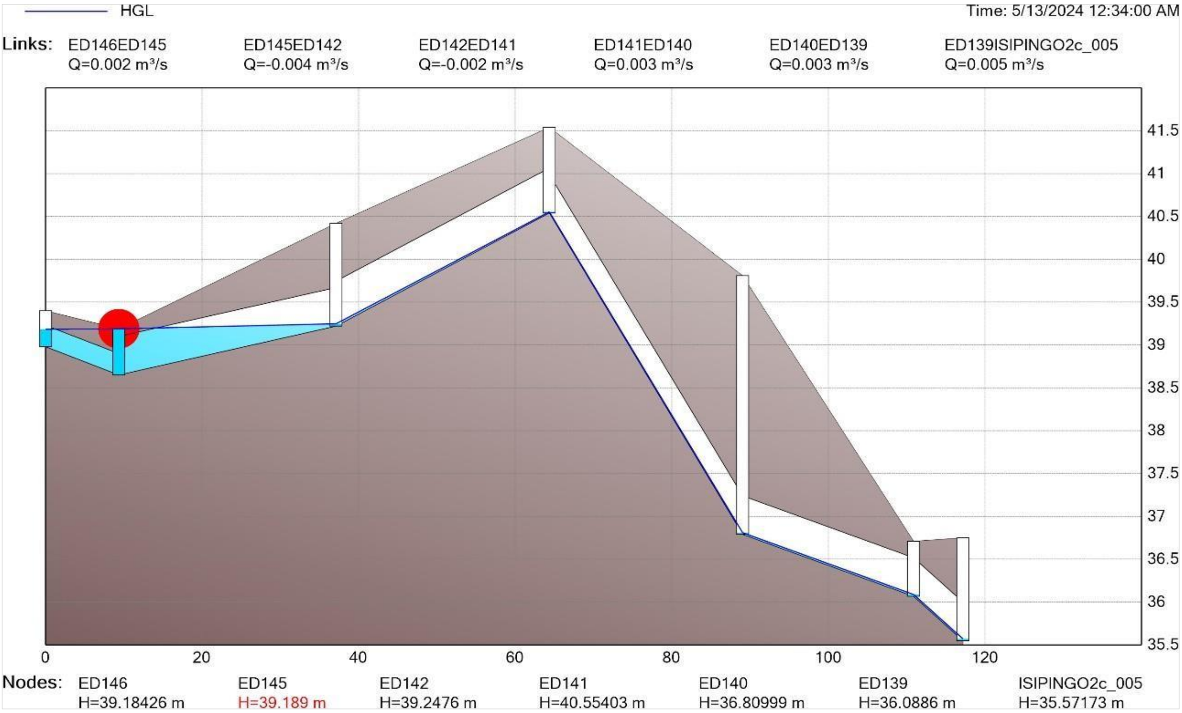


Figure 95: ED146Isipingo2c_005 Longsection (Inner Circuit Road)

Figure 95 illustrates a longsection along Inner Circuit Road. The negative slope of pipes ED142ED141, and ED145ED142 is caused by the incorrect invert elevation of ED142 and ED141. This has led ED145 to flood. This has restricted the flow of stormwater upstream in the network.

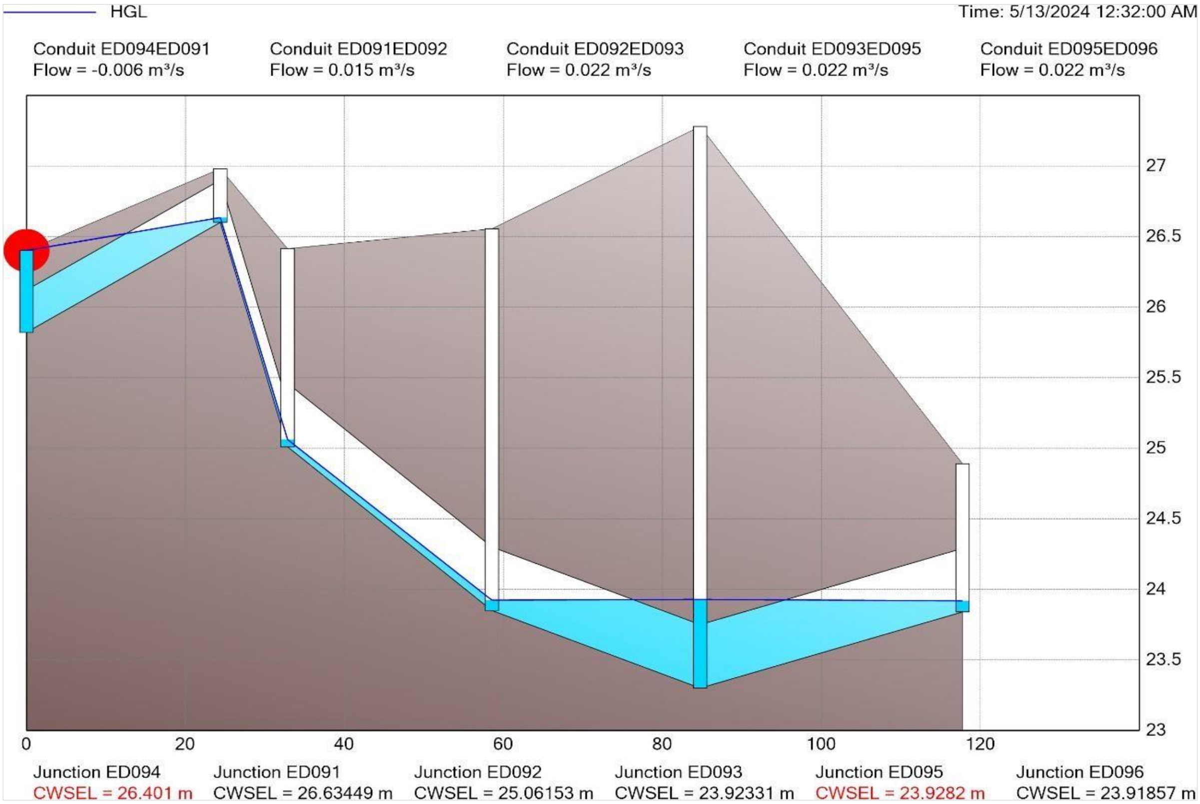


Figure 96: ED094ED096 (Delta Road)

Figure 96 is a longsection along Inner Delta Road. The negative slope of pipe ED094ED091 is caused by the incorrect invert elevation of ED091, leading ED094 to flood upstream. The negative slope of pipe ED095ED096 is caused by the incorrect invert elevation of ED095 and ED096, leading ED095 to surcharge. This has restricted the flow of stormwater upstream and downstream in the network.

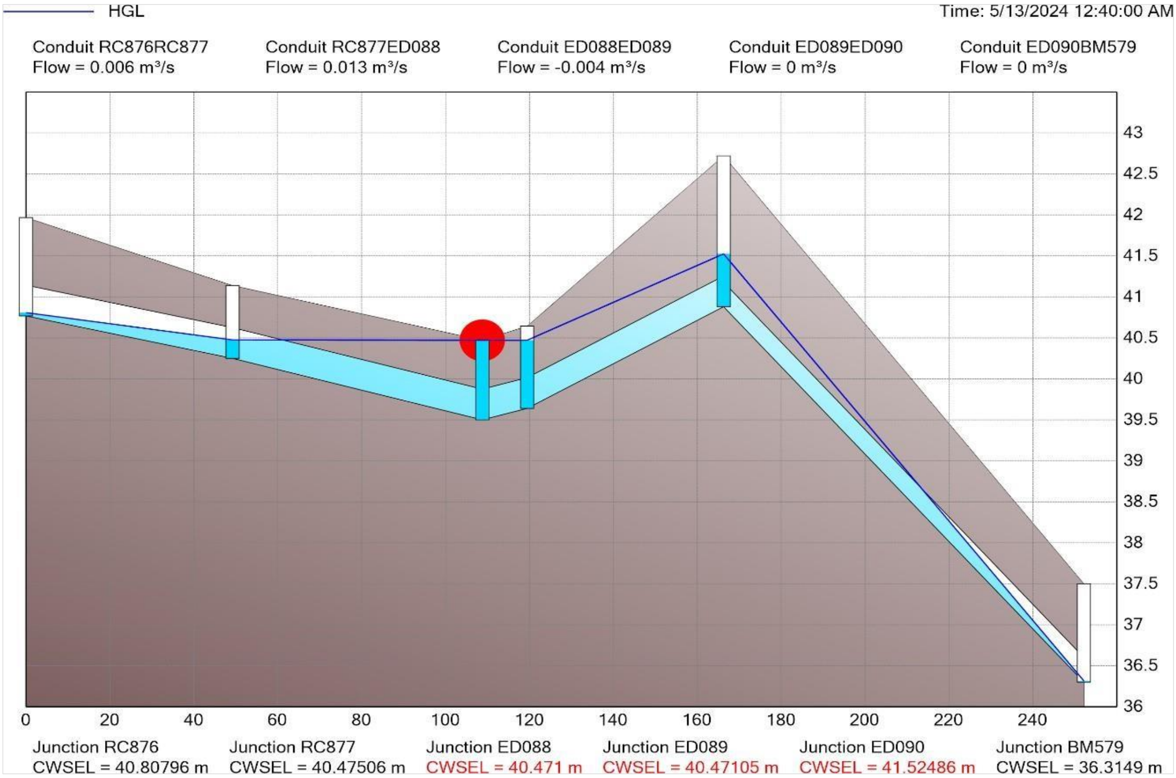


Figure 97: RC876BM879 Longsection (Duiker Road)

Figure 97 illustrates a longsection along Delta Road. The negative slope of pipes ED088ED089 and ED089ED090 is caused by the incorrect invert elevation of ED0889 and ED09909. This has led to ED088 to flood and surcharging of ED089 and ED0909. This has restricted the flow of stormwater in the network causing ED089 vulnerable to possible flooding.

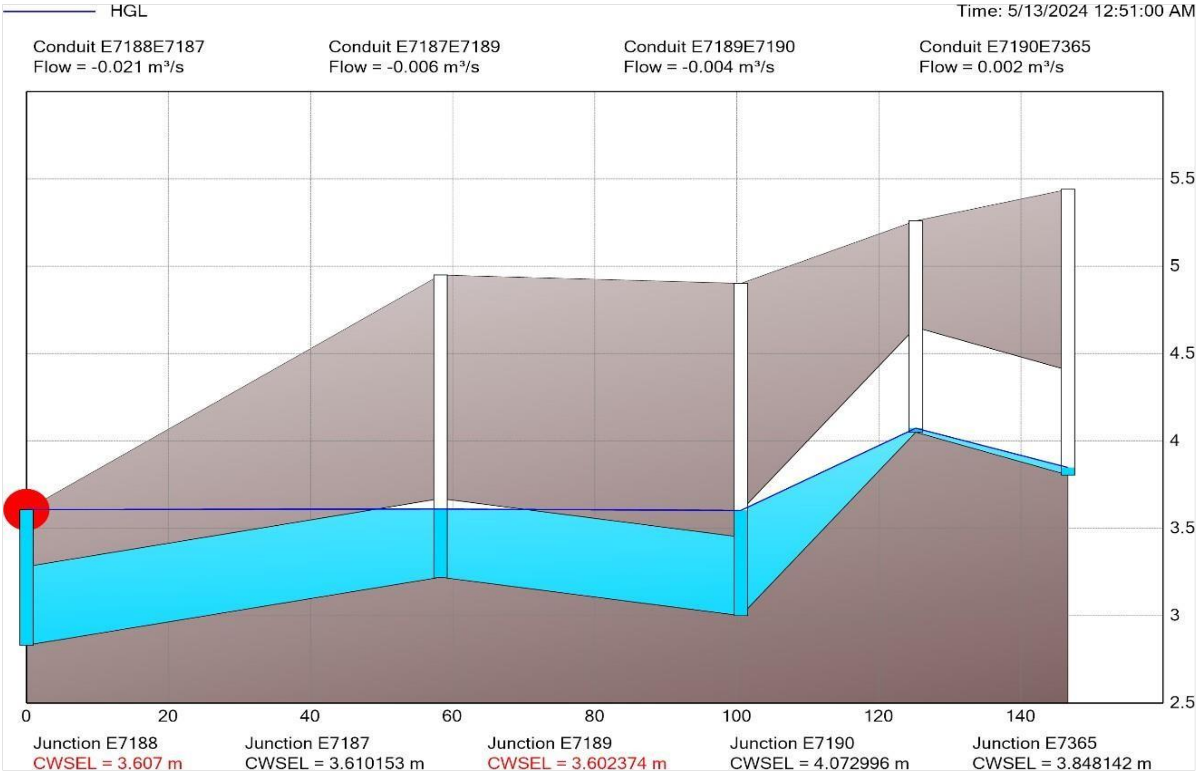


Figure 98: E7188E7365 Longsection (Prospecton Road)

Figure 98 is a longsection along Prospecton Road. The negative slope of pipes E7188E7187, E7187E7189, and E7189E7190 is caused by the incorrect invert elevation of E7187, E7189, E7190 and E8365. This has led to E7188 to flood and surcharging of E7189. This has restricted the flow of stormwater in the network causing E7187 and E7189 vulnerable to possible flooding.

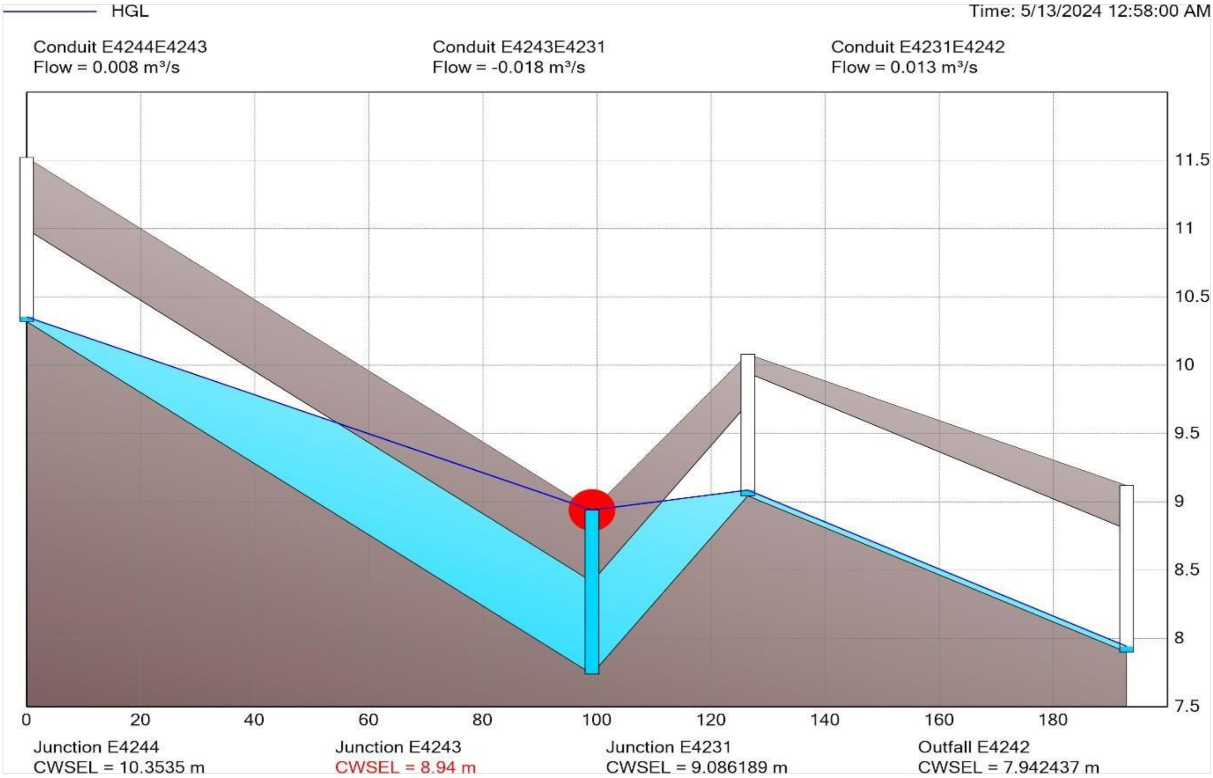


Figure 99: E4244E4242 Longsection (Phila Ndwandwe Road)

Figure 99 is a longsection along Phila Ndwandwe Road. The negative slope of pipes E424E4231 is caused by the incorrect invert elevation of E4231 and E4242 leading to E4243 to flood. This has restricted the flow of stormwater in the network.

5.3.5 Discussion

The results from objective 3 can be summarised in Table 27.

Table 27: Summary of PCSWMM Models Results

<table>
<tr><td colspan="5">Isipingo 1</td></tr>
<tr><td>No. Structures in model</td><td>No. of Surcharging Structures</td><td>Percentage Surcharging %</td><td>No. of Flooding Structures</td><td>Percentage Flooding %</td></tr>
<tr><td>403</td><td>21</td><td>5</td><td>9</td><td>2</td></tr>
<tr><td colspan="5">Isipingo 2a</td></tr>
<tr><td>192</td><td>14</td><td>7</td><td>3</td><td>2</td></tr>
<tr><td colspan="5">Isipingo 2b</td></tr>
<tr><td>279</td><td>15</td><td>5</td><td>2</td><td>1</td></tr>
<tr><td colspan="5">Isipingo 2c</td></tr>
<tr><td>591</td><td>41</td><td>7</td><td>5</td><td>1</td></tr>
</table>

*Refer to Appendix C for the PCSWMM results tables.

In Isipingo 1, there are 21 surcharging structures, with nine experiencing flooding. This is for all of the three assessed rainfall gauges, 148.2 mm shown on Figure 68, 130 mm shown on

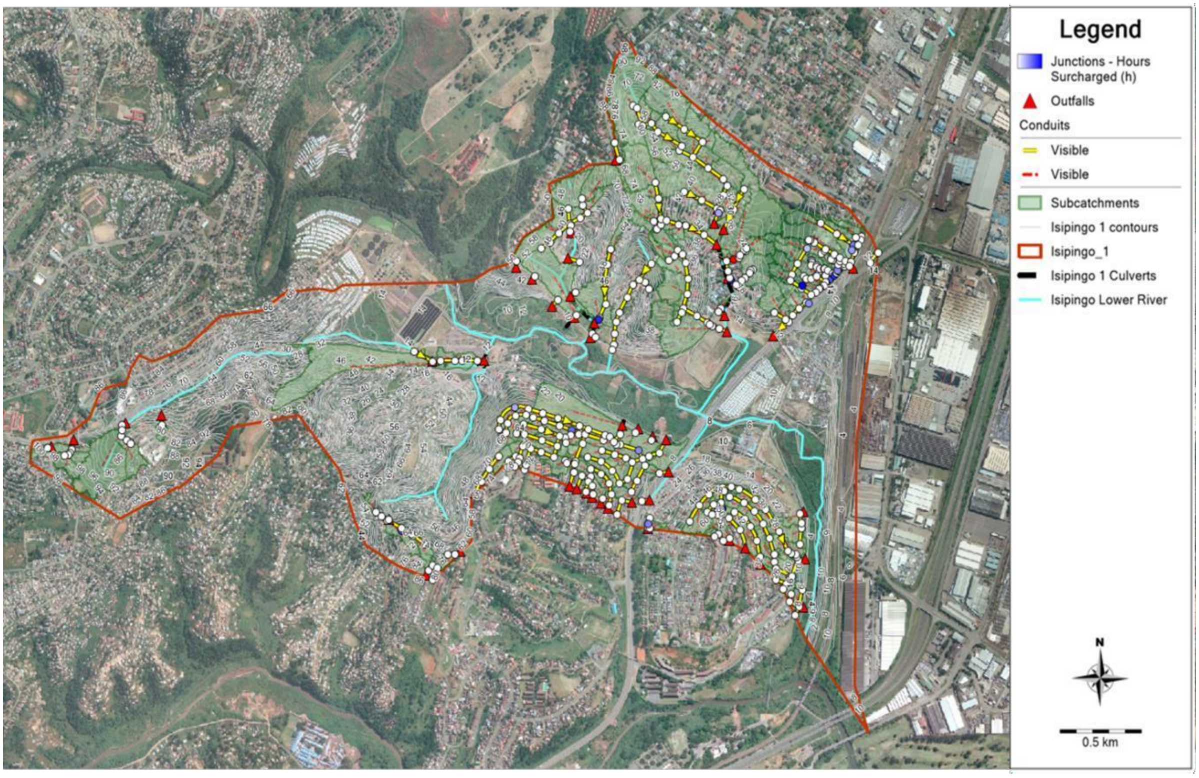


Figure 69 , and 158 mm on Figure 70. The data analysis reveals that Isipingo 1's drainage system performs satisfactorily overall. Particularly, only five per cent of drainage infrastructure is surcharging, while only two percent is flooding. These results indicate that the drainage infrastructure's design and implementation are mainly effective in managing stormwater runoff. However, the findings also highlight certain areas where blockages are present, indicating that improvements are necessary in specific locations.

Further analysis, as shown in the longsections in Figures 71–76, revealed various contributing reasons to the observed blockages. Negative pipe slopes, incorrect cover levels, and unsuitable invert levels have all been found to be crucial obstructions to the effective flow of water through the drainage system. These technical inadequacies cause specific surcharging and flooding. The vulnerable areas in this sub-catchment include Pepperberry Road, Sucrose Road, Nilgiri Road, Platt Road, Delhoo Road, and municipal stormwater servitudes on Plumerai Road and Marigold Road.

The Isipingo 2a region contains 14 surcharging structures. Three of these structures have been related to flooding occurrences, indicating a troubling pattern. This data places Isipingo 2a as having the third-highest number of flooded structures in the overall catchment. An analysis of the model shown in Figures 77, 78, and 79, which show rainfall gauges of 149.3 mm, 130 mm, and 158 mm, respectively, sheds light on the drainage system's performance in Isipingo 2a. The data indicate that the drainage system is performing adequately. Only 7% of the structures surcharge, while only two percent leads to subsequent flooding. This low occurrence of flooding illustrates the drainage system's ability to handle substantial rainfall, demonstrating its resilience and efficacy.

Despite this generally favourable performance, the data reveals the presence of specific places within Isipingo 2a where drainage concerns are more substantial. For example, several locations as shown in Figures 80 – 84 have blockages that limit the drainage system's hydraulic capability. These blockages can be ascribed to a variety of issues, including negative pipe slopes, inadequate cover, and inappropriate invert levels. Such flaws in drainage infrastructure can result in localised surcharging and flooding, showing that, while the system as a whole is robust, focused upgrades are required in certain places to improve overall performance and reduce flooding risks.

Isipingo 2b has a total of 15 surcharging structures, of which only two are prone to flooding. This significant statistic places Isipingo 2b as the sub-catchment with the fewest flooding structures across the whole catchment area, showing its greater resistance to floods when compared to other sub-catchments. In addition, the drainage system at Isipingo 2a performs effectively, indicating that the system has sufficient capacity to mitigate stormwater runoff with all three rain gauges 149.3 mm, 130 mm and 158 mm rainfall as shown in shown in Figure 68,

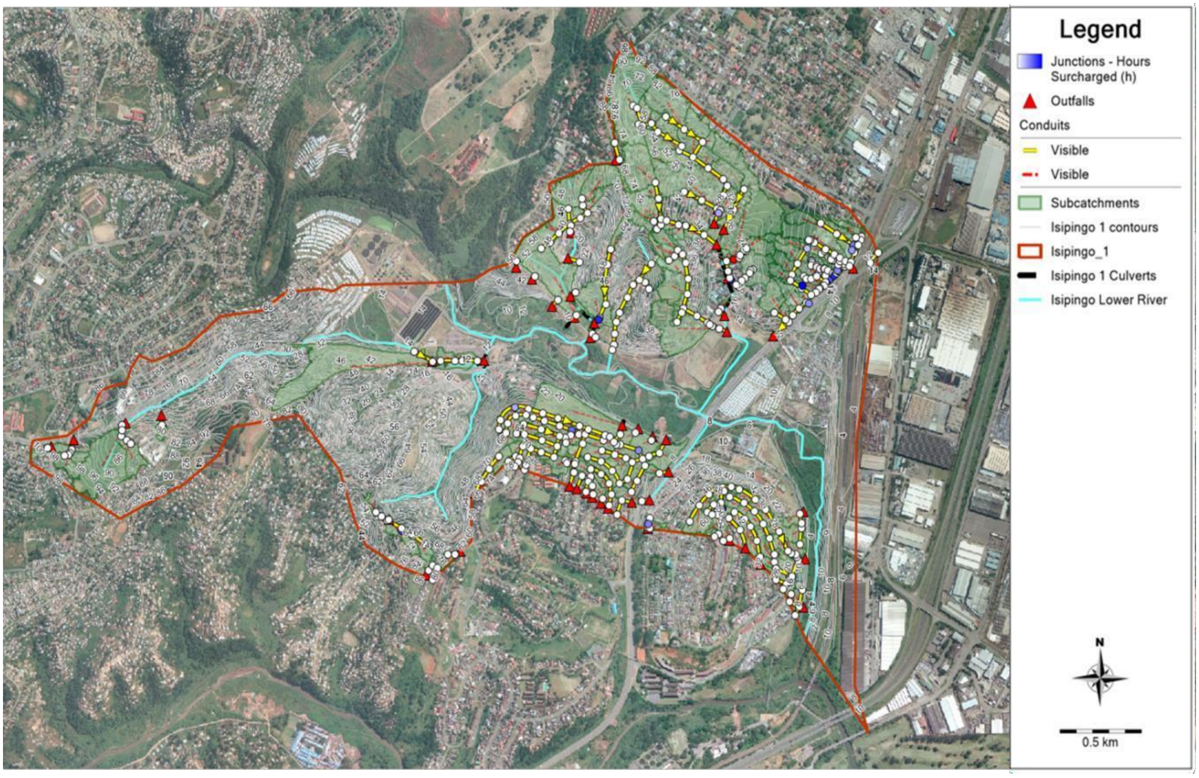


Figure 69, and Figure 70.

However, despite the overall effectiveness of the drainage systems, Isipingo 2b shares some common structural challenges with other sub-catchments. These issues include negative pipe slopes, inadequate cover over drainage pipes, and incorrect invert elevations, all of which can compromise the efficiency of the drainage system. Further assessment has identified specific places within Isipingo 2b that are more vulnerable to drainage issues. Clark Road, Phila Ndwandwe Road, Gokul Road, Mohan Road, and Road ID08054 are among the affected localities. Figures 80–84 depict extensive parts of these sensitive zones, offering a visual sense of the drainage issues experienced in these sites.

Isipingo 2c has been classified as a crucial location for its drainage infrastructure, with the largest number of surcharging structures (41). This concerning statistic demonstrates the scope of the issue, indicating that a significant portion of the drainage system is unable to efficiently maintain the flow of stormwater. Furthermore, Isipingo 2c ranks second in terms of flooded structures, with two incidents reported. This duality of surcharging and flooding indicates possible major flaws in the current drainage network. To quantify the severity of the situation, it is noted that 7% of the structures are experiencing surcharging, while only one percent result in flooding.

Although the proportion of flooding is relatively low, the existence of more surcharging structures indicates that the system is regularly overwhelmed raising the possibility of more severe flooding occurrences in the future.

The models presented in Figures 92, 93, and 94 further illustrate the challenges faced by the drainage infrastructure. This visual representation underscores the inadequacy of the Isipingo 2c drainage system, indicating that while the network is sufficient, its capacity to manage stormwater runoff is significantly limited with all three rain gauges 148.2 mm, 130 mm and 158 mm rainfall. The restricted hydraulic capacity of the drainage network can be attributed to several factors, including negative pipe slopes and inaccuracies in cover and invert elevations. These structural shortcomings add to the system's inefficiency, making it more prone to surcharging and flooding during severe rain events. The vulnerable areas within this sub-catchment are located in the Prospecton industrial area, specifically along the N2, Prospecton Road, Winter Road, Avenue East Road, Joyner Road, Ocean Road, Delta Road, and Duiker Road.

The extensive information acquired by these models in Isipingo 1, 2a, 2b, and 2c testifies to a well-engineered stormwater management system in the Lower Isipingo Catchment. The system's capacity to manage 148.2 mm, 130 mm, and 158 mm rainfall demonstrates its potential to successfully mitigate flooding threats in the sub-catchments Isipingo 1, 2a, 2b and 2c. This is critical during seasons of high rainfall because it allows runoff to be adequately directed away from urban areas, lowering the danger of floods. While the existence of surcharging and flooding structures indicates possible problematic regions, it does not detract from the system's overall efficacy. However, the drainage system is operating with limited capacity due to the subsequent consistent factors: variations in stormwater pipe diameter from upstream to downstream, negative slopes in pipes, inaccurate cover and invert elevations, and incorrect pipe sizes. As a result, the drainage system's structures experience surcharging and subsequent flooding creating vulnerable areas within the catchment with Isipingo 2c being the most vulnerable.

The frequent occurrence of surcharging structures and incidents of flooding in all the sub-catchments emphasises the necessity of upgrading and improving the drainage system to prevent additional flooding and damage to property. Prioritising maintenance and upgrades for the vulnerable locations, which include roads, industrial areas and stormwater servitudes, is necessary to guarantee the security and welfare of Isipingo's residences, citizens and businesses. Additionally, proper planning and design of future infrastructure projects should consider the potential impact of poor construction supervision and materials of the drainage systems to prevent similar issues from occurring in the future.

It is critical to understand that the models suggesting the drainage system's ability to mitigate 148.2 mm, 130 mm, and 158 mm rainfall, do not adequately reflect the actual conditions on site. While these models are valuable for theoretical assessments, they fail to take into account numerous crucial elements that might have a substantial influence on the system's performance during actual heavy rainfall events.

The PCSWMM program has an important limitation in that it cannot account for possible obstacles caused by debris, such as leaves, branches, or waste, which might hinder the flow of water through the drainage system. Furthermore, the program does not account for the likelihood of faulty infrastructure, such as broken pipes, which might impede the system's capacity to adequately manage severe rains. The underlying assumption that all drainage system components are in perfect operating condition is a serious error since it ignores the reality of maintenance issues that many systems encounter.

Given these constraints, it is evident that relying entirely on model outputs and ignoring real-site circumstances might result in an underestimation of the hazards associated with high rainfall occurrences. As a result, frequent site inspections and maintenance processes are critical for ensuring the system's durability and operation. Regular evaluations may assist detect and treat possible problems before they worsen, such as cleaning debris from drainage channels, restoring damaged infrastructure, and verifying that all components are operating properly. Prioritising these proactive actions can improve the resilience of the drainage system, ensuring that it can efficiently control stormwater runoff and reduce the danger of flooding during heavy rainfall events.

In summary, while Lower Isipingo Catchment’s drainage system demonstrates a commendable ability to manage rainfall effectively, the presence of certain structural deficiencies necessitates further investigation and remediation to ensure that all areas within the catchment can benefit from reliable flood management. Addressing these issues will be crucial in maintaining the integrity of the drainage network and protecting the community from potential flooding events in the future. This not only improves the local community's safety and well-being, but it also helps to ensure the urban environment's sustainability over time. The good findings of this study might serve as a model for other communities looking to enhance their stormwater management practices.

CHAPTER SIX: CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

6.1.1 Conclusions for Specific Objective 1

To evaluate the effects of urbanisation on the catchment's drainage system.

- Increasing the catchment's impermeable surface area will indefinitely lead to higher levels of surface runoff and a subsequent increase in peak storm flows in the drainage systems.
- The existing drainage system does not consider how continuous changes in land use affect the volume of runoff and flood peaks, making the Lower Isipingo Catchment vulnerable to flooding.

6.1.2 Conclusions for Specific Objective 2

To determine the extent to which solid waste impacts the drainage system's functionality.

- Flood risk is influenced by factors other than climate change and urbanisation.
- Poor maintenance of the drainage system increases flood risk due to blockages and deteriorated infrastructure.
- Surface runoff carries debris into drainage infrastructure, clogging and filling it with silt and litter, which can further reduce mitigation capacity and increase flooding.
- Urban areas that accommodate larger populations and higher volumes of traffic are more vulnerable to blocked and damaged drainage facilities.

6.1.3 Conclusions for Specific Objective 3

To assess the performance of the existing drainage system with varying rainfall data.

- The existing stormwater infrastructure within the catchment is sufficient to mitigate stormwater runoff for varied rainfall. However, due to hydraulic inconsistency of the stormwater network pipe sizes, slopes, covers and invert levels, the hydraulic capacity has proven to be insufficient in certain areas. This has resulted in localised flooding in various areas downstream in the catchment.
- Hydraulic Models are valuable for theoretical assessments as they cannot account

for possible obstacles on site caused by debris, and waste, which might hinder the performance drainage system.

6.2 Recommendations

6.2.1 Sustainable Methods

Ecosystem-based soft adaptation options can support hard flood control measures and include rehabilitation buffers, retention ponds, and wetlands that will naturally absorb excess water and eliminate pollutants. The existing Isipingo estuary must be rehabilitated to increase hydrological functionality and reduce flood peaks during flooding events. Retrofitting with sustainable urban drainage systems (SUDS) can be used to increase the resilience of existing infrastructure. Retrofitting is a soft infrastructure adaptation method that can be used as an alternative to costly stormwater infrastructure upgrade works. Retrofitting could be introduced progressively over a period of time. New SUDS and WSUD guidelines can be followed.

6.2.2 Stormwater Management

An effective asset management system will prevent costly replacements and malfunctions in the drainage system. Regular maintenance and management of stormwater systems must be implemented through asset management, which will increase the resilience of systems. A regular maintenance plan is required for effective operation. As part of maintenance, regular cleaning of stormwater drains (especially before the rainy season and after all storm events) and control of littering and illegal dumping are important to prevent the clogging of systems. Stormwater drains can be fitted with custom grids to avoid litter accumulating in the systems. Controlling the growth of vegetation, including the extermination of weeds and invader plants, and maintaining grass is part of stormwater system maintenance. Further research is recommended in order to produce flood risk maps as part of stormwater asset management.

REFERENCES

Afzaal, M., Hameed, S., Liaqat, I., Khan, A. A. A., Manan, H. A., Shahid, R. and Altaf, M. 2022. Heavy metals contamination in water, sediments and fish of freshwater ecosystems in Pakistan. *Water Practice & Technology*, 17 (5).

Al-Musharafia, S. K., Mahmoudb, I. Y. and Al-Bahryc, S. N. 2013. Heavy Metal Pollution from Treated Sewage Effluent. *APCBEE Procedia*, 5.

Andersson, E., Borgström, S. and McPhearson, T. 2017. Double Insurance in Dealing with Extremes: Ecological and Social Factors for Making Nature-Based Solutions Last. In: *Nature-Based Solutions to Climate Change Adaptation in Urban Areas*.

Armitage, N. 2011. The proposed South African National Guidelines for Sustainable Drainage systems. Paper presented at the *75th IMESA Conference*. Johannesburg.

Armitage, N., Vice, M., Fisher-Jeffes, L. and Winter, K. 2013. *Alternative Technology for Stormwater Management - The South African Guideline for Sustainable Drainage Systems*. Cape Town, University of Cape Town.

Ashley, R., Garvin, S., Pasche, E., Vassilopoulos, A. and Zevenbergen, C. 2007. *Advances in Urban Flood Management*. Taylor & Francis.

Asiri, M. M., Aldehim, G., Alruwais, N., Allafi, R., Alzahrani, I., Nouri, A. M., Assiri, M. and Ahmed, N. A. 2024. Coastal Flood risk assessment using ensemble multi-criteria decision-making with machine learning approaches. *Environmental Research*, 245.

Azimi, S., Ludwig, A.,.Thevenot, D. R. and Colin, J. L. 2003. Trace metal determination in total atmospheric deposition in rural and urban areas. *The Science of the Total Environment*, 308(1-3), pp.247-256.

Baillache, E. 2015. *Isipingo N2 upgrade a sign of SANRAL's 'divide and conquer' plan*. Available: https://southcoastsun.co.za/66614/isipingo-n2-upgrade-a-sign-of-sanrals-divide-and-conquer-plan/ (Accessed 20 September 2023).

Ballard, B. and Kellagher, R. 2007. *The SUDS Manual. Construction Industry Research & Information Association (CIRIA)*.

Bangelesa, F., Abel, D., Pollinger, F., Rai, P., Ziegler, K., Ebengo, D., Tshimanga, R. M., Ali, M. M., Knight, J. and Paeth, H. 2023. Projected changes in rainfall amount and distribution in the Democratic Republic of Congo – Evidence from an ensemble of high-resolution climate simulations. *Weather and Climate Extremes*, 42.

Begg, G. 1978. *The estuaries of Natal*. Natal Town and Regional Planning Commission, Pietermaritzburg, Natal, South Africa, 1978.

Björklund, K., Bondelind, M., Karlsson, A., Karlsson, D. and Sokolova, E. 2018. Hydrodynamic modelling of the influence of stormwater and combined sewer overflows on receiving water quality: Benzo(a)pyrene and copper risks to recreational water. *Journal of Environmental Management*, 207: 35-42.

Bles, T., Bessembinder, J., Chevreuil, M., Danielsson, P., Falemo, S., Venmans, A., Ennesserc, Y. and Löfroth, H. 2016. *Transportation Research Procedia*, 14: 58-67.

Bohman, A., Glaas, E. and Karlson, M. 2020. Integrating Sustainable Stormwater Management in Urban Planning: Ways Forward Towards Institutional Change and Collaborative Action. *Journal of Water* 12.

Botturi, A., Ozbayram, E. G., Tondera, K., Gilbert, N. I., Rouault, P., Caradot, N., Gutierrez, O., Daneshgar, S., Frison, N., Akyol, Ç., Foglia, A., Eusebi, A. L. and Fatone, F. 2021. Combined sewer overflows: A critical review on best practice and innovative solutions to mitigate impacts on environment and human health. *Critical Reviews in Environmental Science and Technology*, 51 (15).

Brandt, H. C. A. and Groot, P. C. D. 2001. Aqueous leaching of polycyclic aromatic hydrocarbons from bitumen and asphalt. *Water Research* 17.

Brown, R. R. and Farrelly, M. A. 2009. Delivering sustainable urban water management: a review of the hurdles we face *Water Science & Technology*, 59 (5): 839-846.

Bushesha, M. S. and Mbura, J. A. 2015. Identification of Reasons for and Socio-Economic Impacts of Persistent Floods in Dar Es Salaam. *World Journal of Social Science Research*, 2 (2).

C40 Cities Finance Facility. 2020. River Vulnerability Assessment for the eThekwini Municipality. *Business Case for Durban's Transformative Riverine Management Programme.*

Carle, M. V., Halpin, P. N. and Stow, C. A. 2005. Patterns of watershed urbanization and impacts on water quality *Journal of The American Water Resources Association* 503-741.

Chahinian, N., Moussa, R., Andrieux, P. and Voltz, M. 2005. Journal of Hydrology *Comparison of infiltration models to simulate flood events at the field scale*, 306 (2005): 191-204.

Chan, F. K. S., Griffiths, J. A., Higgitt, D., Xu, S., Zhu, F., Tang, Y.-T., Xu, Y. and Thorne, C. R. 2018. "Sponge City" in China—A breakthrough of planning and flood risk management in the urban context. *Land Use Policy* 76.

Chang, H. K., Tan, Y. C., Lai, J. S., Pan, T. Y., Liu, T.-M. and Tung, C. P. 2013. Improvement of a drainage system for flood management with assessment of the potential effects of climate change. *Journal of Hydrological Sciences* 58 (8), pp.1581-1597.

Chang, J., Liu, M., Xu, S., L.J. Hou, Wang, H. and Ballo, S. 2006. Temporal-spatial distribution and first flush effect of urban stormwater runoff pollution in Shanghai City (in Chinese). *Journal of Geographical Research*, 25 (6): 994-1002.

Che, L., Yin, S. and Guo, Y. 2024. Flood risk assessment combining the historical disaster statistics method with the index system method. *Hydrological Sciences Journal* 70 (3).

Chen, J., Gao, C., Zhou, H., Wang, Q., She, L., Qing, D. and Cao, C. 2024. Urban Flood Risk Assessment Based on a Combination of Subjective and Objective Multi-Weight Methods. *Applied Sciences*, 14 (9).

Chen, M., Li, Z., Gao, S., Xue, M., Gourley, J. J., Kolar, R. L. and Hong, Y. 2022. A flood predictability study for Hurricane Harvey with the CREST-iMAP model using high-resolution quantitative precipitation forecasts and U-Net deep learning precipitation nowcasts. *Journal of Hydrology*, 612.

Chen, S. and Ravallion, M. 2007. Absolute poverty measures for the developing world, 1981–2004. *National Academy of Sciences* 104 (43): 16757-16762.

Chen, X., Zhang, H., Chen, W. and Huang, G. 2021. Urbanization and climate change impacts on future flood risk in the Pearl River Delta under shared socioeconomic pathways. *Science of the total environment* 762.

Cheng, C., Zhang, F., Shi, J. and Kung, H. T. 2022. What is the relationship between land use and surface water quality? A review and prospects from a remote sensing perspective. *Environmental Science and Pollution Research* 29: 56887-56907.

Chimnonyerem, N. U., Chiemelu, N. E., Nkwuonwo, U. and Nkwunonwo, U. 2016. Exploring the Inadequacy of Pertinent Capacities for Urban Flood Risk Management in the Developing Countries. *Journal of Social Sciences*.

Chocat, B., Ashley, R., Marsalek, J., Matos, M. R., Rauch, W., Schilling, W. and Urbonas, B. 2007. Toward the Sustainable Management of Urban Stormwater. *Indoor and Built Environment* 16 (Google Earth Pro 7.3).

Coastal Stormwater and Catchment Management. 2022. *Ethekwini Municipality Online Datafeeds*. Available: https://data.ethekwinifews.durban/instrument/cameras (Accessed 10 March 2023).

COGTA. 2020. *Ethekwini Metropolitan KZN - Profile & Analysis - District Development Model* Pretoria, Government Printer Available: https://www.cogta.gov.za/ddm/wp-content/uploads/2020/07/Metro-Profile_Ethekwini.pdf (Accessed August 2021).

Cohen, L., Pooley, J., Ferguson, C. and Harms, C. 2011. Psychologists' Understandings of Resilience: Implications for the Discipline of Psychology and Psychology Practice. *The Australian Community Psychologist* 23.

Cook, M. 2016. *Personnel Selection: Adding Value Through People - A Changing Picture, 6th Edition*. John Wiley & Sons.

Cotterell, G. 2022. *KZN floods: 58 healthcare facilities damaged as eThekwini tries to restore water and electricity to areas*. Available: https://www.citizen.co.za/news/south-africa/kzn-floods-healthcare-facilities-damaged-water-electricity/ (Accessed 20 August 2023).

Cousins, J. J. 2018. Remaking stormwater as a resource: technology, law, and citizenship. *WIREs Water*, 5.

CSIR. 2019. *Climate Change: Detailed projections of future climate change over South Africa." In GreenBook National Overview*. Available: https://pta-gis-2-web1.csir.co.za/portal/apps/GBCascade/index.html?appid=b161b2f892194ed5938374fe2192e537 (Accessed 5 July 2023).

D'Ambrosio, R., Balbo, A., Longobardi and Rizzo, A. 2022. Re-think urban drainage following a SUDS retrofitting approach against urban flooding: A modelling investigation for an Italian case study. *Urban Forestry & Urban Greening*, 70.

Department of Environmental Affairs. N.D *Climate Change Adaptation Climate Information and Early Warning Systems [Fact sheet]*. DEA, SANBI, GIZ. Available: https://www.dffe.gov.za/sites/default/files/reports/ltas_factsheet_climateinformationandearlywarningsystems.pdf (Accessed 02 February 2024).

Department of Human Settlements. Department of Human Settlements. 2019. *The Neighbourhood Planning and Design Guide*. South Africa South African Government.

Department of Public Works. 2012. *Small Wastewater Treatment Works DWP Guidelines.*

Dhakal, K. P. and Chevalier, L. R. 2017. Managing urban stormwater for urban sustainability: Barriers and policy solutions for green infrastructure application. *Journal of Environmental Management*, 203 (1): 171-181.

Dieppois, B., Rouault, M. and New, M. G. 2015. The impact of ENSO on Southern African rainfall in CMIP5 Ocean Atmosphere coupled climate models. *Climate Dynamics*.

Dijkstra, H. A. 2024. The role of conceptual models in climate research. *Physica D: Nonlinear Phenomena*, 457.

Dubrovsky, N., Burow, K., Clark, G., Gronberg, J., Hamilton, P., Hitt, K., Muelle, D., Munn, M., Nolan, B., Puckett, L. and Rupert, M. 2010. *The quality of our nation's waters: Nutrients in the nation's streams and groundwater, 1992-2004*. U.S. Geological Survey.

Duong, T. T. T. and Lee, B. K. 2011. Determining contamination level of heavy metals in road dust from busy traffic areas with different characteristics. *Journal of Environmental Management*, 92: 554-562.

Edwards, B. 2022. *Isipingo canal causing Prospecton businesses to flood*. Available: https://southcoastsun.co.za/213086/isipingo-canal-causing-prospecton-businesses-to-flood/ (Accessed October 2022).

EEA. 2016. *Urban adaptation to climate change in Europe 2016*. European Environment Agency.

Efraimidou, E. and Spiliotis, M. 2024. A GIS-Based Flood Risk Assessment Using the Decision-Making Trial and Evaluation Laboratory Approach at a Regional Scale Methodology. *Environmental Processes*, 11.

Ellis, J. B. 2006. Pharmaceutical and personal care products (PPCPs) in urban receiving waters. *Environmental Pollution* 144: 184-189.

Ellis, J. B. and Lundy, L. 2016. Implementing sustainable drainage systems for urban surface water management within the regulatory framework in England and Wales. *Journal of Environmental Management*, 183: 630-636.

Engelbrecht, F. A., Steinkopf, J., Padavatan, J. and Midgley, G. F. 2024. Projections of Future Climate Change in Southern Africa and the Potential for Regional Tipping Points. *Ecological Studies*, 248

EPA. 2021. *Climate Change Indicators: Heavy Precipitation*. Available: www.epa.gov/climate-indicators/climate-change-indicators-heavy-precipitation#:~:text=Climate%20change%20can%20affect%20the,heavier%20rain%20and%20snow%20storms. (Accessed 20 June 2023).

eProp. 2013. *Isipingo CBD set to become a dynamic Commercial Node*. Available: https://eprop.co.za/commercial-property-news/item/15134-isipingo-cbd-set-to-become-a-dynamic-commercial-node (Accessed 12 December 2023).

Erasmus, D. 2019. Poor planning, lack of maintenance add to KZN woes as storms wreak havoc. *City Press* Available: https://www.news24.com/citypress/News/poor-planning-lack-of-maintenance-add-to-kzn-woes-as-storms-wreak-havoc-20191117 (Accessed 15 November 2023).

eThekwini Municipality. 2007. *South Durban Basin - Area Based Catchment Management : A Catalyst for change* Durban, South Africa eThekwini Municipality.

eThekwini Municipality. 2008. *Design Manual: Guidelines And Policy For The Design Of Stormwater Drainage And Stormwater Management Systems*. Durban Engineering Unit : Coastal Stormwater & Catchment Management Department.

eThekwini Municipality. 2018. *Integrated Development Plan 5 Year Plan: 2017/18 to 2021/22 - 2017/2018 Review* Durban, South Africa Ethekwini Municipality.

eThekwini Municipality. 2019. *Durban Climate Action Plan 2019*. Durban, South Africa Available: https://www.durban.gov.za/ (Accessed 4 July 2023).

eThekwini Municipality. 2021. *Integrated Development Plan- 5 Year Plan: 2017/18 to 2021/22 - 2020 /2021 Review*. Durban, South Africa Ethekwini Municipality.

eThekwini Municipality. 2022a. *Durban Climate Change Strategy 2022*. Durban, South Africa.

eThekwini Municipality. 2022b. *eThekwini Datafeeds* Available: https://data.ethekwinifews.durban/instrument/rain (Accessed 28 June 2023).

eThekwini Municipality. 2022c. *eThekwini Municipality Open GIS Data*. Available: https://gis-ethekwini.opendata.arcgis.com/ (Accessed 25 June 2023).

eThekwini Municipality. 2022d. *Rainfall Data* Available: https://www.durban.gov.za/pages/residents/rainfall-data (Accessed 28 June 2023).

eThekwini Municipality. 2023. *eThekwini Strategic Hub*. Available: https://strathub.durban.gov.za/ (Accessed 5 July 2023).

eThekwini Municipality and C40 Cities. 2023. *Climate Projections and Risk Assessment for eThekwini Municipality* Available: https://ethekwini.maps.arcgis.com/apps/MapSeries/index.html?appid=4c59620219d343a1aec468b87aa0ffc5 (Accessed 4 July 2023).

European Parliament. 2023. *Climate change: the greenhouse gases causing global warming*. Available: https://www.europarl.europa.eu/news/en/headlines/society/20230316STO77629/climate-change-the-greenhouse-gases-causing-global-warming#:~:text=Greenhouse%20gases%20act%20similarly%20to,be%2C%20supporting%20life%20on%20Earth. (Accessed 4 July 2023).

Filatova, T. 2014. Market-based instruments for flood risk management: A review of theory, practice and perspectives for climate adaptation policy. *Environmental Science & Policy*, 37: 227-242.

Fletcher, T. D. and Deletic, A. 2007. Statistical evaluation and optimisation of stormwater quality monitoring programmes. *Water Science & Technology*, 56 (12): 1-9.

Fletcher, T. D., Vietz, G. and Walsh, C. J. 2014. Protection of stream ecosystems from urban stormwater runoff : The multiple benefits of an ecohydrological approach. *Progress in Physical Geography Earth and Environment* 38 (5).

Fletchera, T. D., Shusterb, W., Huntc, W. F., Ashleyd, R., Butlere, D., Arthurf, S., Trowsdaleg, S., Barraudh, S., Semadeni-Daviesi, A., Bertrand-Krajewskih, J.-L., Mikkelsenj, P. S., Rival, G., Uhll, M., Dagenaismand, D. and Viklander, M. 2015. SUDS, LID, BMPs, WSUD and more – The evolution and application of terminology surrounding urban drainage. *Urban Water Journal*, 12 (Google Earth Pro 7.3).

Foekema, E. M., Gruijter, C. D., Mergia, M. T., Franeker, J. A. V., Murk, A. J. and Koelmans, A. A. 2013. Plastic in North Sea fish. *Environmental Science & Technology* 47: 8818-8824.

Fokazi, S. 2022. *R17bn — That's the estimated cost of KZN floods damage*. Available: https://www.timeslive.co.za/news/south-africa/2022-04-24-almost-r1-trillion-thats-what-it-will-cost-sa-to-rebuild-kzn/ (Accessed November 2023).

Forbes, A. T. and Demetriades, N. T. 2008. *Estuaries of Durban, KwaZulu-Natal, South Africa*. Environmental Management Department, eThekwini Municipality. .

Future Water and Climate Adaptation Services. 2018. *Climate Projections and Risk Assessment for eThekwini Municipality (South African National Treasury)*.

Gamerith, V., Gruber, G. and Muschalla, D. 2011. Single- and Multi-event Optimization in Combined Sewer Flow and Water Quality Model Calibration. *Journal of Environmental Engineering*, 137 (Google Earth Pro 7.3).

Gani, K. M. and Kazmi, A. A. 2016. Contamination of Emerging Contaminants in Indian Aquatic Sources: First Overview of the Situation. *Journal of Hazardous, Toxic, and Radioactive Waste*, 21 (Google Earth Pro 7.3).

Gardner, C. B. and Carey, A. E. 2004. Trace Metal and Major Ion Inputs into the Olentangy River from an Urban Storm Sewer. *Environmental Science and Technology* 38 (20): 5319-5326.

Gelhaus, C. 2017. *Reducing Pollution from Combined Sewer Overflows*. Available: hubsa.com (Accessed 14 October 2023).

Geyer, R., Jambeck, J. R. and Lavender, K. 2017. Production, use, and fate of all plastics ever made. *Science Advances*, 3 (Google Earth Pro 7.3).

Ghodsi, S. H., Zahmatkesh, Z., Goharian, E., Kerachian, R. and Zhu, Z. 2020. Optimal design of low impact development practices in response to climate change. *Journal of Hydrology*, 580.

Giannakidou, C., Diakoulaki, D. and Memos, C. D. 2020 Vulnerability to Coastal Flooding of Industrial Urban Areas in Greece. *Environmental Processes*, 7 (749-766).

Gilbreath, A. N. and McKee, L. J. 2015. Concentrations and loads of PCBs, dioxins, PAHs, PBDEs, OC pesticides and pyrethroids during storm and low flow conditions in a small urban semi-arid watershed. *Science of the Total Environment* 526.

Giri, S. and Qiu, Z. 2016. Understanding the relationship of land uses and water quality in Twenty First Century: A review. *Journal of Environmental Management*, 173: 41-48.

Gnecco, I., Berretta, C., Lanza, L. G. and Barbera, P. L. 2005. Storm water pollution in the urban environment of Genoa, Italy. *Atmospheric Research*, 77 (1-4): 60-73.

Goonetilleke, A. and Lampard, J.-L. 2019. Chapter 3- Stormwater Quality, Pollutant Sources, Processes, and Treatment Options. In: *Approaches to Water Sensitive Urban Design*. Woodhead Publishing.

Goulden, S., Portman, M. E., Carmon, N. and Alon-Mozes, T. 2018. From conventional drainage to sustainable stormwater management: Beyond the technical challenges. *Journal of Environmental Management*, 219: 37-45.

Green, D., O'Donnell, E., Johnson, M., Slater, L., Thorne, C., Zheng, S., Stirling, R., Chan, F. K. S., Li, L. and Boothroyd, R. J. 2021. Green infrastructure: The future of urban flood risk management? *Water* 8(6).

Guhathakurta, P. and Sreejith, O. P. 2011. Impact of climate change on extreme rainfall events and flood risk in India. Journal of Earth System Science, 120, pp.359-373.

Gunawardena, J., Egodawatta, P., Ayoko, G. A. and Goonetilleke, A. 2013. Atmospheric deposition as a source of heavy metals in urban stormwater. *Atmospheric Environment* 68: 235-242.

Hahladakis, J. N., Velis, C. A., Weber, R., Iacovidou, E. and Purnell, P. 2018. An overview of chemical additives present in plastics: Migration, release, fate and environmental impact during their use, disposal and recycling. *Journal of Hazardous Materials*, 344: 179-199.

Han, M. Y. and Mun, J. S. 2011. Operational data of the Star City rainwater harvesting system and its role as a climate change adaptation and a social influence. *Water Science and Technology* 63 (12).

He, P., Chen, L., Shao, L., Zhang, H. and Lü, F. 2019. Municipal solid waste (MSW) landfill: A source of microplastics? Evidence of microplastics in landfill leachate. *Water Research* 159 (38-45).

Heavy AI. *Remote Sensing*. Available: https://www.omnisci.com/technical-glossary/remote-sensing (Accessed September 2021).

Heinz, B., Birk, S., Liedl, R., Geyer, T., Straub, K. L., Andresen, J., Beste, K. and Kappler, A. 2009. Water quality deterioration at a karst spring (Gallusquelle, Germany) due to combined sewer overflow: evidence of bacterial and micro-pollutant contamination. *Environmental Geology* 57: 797-808.

Hendricks, M. D., Meyerb, M. A., Gharaibeh, N. G., Zandt, S. V., Mastersond, J., Horneye, J. A. and Berk, P. 2018. The development of a participatory assessment technique for infrastructure: neighborhood-level monitoring towards sustainable infrastructure systems. *Sustainable Cities and Society*, 38: 265-274.

Herngrena, L., Goonetillekea, A. and Ayokob, G. A. 2005. Understanding heavy metal and suspended solids relationships in urban stormwater using simulated rainfall. *Journal of Environmental Management* 76: 149-158.

Hoban, A. 2019. *Chapter 2: Water Sensitive Urban Design Approaches and Their Description*. Woodhead Publishing.

Hoedjes, J. C. B., Kooiman, A., Maathuis, B. H. P., Said, M. Y., Becht, R., Limo, A., Mumo, M., Nduhiu-Mathenge, J., Shaka, A. and Su, B. 2014. A conceptual flash flood early warning system for Africa, based on terrestrial microwave links and flash flood guidance. *ISPRS International Geo-Information*: 591-592.

Hou, J., Zhang, Y., Xia, J., Wang, Y., Zhang, S., Pan, X., Yang, M., Leng, G. and Dou, M. 2022. Simulation and Assessment of Projected Climate Change Impacts on Urban Flood Events: Insights from Flooding Characteristic Metrics. *Journal of Geophysical Research*, 127 (Google Earth Pro 7.3).

Hou, X., Guo, H., Wang, F., Li, M., Xue, X., Liu, X. and Zeng, S. 2020. Is the sponge city construction sufficiently adaptable for the future stormwater management under climate change? *Journal of Hydrology*, 588.

Huong, H. T. L. and Pathirana, A. 2013. Urbanization and climate change impacts on future urban flooding in Can Tho city, Vietnam. *Hydrology and Earth System Sciences*, 17 (1): 379-394.

Hussain, S.N., Zwain, H.M. and Nile, B.K., 2022. Modeling the effects of land-use and climate change on the performance of stormwater sewer system using SWMM simulation: case study *Water & Climate Change* 13 (1).

IFRC. 2021. Hazard Definitions In: *Public awareness and public education for disaster risk reduction*. 7-4.

IPCC. 2007. *Global climate projections. In Climate Change 2007: The Physical Science Basis : Solomon, S., Qin, D., Manning, M., Chen, Z., Marquis, M., Averyt, K.B., Tignor, M., Miller, H.L., Eds.* Cambridge, UK; New York, NY, USA: Cambridge University Press.

Matthews, T. K. Maycock, T. Waterfield, O. Yelekçi, R. Yu, and B. Zhou (eds.) Cambridge, United Kingdom and New York, NY, USA, 2391 Cambridge University Press.

IPCC. 2021b. *IPCC Sixth Assessment Report*.

Jambeck, J. R., Geyer, R., Wilcox, C., Siegler, T. R., Perryman, M., Andrady, A., Narayan, R. and Law, K. L. 2015. Plastic waste inputs from land into the ocean. *Science* 347 (6223).

James Environmental. 2021. *What is TSS?* Available: https://www.jamesenvironmental.com/what-is-tss-total-suspended-solids/ (Accessed 23 February 2024).

Jeremy B. C. Jackson, Kirby, M. X., Berger, W. H., Bjorndal, K. A., Botsford, L. W., Bourque, B. J., Bradbury, R. H., Cooke, R., Erlandson, J., Estes, J. A., Hughes, T. P., Kidwell, S., Lange, C. B., Lenihan, H. S., Pandolfi, J. M., Peterson, C. H., Steneck, R. S., Tegner, M. J. and Warner, A. R. R. 2001. Historical Overfishing and the Recent Collapse of Coastal Ecosystems. *Science* 293 (5530): 629-637.

Jing Suna, b., Zhua, Z.-R., Li, W.-H., Yana, X., Wanga, L.-K., Zhanga, L., Jind, J., Dai, X. and Ni, B.-J. 2021. Revisiting Microplastics in Landfill Leachate: Unnoticed Tiny Microplastics and Their Fate in Treatment Works. *Water Research*, 190.

JLB Consulting. 2022. *Toyota Stormwater Culvert to Outfall Project, Prospecton, Ethekwini Municipality, Kwazulu-Natal* JLB Consulting.

Jung, M., Kim, H., Mallari, K. J. B., Pak, G. and Yoon, J. 2014. Analysis of effects of climate change on runoff in an urban drainage system: a case study from Seoul, Korea *Water Science & Technology* 71 (5).

Jury, M. R. 2018. South Africa's Future Climate: Trends and Projections. *The Geography of South Africa*: 305-312.

Kalicharran, S. and Diab, R. 1993. Proposals for rehabilitation and management of Isipingo lagoon and estuary, South Africa. *Environmental Management* 17: 759–764.

Kanamarlapudi, S., Chintalpudi, V. and Muddada, S. 2018. Application of biosorption for removal of heavy metals from wastewater. *Biosorption*, 18: 69-116.

Kapelewska, J., Kotowska, U., Karpińska, J., Kowalczuk, D., Arciszewska, A. and Świrydo, A. 2018. Occurrence, removal, mass loading and environmental risk assessment of emerging organic contaminants in leachates, groundwaters and wastewaters. *Microchemical Journal* 137: 292-301.

Kauffman, G. J., Belden, A. C., Vonck, K. J. and Homsey, A. R. 2009. Link between Impervious Cover and Base Flow in the White Clay Creek Wild and Scenic Watershed in Delaware. *Journal of Hydrology Engineering* 14 (4): 324-334.

Khan, A. J. 2023. *Water quality worries hang over Durban months after deadly flooding*. Available: https://www.theguardian.com/environment/2023/jan/09/water-quality-worries-hang-over-durban-months-after-deadly-flooding (Accessed 22 June 2023).

Kikwasi, G. and Mbuya, E. 2019. Vulnerability analysis of building structures to floods: The case of flooding informal settlements in Dar es salaam, Tanzania. *International Journal of Building Pathology and Adaptation*, 37: 629-656.

Kim, S., Karahan, G., Sharma, M. and Pachepsky, Y. 2021. Vadose Zone Journal. *The site-specific selection of the infiltration model based on the global dataset and random forest algorithm*.

Kleidorfer, M., Mikovits, C., Jasper-Tönnies, Huttenlau, M., Einfalt, T. and Rauch, W. 2014. Impact of a Changing Environment on Drainage System Performance. *Procedia Engineering*, 70: 943-950.

Konrad, C. P. 2003. *Effects of Urban Development on Floods*. U.S. Geological Survey.

Labropoulou, E. and McKirdy, E. 2017. *Athens flash floods: 16 dead as rain wreaks havoc on Greek capital*. Available: https://edition.cnn.com/2017/11/15/europe/greece-flash-floods/index.html (Accessed 20 April 2023).

Lee, J. Y., Kim, H., Kim, Y. and Ha, M. Y. 2011. Characteristics of the event mean concentration (EMC) from rainfall runoff on an urban highway. *Environmental Pollution*, 159 (4): 884-888.

Li, C., Sun, N., Lu, Y., Guo, B., Wang, Y., Sun, X. and Yao, Y. 2023. Review on Urban Flood Risk Assessment. *Sustainability* 15 (1).

Liu, C., Guo, L., Ye, L., Zhang, S., Zhao, Y. and Song, T. 2018. A review of advances in China's flash flood early-warning system. *Natural Hazards*, 92: 619-634.

Liu, J. and Niyogi, D. 2019. Meta-analysis of urbanization impact on rainfall modification. *Scientific Reports*, 9 (1).

Luo, P., Wang, X., Zhang, L., Rozainy, M. R., Zainol, M. A., Duan, W., Hu, M., Zhang, Y., Wang, Y. and Nover, D. 2023. Future Land Use and Flood Risk Assessment in the Guanzhong Plain, China: Scenario Analysis and the Impact of Climate Change. *Remote Sensing* 15 (24)

Magnusson, K., Eliasson, K., Fråne, A., Haikonen, K., Hultén, J., Olshammar, M., Stadmark, J., Voisin, A. and Miljöinstitutet, I. S. 2016. *Swedish sources and pathways for microplastics to the marine environment - A review of existing data*. VL Swedish Environmental Research Institute.

Magomelo, M., Chikwiriro, H. and Gurure, C. 2014. An Implementation of Early Warning of Floods along Zambezi Basin Through the Use of Context-Awareness *International Journal of Computer Science and Mobile Computing* 3(8): 679-693.

Mahmood, M., Elagib, N. A., Horn, F. and Saad, S. A. G. 2017. Science of the Total Environment. *Lessons learned from Khartoum flash flood impacts: An integrated assessment*, 601-602: 1031-1045.

Mahmoud, S.H. and Gan, T.Y. 2018. Urbanization and climate change implications in flood risk management: Developing an efficient decision support system for flood susceptibility mapping. *The Science of The Total Environment, 636, pp.152–167*

Marambanyika, T. and Beckedahl, H. 2016. Wetland utilisation patterns in semi-arid communal areas of Zimbabwe between 1985 and 2013 and the associated benefits to livelihoods of the surrounding communities. *Transactions of the Royal Society of South Africa*, 72 (2)

Markiewicz, A., Björklund, K., Eriksson, E., Kalmykova, Y., Strömvall, A.-M. and Siopi, A. 2017. Emissions of organic pollutants from traffic and roads: Priority pollutants selection and substance flow analysis. *Science of The Total Environment*, 580: 1162-1174.

Masson-Delmotte, V., Zhai, P., Pirani, A., Connors, S.L., Péan, C., Berger, S., Caud, N., Chen, Y., Goldfarb, L., Gomis, M.I. and Huang, M., 2021. Climate change 2021: the physical science basis. Contribution of working group I to the sixth assessment report of the intergovernmental panel on climate change, 2(1), 2391.

McCabe, K. M., Smith, E. M., Lang, S. Q., Osburn, C. L. and Benitez-Nelson, C. R. 2021. Particulate and Dissolved Organic Matter in Stormwater Runoff Influences Oxygen Demand in Urbanized Headwater Catchments. *Environmental Science & Technology* 55 (2): 952-961.

Meng, X., Li, X., Nghiem, L. D., Ruiz, E., Johir, M. A., Gao, L. and Wang, Q. 2022. Improved stormwater management through the combination of the conventional water sensitive urban design and stormwater pipeline network. *Process Safety and Environmental Protection*, 159.

Miao, A., Wang, H., Dong, C. and Qin, A. 2021. Statistical characteristics and risk zoning of different duration heavy rainfall in Shanxi. *Natural Hazards*.

MILE eThekwini Municipality. n.d. *Urban Regeneration Initiatives in Isipingo* eThekwini Municipality September 2022).

Mizutori, M. and Guha-Sapir, D. 2020. *The human cost of disasters: an overview of the last 20 years (2000-2019)*. Belgium and Switzerland: United Nations Office for Disaster Risk Reduction, Centre for Research on the Epidemiology of Disasters.

MPCA. 2023. *Total Suspended Solids in stormwater*. Available: https://stormwater.pca.state.mn.us/index.php/Total_Suspended_Solids_(TSS)_in_stormwater (Accessed 23 February 2023).

Mthalane, V. 2022. *Floods hit Prospecton industries hard*. Available: https://southcoastsun.co.za/213231/floods-hit-prospecton-industries-hard/ (Accessed 23 April 2023).

Mugume, S. and Butler, D. 2017. Evaluation of functional resilience in urban drainage and flood management systems using a global analysis approach. *Urban Water.*

Mukhtar, M. A., Shangguan, D., Ding, Y., Anjum, M. N., Banerjee, A., Butt, A. Q., yadav, N., Li, D., Yang, Q., Khan, A. A., Muhammad, A. and He, B. B. 2024. Integrated flood risk assessment in Hunza-Nagar, Pakistan: unifying big climate data analytics and multi-criteria decision-making with GIS. *Big Data, AI, and the Environment*, 12.

Müller, A., Österlund, H., Marsalek, J. and Viklander, M. 2020. The pollution conveyed by urban runoff: A review of sources. *Science of The Total Environment*, 709.

Naidoo, M. 2022. *Dam Engineers Prevented a Greater Flood Catastrophe* Available: https://www.pressreader.com/south-africa/sunday-tribune-south-africa/20220501/281603834038322 (Accessed October 2022).

NASA. 2023. *Global Climate Change: Vital Signs of the Planet - Global Temperature* Available: https://climate.nasa.gov/ (Accessed 4 July 2023).

Ncwane, N. 2022. *KZN floods: SAPREF workers airlifted in submerged refinery*. Available: https://www.thesouthafrican.com/news/breaking-sapref-refinery-workers-airlifted-kzn-durban-floods/ (Accessed 20 August 2023).

Ngema, T. 2022. *Repair of flood-damaged roads coming along in KZN*. Available: https://www.iol.co.za/dailynews/news/kwazulu-natal/repair-of-flood-damaged-roads-coming-along-in-kzn-643fbdda-7da6-41f7-a18a-1b10bbff5e02 (Accessed 21 June 2023).

Nicolson, G. 2022. *Tragedy in KZN as floods cause devastation, mostly for the poor in informal settlements*. Available: https://www.dailymaverick.co.za/article/2022-04-12-tragedy-in-kzn-as-floods-cause-devastation-mostly-for-the-poor-in-informal-settlements/ (Accessed 20 June 2023).

Noor, M., Ismail, T., Shahid, S., Asaduzzaman, M. and Dewan, A. 2022. Sustainable Cities and Society. *Projection of rainfall intensity-duration-frequency curves at ungauged location under climate change scenarios*, 830.

Nyairo, W. and Owuor, P. 2015. Effect of anthropogenic activities on the water quality of Amala and Nyangores tributaries of River Mara in Kenya. *Environmental Monitoring and Assessment*, 187 (11).

Nyoka, S. 2022. *Durban floods: South Africa floods kill more than 300*. Available: https://www.bbc.com/news/world-africa-61092334 (Accessed 21 June 2023).

Palfreman, J. 2022. *Drone Mapping Reflects Solid Waste and Ocean Plastic Impact of the Durban Floods*. Available: https://dai-global-digital.com/drone-mapping-reflects-solid-waste-and-ocean-plastic-impact-of-the-durban-floods.html (Accessed 21 June 2023).

Pariartha, I. G. S., Aggarwal, S., Rallapalli, S., Egodawatta, P., McGree, J. and Goonetilleke, A. 2023. Compounding effects of urbanization, climate change and sea-level rise on monetary projections of flood damage. *Journal of Hydrology*, 620 (Part B).

Park, G. and Park, H. 2018. *Influence Analysis of Land Use By Population Growth on Urban Flood Risk Using System Dynamics*, WIT Transactions on Ecology and the Environment (215): 195 – 205.

Parnas, F. E. Å., Abdalla, E. M. H. and Muthanna, T. M. 2021. Hydrology Research. *Evaluating three commonly used infiltration methods for permeable surfaces in urban areas using the SWMM and STORM*, 52 (1).

Patel, F. 2022. *WATCH: Toyota SA halts operations after devastating KwaZulu-Natal floods*. Available: https://www.citizen.co.za/news/south-africa/watch-toyota-sa-halts-operations-after-devastating-floods/ (Accessed 20 August 2023).

PCSWMM Support. 2022. *Soil Characteristics* Available:
https://support.chiwater.com/77766/soil-characteristics (Accessed 28 June 2023).

Peng, L., Wang, Y., Yang, L., Garchagen, M. and Deng, X. 2024. A comparative analysis on flood risk assessment and management performances between Beijing and Munich. *Environmental Impact Assessment Review*, 104.

Petrie, B. 2021. A review of combined sewer overflows as a source of wastewater-derived emerging contaminants in the environment and their management. *Environmental Science and Pollution Research* 28: 32095-32110.

Pham, B. T., b, C. L., Dao, D. V., Phong, T. V., Nguyen, H. D., a, H. V. L., Meding, J. v. and Prakash, I. 2021. Flood risk assessment using deep learning integrated with multi-criteria decision analysis. *Knowledge-Based Systems*, 219.

Piadeh, F., Behzadian, K. and Alani, A. M. 2022. Journal of Hydrology *A critical review of real-time modelling of flood forecasting in urban drainage systems*, 607.

Pillay, R. K. 2013. An integrated study of the Isipingo River and estuary: Water and sediment quality, estuary-nearshore material fluxes, anthropogenic impacts and management. Master of Science in the School of Environmental Science University of Kwa-Zulu Natal.

Pillay, R. K., Pillay, S., Bissessur, A. and Ballabh, H. 2014. Net Flux of Heavy Metals Between Estuarine and Nearshore Environments: A Case Study of the Isipingo Estuary, KwaZulu-Natal, South Africa. *International Journal of Environmental Research* 8(4): 1241-1250.

Pinto, I., Zachariah, M., Wolski, P., Landman, S., Phakula, V., Maluleke, W., Bopape, M.-J., Engelbrecht, C., Jack, C., McClure, A., Bonnet, R., Vautard, R., Philip, S., Kew, S., Heinrich, D., Vahlberg, M., Singh, R., Arrighi, J., Thalheimer, L., Aalst, M. v., Li, S., Sun, J., Vecchi, G., Yang, W., Tradowsky, J., Otto, F. E. L. and Dipura, R. 2022. *Climate change exacerbated rainfall causing devastating flooding in Eastern South Africa*.

Pour, S. H., Wahab, A. K. A., Shahid, S., Md Asaduzzaman and Dewa, A. 2020. Low impact development techniques to mitigate the impacts of climate-change-induced urban floods: Current trends, issues and challenges. *Sustainable Cities and Society*, 62.

Price, K. 2011. Effects of watershed topography, soils, land use, and climate on baseflow hydrology in humid regions: A review. *Progress in Physical Geography: Earth and Environment*, 35 (4).

Pringle, J. 2022. Early warnings for floods in South Africa: engineering for future climate change. *Environment + Energy*,

Read, C. 2019. *Flash floods DEVASTATE Afghanistan killing 20 and destroying 2,000 homes*. Available: https://www.express.co.uk/news/world/1094803/afghanistan-floods-death-toll-Kandahar-city-united-nations (Accessed 20 April 2023).

Ringo, J., Sabai, S. and Mahenge, A. 2024. Performance of early warning systems in mitigating flood effects. A review. *Journal of African Earth Sciences*, 210.

Rogers, A. 1982. Sources of Urban Population Growth and Urbanization, 1950-2000: A Demographic Accounting. *Economic Development and Cultural Change*, 3 (Google Earth Pro 7.3).

Saldana, J. 2011. *Fundamentals of Qualitative Research*. Oxford University Press.

Salimi, M. and Al-Ghamd, S. G. 2020. Sustainable Cities and Society. *Climate change impacts on critical urban infrastructure and urban resiliency strategies for the Middle East*, 54.

Salvadore, E., Bronders, J. and Batelaan, O. 2015. Hydrological modelling of urbanized catchments: A review and future directions. *Journal of Hydrology* 529 (62-81).

SANRAL. 2019a. *N2/N3 Freeway upgrades* SANRAL Department of Department of Transport Available: https://stop-over.co.za/publications/update-series/2019/07/n2-n3-freeway/index.html (Accessed 20 September 2023).

SANRAL. 2019b. *National roads flooded but intact after KZN heavy rains*. Available: https://www.cover.co.za/news/national-roads-flooded-but-intact-after-kzn-heavy-rains (Accessed 22 April 2023).

SANRAL. 2021. *SIP 2 SANRAL Presentation N2 & N3 Projects Roll Out*: SANRAL.

SAWS. 2017. *The South African Weather Service's Response To The Two Severe Weather Events In Gauteng And KZN In The Month Of October 2017*. Available: https://www.weathersa.co.za/home/mediareleases (Accessed 4 July 2023).

SAWS. 2019a. *More rain expected as learners' head back to school post long weekend*. Available: https://www.weathersa.co.za/home/mediareleases (Accessed 4 July 2023).

SAWS. 2019b. *Widespread showers and thundershowers over central and south-eastern South Africa 21-22 April 2019 and caution to the Easter weekend traffic*. Available: https://www.weathersa.co.za/home/mediareleases (Accessed 4 July 2023).

SAWS. 2020. *IMPACT BASED SEVERE WEATHER WARNING SYSTEM (ImpB-SWWS)*. Available: https://www.weathersa.co.za/home/forecastques (Accessed 02 February 2024).

SAWS. 2022a. *Extreme rainfall and widespread flooding overnight: KwaZulu-Natal and parts of Eastern Cape*. Available: https://www.weathersa.co.za/home/mediareleases (Accessed 4 July 2023).

SAWS. 2022b. *Flooding Expected In Parts Of South Africa This Weekend (8 - 11 April 2022). Accompanied By Generally Frigid Conditions.* Available: https://www.weathersa.co.za/home/mediareleases (Accessed 4 July 2023).

Scarlett, R. D., Subramaniam, M., McMillan, S. K., Ingermann, A. T. and Sandra M. Clinton. 2021. Stormwater on the margins: Influence of race, gender, and education on willingness to participate in stormwater management. *Journal of Environmental Management*, 290.

Schneiderbauer, S. and Ehrlich, D., 2004. Risk, hazard and people's vulnerability to natural hazards. *A review of definitions, concepts and data. European Commission Joint Research Centre. EUR, 21410, p.40.*

Schertzinger, G., Zimmermann, S. and Sures, B. 2019. Predicted sediment toxicity downstream of combined sewer overflows corresponds with effects measured in two sediment contact bioassays. *Environmental Pollution* 782-791.

Schulze, R. E. 2023. The April 2022 flood producing rainfalls in KwaZulu-Natal in perspective: A historical review and a comparative overview *Centre for Water*

Resources Research, University of KwaZulu-Natal, Pietermaritzburg, South Africa.

Semadeni-Davies, A., Hernebring, C., Svensson, G. and Gustafsson, L.G. 2008. The impacts of climate change and urbanization on drainage in Helsingborg, Sweden: suburban stormwater. *Journal of Hydrology* 350 (114-125).

Shadid, S., Wang, X., Minhans, A. and Harun, S. 2016. Climate variability and changes in the major cities of Bangladesh: Observations, possible impacts and adaptation. *Regional Environmental Change*, 16 (2): 459-471.

Shafi, M., Jan, R. and Gani, K. M. 2023. Selection of priority emerging contaminants in surface waters of India, Pakistan, Bangladesh, and Sri Lanka. *Chemosphere* 341.

Shafi, M., Lodh, A., Khajuria, M., Ranjan, V. P., Gani, K. M., Chowdhury, S. and Goel, S. 2024. Are we underestimating stormwater? Stormwater as a significant source of microplastics in surface waters. *Journal of Hazardous Materials*, 465.

Shepherd, J. M., Andersen, T., Strother, C. and Horst, A. 2013. Earthzine *Urban Climate Archipelagos: A New Framework for Urban Impacts on Climate*,

Singh, A., Sharma, A., Verma, R. K., Chopade, R. L., Pandit, P. P., Nagar, V., Aseri, V., Choudhary, S. K., Awasthi, G., Awasthi, K. K. and Sankhla, M. S. 2022. *Heavy Metal Contamination of Water and Their Toxic Effect on Living Organisms*.

Sirviente, S., Sánchez-Rodrígue, J., Gomiz-Pascual, J. J., Bolado-Penagos, M., Sierra, A., Ortega, T., Álvarez, O., Forja, J. and Bruno, M. 2023. A numerical simulation study of the hydrodynamic effects caused by morphological changes in the Guadalquivir River Estuary *Science of the Total Environment*, 902.

Smit, J. 2022. *12 000 Family homes destroyed in devastating floods*. Available: https://www.news24.com/citypress/news/12-000-family-homes-destroyed-in-devastating-family-floods-20220417 (Accessed).

Sörensen, J., Persson, A., Sternudd, C., Aspegren, H., Nilsson, J., Nordström, J., Jönsson, K., Mottaghi, M., Becker, P., Pilesjö, P., Larsson, R., Berndtsson, R. and Mobin, S. 2016. Re-Thinking Urban Flood Management—Time for a Regime Shift. *Journal of Water* 8.

South African Government. 2022. *Declaration of a national state of disaster to respond to widespread flooding*. Available: https://www.gov.za/speeches/president-cyril-ramaphosa-declaration-national-state-disaster-respond-widespread-flooding (Accessed 20 June 2023).

South African National Treasury. 2022. *Treasury on funding framework for the response to the national disaster*. Available: https://www.gov.za/news/media-statements/treasury-funding-framework-response-national-disaster-07-jul-2022 (Accessed November 2023).

SSI Engineers and Marine and Estuarine Research. 2011. *Isipingo estuary management plan part i. Situation assessment*. Coastal Stormwater and Catchment

Management (CSCM) eThekwini Municipality.

Stewart, R. and Hytiris, N. 2008. The role of Sustainable Urban Drainage Systems in reducing the flood risk associated with infrastructure. Paper presented at the *11th International Conference on Urban Drainage*. Edinburgh, United Kingdom.

Sun, N., Li, C., Guo, B., Sun, X., Yao, Y. and Wang, Y. 2023. Urban flooding risk assessment based on FAHP–EWM combination weighting: a case study of Beijing. *Geomatics, Natural Hazards and Risk*, 14 (1).

Susdrain. 2016. *Melton, School SUDS scheme, Mowbray*. Available: https://www.susdrain.org/casestudies/case_studies/melton_school_SUDS_scheme_mowbray.html (Accessed December 2023).

Swan, A. 2010. How increased urbanisation has induced flooding problems in the UK: A lesson for African cities? *Physics and Chemistry of the Earth* 35: 643-647.

Swart, H. 1986. *Rehabilitation of the Isipingo Estuary and Lagoon* Natal Town and Regional Planning Commission, Pietermaritzburg, South Africa.

Tabari, H. 2020. Climate change impact on flood and extreme precipitation increases with water availability. *Scientific reports,* 10(1): 13768.

Tabari, H., Taye, M. T. and Willems, P. 2015. Water availability change in central Belgium for the late 21st century. *Global and Planetary Change*, 131: 115-123.

Taha, H. 1997. Urban climates and heat islands: albedo, evapotranspiration, and anthropogenic heat. *Energy and Buildings*, 25 (2): 99-103.

Tarmizi, A. H. A., Rahmat, S. N., Karim, A. T. A. and Tukimat, N. N. A. 2019. Climate Change and Its Impact on Rainfall. *The International Journal of Integrated Engineering*, 11: 170-177.

Tate, E., Rahman, M. A., Emrich, C. T. and Sampson, C. C. 2021. Flood exposure and social vulnerability in the United States. *Natural Hazards* 106: 435 - 457

The Planning Initiative. 2019. *Isipingo Cbd Urban Design Framework And 3-D Rendition: Detailed Urban Design Layout and Implementation Plan 1N-36296*. Durban, South Africa eThekwini Municipality

The Witness. 2022. *KZN Floods: Durban is in a "state of disaster", says Mayor Kaunda*. Available: https://witness.co.za/news/2022/04/12/kzn-floods-durban-is-in-a-state-of-disaster-says-mayor-kaunda-20220412/ (Accessed 20 November 2023).

Thomson, G. and Newman, P. 2018. Urban fabrics and urban metabolism – from sustainable to regenerative cities. *Resources, Conservation and Recycling*, 132: 218-229.

Thorslund, J., Jarsjo, J., Jaramillo, F., Jawitz, J. W., Manzoni, S., Basu, N. B., Chalov, S. R., Cohen, M. J., Creed, I. F., Goldenberg, R., Hylin, A., Kalantari, Z., Koussis, A.

D., Lyon, S. W., Mazi, K., Mard, J., Persson, K., Pietro, J., Prieto, C., Quin, A., Meter, K. V. and Destouni, G. 2017. Wetlands as large-scale nature-based solutions: Status and challenges for research, engineering and management. *Ecological Engineering*, 108 (Part B): 489-497.

Timeslive. 2022. *Ramaphosa announces national state of disaster after floods*. Available: https://www.businesslive.co.za/bd/national/2022-04-18-read-in-full-ramaphosa-announces-national-state-of-disaster-after-floods/ (Accessed 20 August 2023).

UNISDR. 2004. *Living with Risk: A Global Review of Disaster Reduction Initiatives, Ist Edn*. New York United Nations.

USEPA. 1983 *Result of the National Urban Runoff Project - Final Report* Washington DC: United States Environmental Protection Agency.

Vargus, D. M. 2009. Rainwater harvesting: A sustainable solution to stormwater management. Master of science The Pennsylvania State University.

Vizintin, G., Souvent, P., Veselič, M. and Curk, B. C. 2009. Determination of urban groundwater pollution in alluvial aquifer using linked process models considering urban water cycle. *Journal of Hydrology*, 377 (3-4): 261-273.

Vorreiter, L. and Hickey, C. 1994. Incidence of the first flush phenomenon in catchments of the Sydney region. Paper presented at the *Water Down Under*.

Wang, M., Fu, X., Zhang, D., Chen, F., Liu, M., Zhou, S., Su, J. and Tan, S. K. 2023. Assessing urban flooding risk in response to climate change and urbanization based on shared socio-economic pathways. *Science of The Total Environment*, 880

Wang, S., He, Q., Ai, H., Wang, Z. and Zhang, Q. 2013. Pollutant concentrations and pollution loads in stormwater runoff from different land uses in Chongqing. *Journal of Environmental Sciences* 25 (Google Earth Pro 7.3): 502-510.

Wang, X.-j., Zhang, J.-y., Shahid, S., Guan, E.-h., Wu, Y.-x., Gao, J. and He, R.-m. 2016a. Adaption to climate change impacts on water demand. *Mitigation and Adaption Strategies for Global Change*, 21: 81-99.

Wang, X.-j., Zhang, J.-y., Shahid, S., Guan, E.-h., Wu, Y.-x., Gao, J. and He, R.-m. 2016b. Mitigation and Adaptation Strategies for Global Change. *Adaptation to climate change impacts on water demand*, 21: 81-99.

Ward, C. J. 1980. *The plant ecology of the Isipingo Beach area, Natal, South Africa*. Pretoria Botanical Research Institute.

Wasko, C., Nathan, R., Stein, L. and O'Shea, D. 2021. Evidence of shorter more extreme rainfalls and increased flood variability under climate change. *Journal of Hydrology*, 603 (Part b)

Wen, X., Fang, G., Qi, H., Zhou, L. and Gao, Y. 2016. Changes of temperature and precipitation extremes in China: past and future. *Theoretical and Applied Climatology*, 126 (1-2): 369-383.

Wicks, B. 2022. *Picking up the pieces: KZN residents try to rebuild homes following floods.* . Available: https://ewn.co.za/2022/05/26/picking-up-the-pieces-kzn-residents-try-to-rebuild-homes-following-floods (Accessed 22 April 2023).

Wijesiri, B., Egodawatta, P., McGree, J. and Goonetilleke, A. 2015. Influence of pollutant build-up on variability in wash-off from urban road surfaces. *Science of The Total Environment*, 527-528: 344-350.

WITS. 2023. *The 2022 Durban floods were the most catastrophic yet recorded in KwaZulu-Natal*. Available: https://www.wits.ac.za/news/latest-news/general-news/2023/2023-04/the-2022-durban-floods-were-the-most-catastrophic-yet-recorded-in-kwazulu-natal.html (Accessed 20 June 2023).

Wong, T. 2006. Water sensitive urban design-the journey thus far. *Australasian Journal of Water Resources*, 10 (Google Earth Pro 7.3).

World Bank Group. 2016. *Promoting Green Urban Development in African Cities: eThekwini, South Africa Urban Environmental Profile*. Washington DC: World Bank.

Wu, Y., Sun, J., Hu, B., Zhang, G. and Roussea, A. N. 2023. Wetland-based solutions against extreme flood and severe drought: Efficiency evaluation of risk mitigation. *Climate Risk Management*, 40.

Xiong, Y., Mo, S., Wu, H., Qu, X., Liu, Y. and Zhou, L. 2023. Influence of human activities and climate change on wetland landscape pattern—A review. *Science of the Total Environment*, 879.

Xolo, N. 2022. *Floods bring catastrophic personal losses and costs*. Available: https://www.newframe.com/floods-bring-catastrophic-personal-losses-and-costs/ (Accessed 21 June 2023).

Yang, Y.-Y. and Lusk, M. G. 2018. Nutrients in Urban Stormwater Runoff: Current State of the Science and Potential Mitigation Options. *Water Pollution*, 4: 112-127.

Yin, J., Yu, D., Yin, Z., Wang, J. and Xu, S. 2015. Modelling the anthropogenic impacts on fluvial flood risks in a coastal mega-city: A scenario-based case study in Shanghai, China. *Landscape and Urban Planning*, 136: 144-155.
Zhang, X. Q. 2016. The trends, promises and challenges of urbanisation in the world. *Habitat International*, 54 (3): 241-252.

Zhang, T., Xiao, Y., Liang, D., Tang, H., Xu, J., Yuan, S. and Luan, B. 2020. A physically-based model for dissolved pollutant transport over impervious surfaces. *Journal of Hydrology* 590.

Zhao, H., Li, X. and Xiaomei Wang, D. T. 2010. Grain size distribution of road-deposited sediment and its contribution to heavy metal pollution in urban runoff in Beijing, China. *Journal of Hazardous Materials*, 183 (1-3): 203-210.

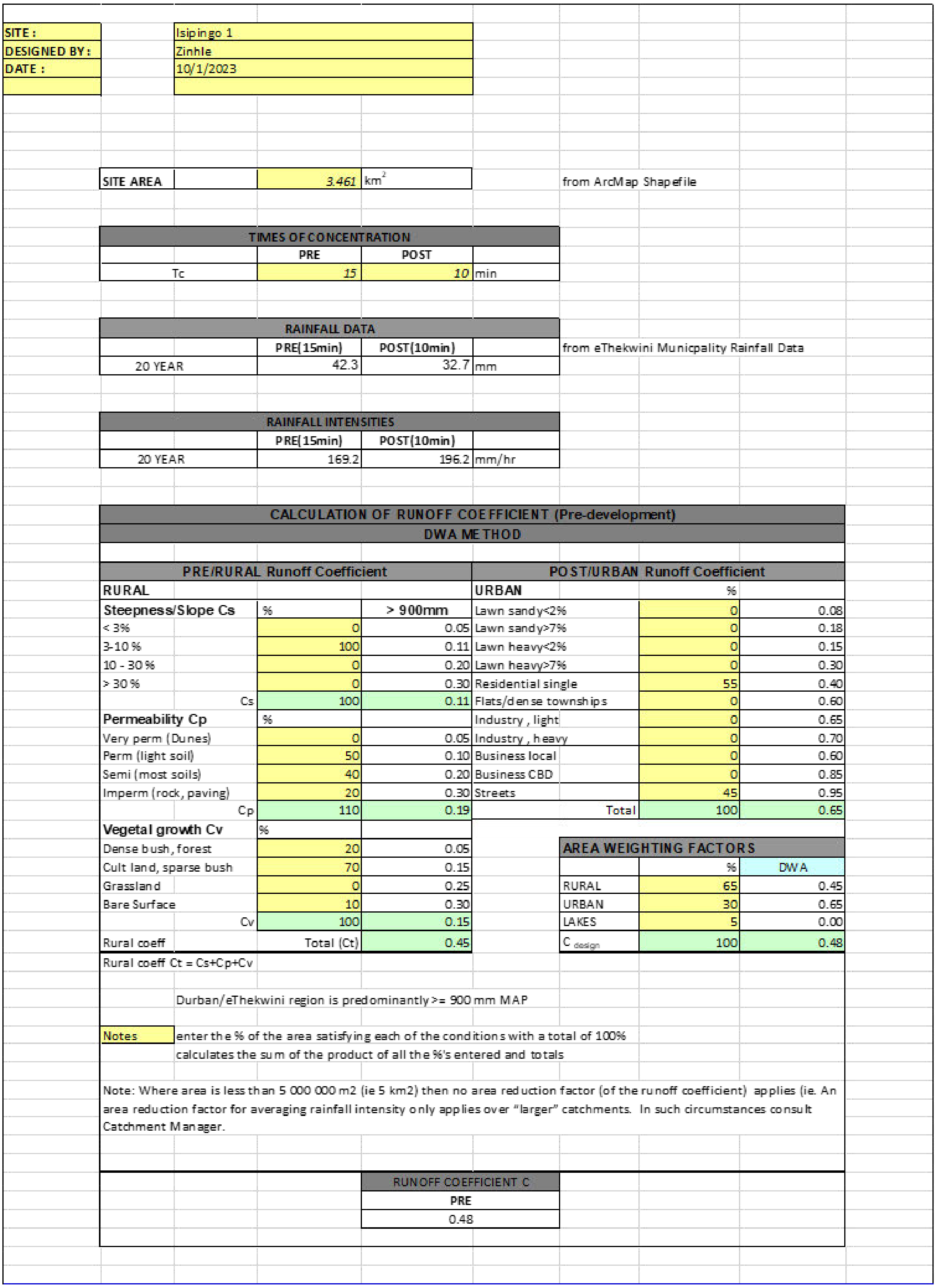
Zhou, Q., Leng, G., Su, J. and c, Y. R. 2019. Comparison of urbanization and climate change impacts on urban flood volumes: Importance of urban planning and drainage adaptation. *Science of The Total Environment*, 658: 24-33.

Zhu, W., Bian, B. and Li, L. 2007. Heavy metal contamination of road-deposited sediments in a medium size city of China. *Environmental Monitoring and Assessment* 147: 171-181.

Zivkovic, J. 2019. Human Settlements and Climate In: *Encyclopedia of the UN Sustainable Development Goals* 1-11

APPENDIX A

Table 28: Isipingo 1 pre-development calculations



SITE :	Isipingo 1
DESIGNED BY :	Zinhle
DATE :	10/1/2023

SITE AREA	3.461	km^2	from ArcMap Shapefile

TIMES OF CONCENTRATION			
	PRE	POST	
Tc	15	10	min

RAINFALL DATA				
	PRE(15min)	POST(10min)		from eThekwini Municpality Rainfall Data
20 YEAR	42.3	32.7	mm	

RAINFALL INTENSITIES			
	PRE(15min)	POST(10min)	
20 YEAR	169.2	196.2	mm/hr

CALCULATION OF RUNOFF COEFFICIENT (Pre-development)

DWA METHOD

PRE/RURAL Runoff Coefficient			POST/URBAN Runoff Coefficient		
RURAL			**URBAN**	%	
Steepness/Slope Cs	%	> 900mm	Lawn sandy<2%	0	0.08
< 3%	0	0.05	Lawn sandy>7%	0	0.18
3-10 %	100	0.11	Lawn heavy<2%	0	0.15
10 - 30 %	0	0.20	Lawn heavy>7%	0	0.30
> 30 %	0	0.30	Residential single	55	0.40
Cs	100	0.11	Flats/dense townships	0	0.60
Permeability Cp	%		Industry , light	0	0.65
Very perm (Dunes)	0	0.05	Industry , heavy	0	0.70
Perm (light soil)	50	0.10	Business local	0	0.60
Semi (most soils)	40	0.20	Business CBD	0	0.85
Imperm (rock, paving)	20	0.30	Streets	45	0.95
Cp	110	0.19	Total	100	0.65
Vegetal growth Cv	%				
Dense bush, forest	20	0.05	**AREA WEIGHTING FACTORS**		
Cult land, sparse bush	70	0.15		%	DWA
Grassland	0	0.25	RURAL	65	0.45
Bare Surface	10	0.30	URBAN	30	0.65
Cv	100	0.15	LAKES	5	0.00
Rural coeff	Total (Ct)	0.45	C_{design}	100	0.48

Rural coeff Ct = Cs+Cp+Cv

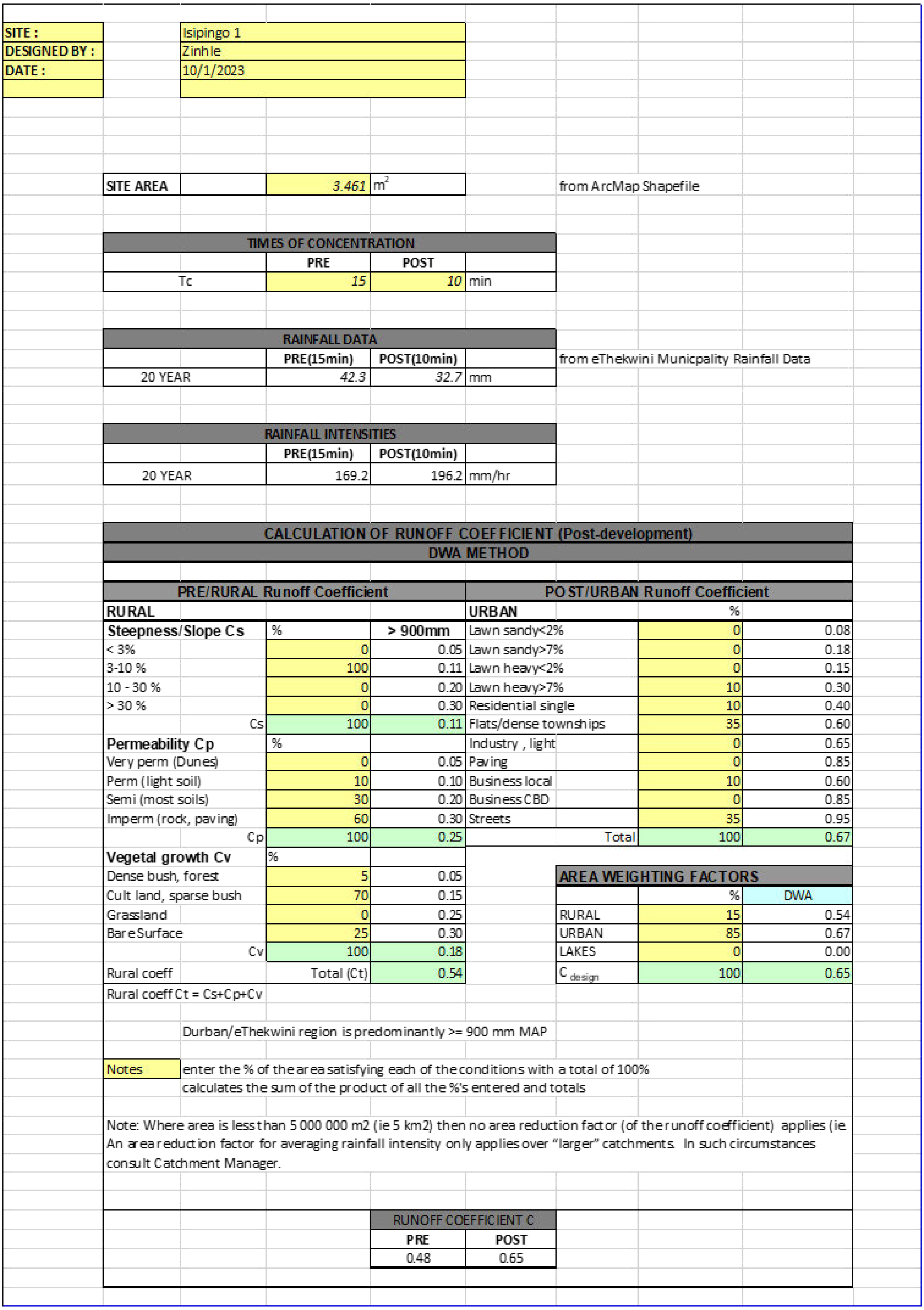
Durban/eThekwini region is predominantly >= 900 mm MAP

Notes: enter the % of the area satisfying each of the conditions with a total of 100%
calculates the sum of the product of all the %'s entered and totals

Note: Where area is less than 5 000 000 m2 (ie 5 km2) then no area reduction factor (of the runoff coefficient) applies (ie. An area reduction factor for averaging rainfall intensity only applies over "larger" catchments. In such circumstances consult Catchment Manager.

RUNOFF COEFFICIENT C
PRE
0.48

Table 29: Isipingo 1 post-development calculations



SITE :	Isipingo 1
DESIGNED BY :	Zinhle
DATE :	10/1/2023

SITE AREA	*3.461*	m^2	from ArcMap Shapefile

TIMES OF CONCENTRATION			
	PRE	**POST**	
Tc	*15*	*10*	min

RAINFALL DATA				
	PRE(15min)	**POST(10min)**		from eThekwini Municpality Rainfall Data
20 YEAR	*42.3*	*32.7*	mm	

RAINFALL INTENSITIES			
	PRE(15min)	**POST(10min)**	
20 YEAR	169.2	196.2	mm/hr

CALCULATION OF RUNOFF COEFFICIENT (Post-development)

DWA METHOD

PRE/RURAL Runoff Coefficient				**POST/URBAN Runoff Coefficient**		
RURAL				**URBAN**	%	
Steepness/Slope Cs	%	**> 900mm**		Lawn sandy<2%	0	0.08
< 3%		0	0.05	Lawn sandy>7%	0	0.18
3-10 %		100	0.11	Lawn heavy<2%	0	0.15
10 - 30 %		0	0.20	Lawn heavy>7%	10	0.30
> 30 %		0	0.30	Residential single	10	0.40
	Cs	100	0.11	Flats/dense townships	35	0.60
Permeability Cp	%			Industry , light	0	0.65
Very perm (Dunes)		0	0.05	Paving	0	0.85
Perm (light soil)		10	0.10	Business local	10	0.60
Semi (most soils)		30	0.20	Business CBD	0	0.85
Imperm (rock, paving)		60	0.30	Streets	35	0.95
	Cp	100	0.25	Total	100	0.67
Vegetal growth Cv	%					
Dense bush, forest		5	0.05			
Cult land, sparse bush		70	0.15			
Grassland		0	0.25			
Bare Surface		25	0.30			
	Cv	100	0.18			
Rural coeff	Total (Ct)		0.54			

AREA WEIGHTING FACTORS		
	%	DWA
RURAL	15	0.54
URBAN	85	0.67
LAKES	0	0.00
C_{design}	100	0.65

Rural coeff Ct = Cs+Cp+Cv

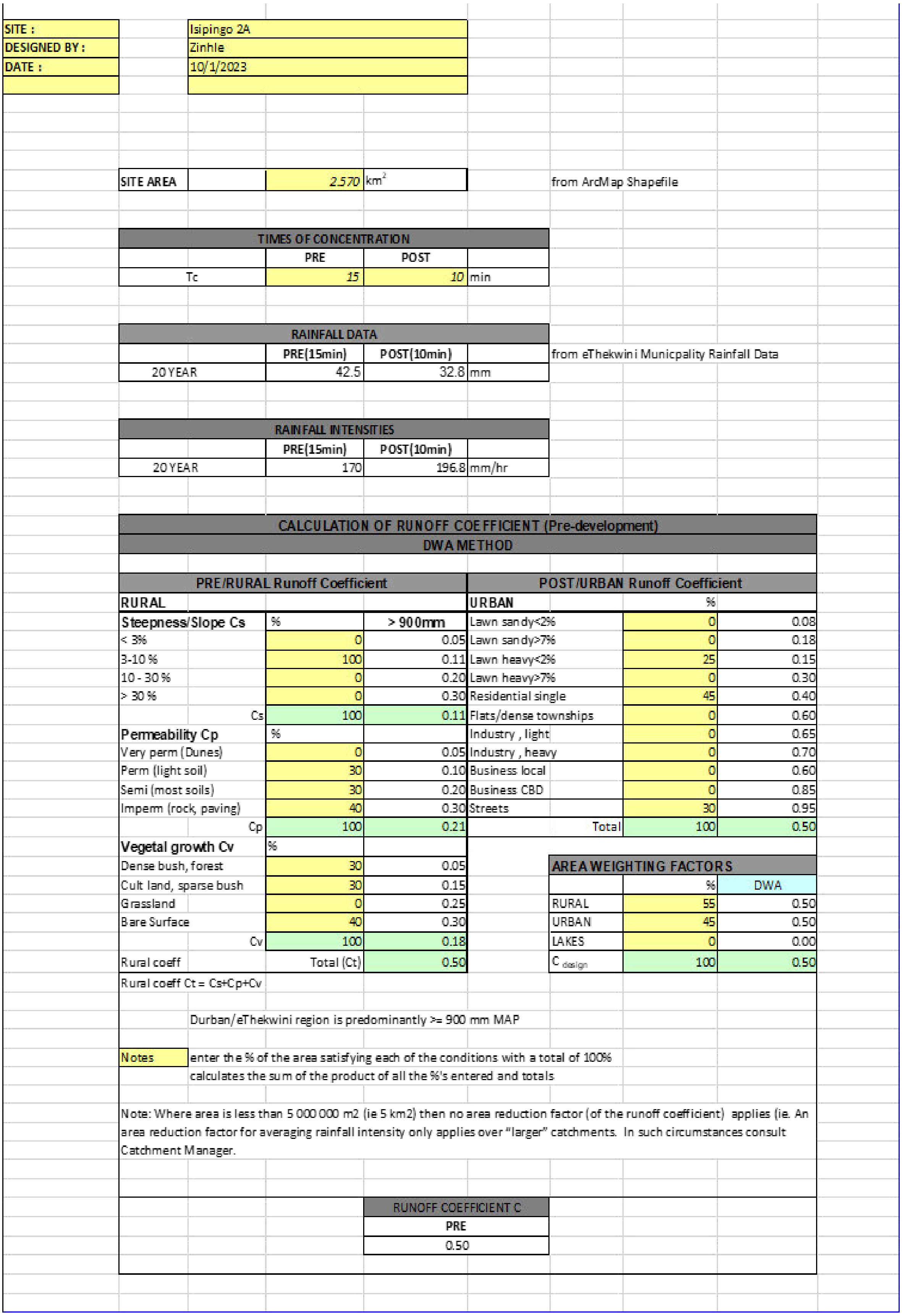
Durban/eThekwini region is predominantly >= 900 mm MAP

Notes: enter the % of the area satisfying each of the conditions with a total of 100%
calculates the sum of the product of all the %'s entered and totals

Note: Where area is less than 5 000 000 m2 (ie 5 km2) then no area reduction factor (of the runoff coefficient) applies (ie An area reduction factor for averaging rainfall intensity only applies over "larger" catchments. In such circumstances consult Catchment Manager.

RUNOFF COEFFICIENT C	
PRE	POST
0.48	0.65

Table 30: Isipingo 2a pre-development calculations



SITE :	Isipingo 2A
DESIGNED BY :	Zinhle
DATE :	10/1/2023

SITE AREA 2.570 km² from ArcMap Shapefile

TIMES OF CONCENTRATION			
	PRE	POST	
Tc	15	10	min

RAINFALL DATA			
	PRE(15min)	POST(10min)	
20 YEAR	42.5	32.8	mm

from eThekwini Municpality Rainfall Data

RAINFALL INTENSITIES			
	PRE(15min)	POST(10min)	
20 YEAR	170	196.8	mm/hr

CALCULATION OF RUNOFF COEFFICIENT (Pre-development)

DWA METHOD

PRE/RURAL Runoff Coefficient

RURAL		
Steepness/Slope Cs	%	> 900mm
< 3%	0	0.05
3-10 %	100	0.11
10 - 30 %	0	0.20
> 30 %	0	0.30
Cs	100	0.11
Permeability Cp	%	
Very perm (Dunes)	0	0.05
Perm (light soil)	30	0.10
Semi (most soils)	30	0.20
Imperm (rock, paving)	40	0.30
Cp	100	0.21
Vegetal growth Cv	%	
Dense bush, forest	30	0.05
Cult land, sparse bush	30	0.15
Grassland	0	0.25
Bare Surface	40	0.30
Cv	100	0.18
Rural coeff	Total (Ct)	0.50

Rural coeff Ct = Cs+Cp+Cv

POST/URBAN Runoff Coefficient

URBAN	%	
Lawn sandy<2%	0	0.08
Lawn sandy>7%	0	0.18
Lawn heavy<2%	25	0.15
Lawn heavy>7%	0	0.30
Residential single	45	0.40
Flats/dense townships	0	0.60
Industry , light	0	0.65
Industry , heavy	0	0.70
Business local	0	0.60
Business CBD	0	0.85
Streets	30	0.95
Total	100	0.50

AREA WEIGHTING FACTORS		
	%	DWA
RURAL	55	0.50
URBAN	45	0.50
LAKES	0	0.00
C_{design}	100	0.50

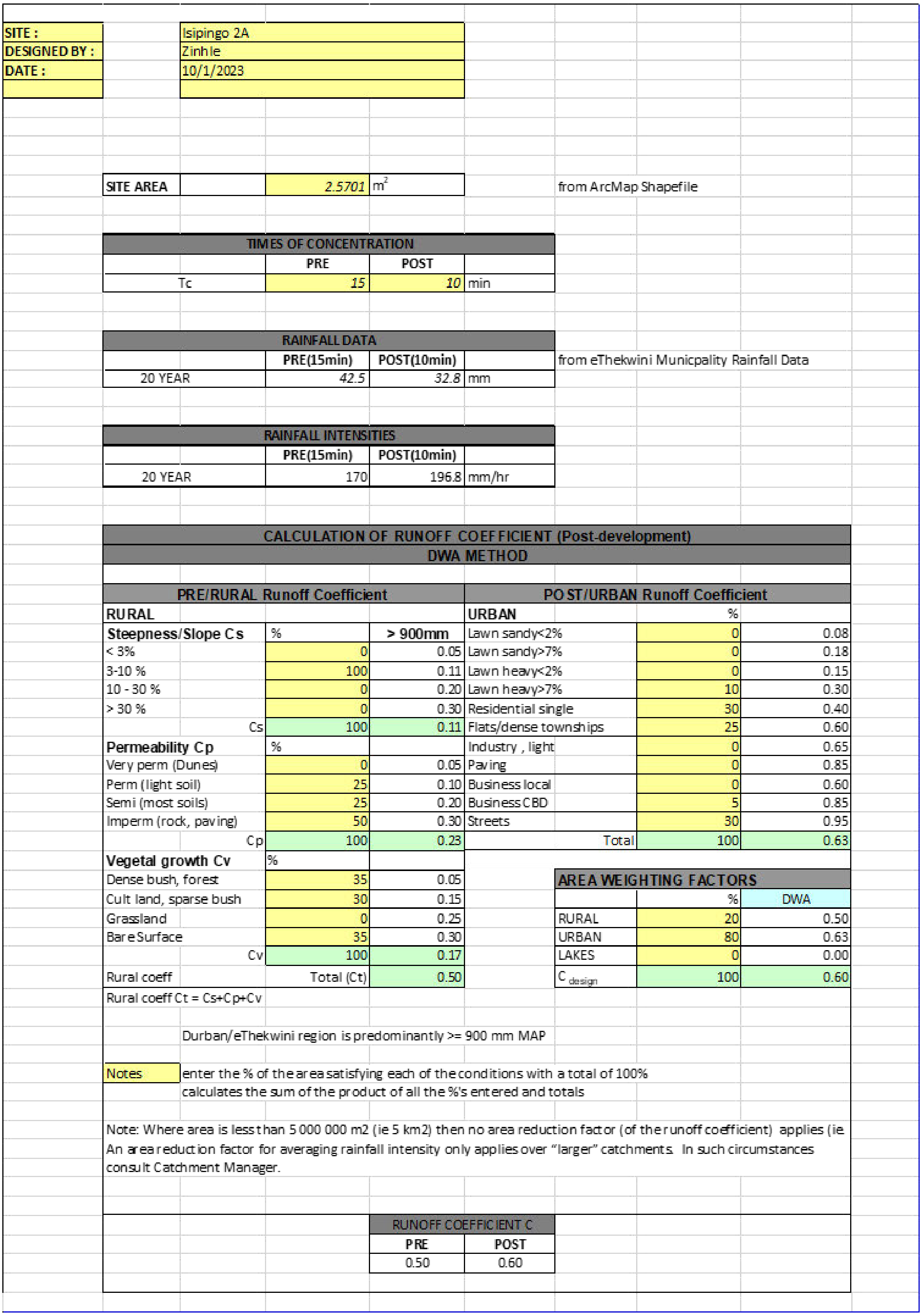
Durban/eThekwini region is predominantly >= 900 mm MAP

Notes: enter the % of the area satisfying each of the conditions with a total of 100%
calculates the sum of the product of all the %'s entered and totals

Note: Where area is less than 5 000 000 m2 (ie 5 km2) then no area reduction factor (of the runoff coefficient) applies (ie. An area reduction factor for averaging rainfall intensity only applies over "larger" catchments. In such circumstances consult Catchment Manager.

RUNOFF COEFFICIENT C
PRE
0.50

Table 31: Isipingo 2a post-development calculations



SITE :	Isipingo 2A
DESIGNED BY :	Zinhle
DATE :	10/1/2023

SITE AREA	*2.5701*	m^2	from ArcMap Shapefile

TIMES OF CONCENTRATION			
	PRE	**POST**	
Tc	*15*	*10*	min

RAINFALL DATA				
	PRE(15min)	**POST(10min)**		from eThekwini Municpality Rainfall Data
20 YEAR	*42.5*	*32.8*	mm	

RAINFALL INTENSITIES			
	PRE(15min)	**POST(10min)**	
20 YEAR	170	196.8	mm/hr

CALCULATION OF RUNOFF COEFFICIENT (Post-development)

DWA METHOD

PRE/RURAL Runoff Coefficient			
RURAL			
Steepness/Slope Cs	%	**> 900mm**	
< 3%	0	0.05	
3-10 %	100	0.11	
10 - 30 %	0	0.20	
> 30 %	0	0.30	
	Cs	100	0.11
Permeability Cp	%		
Very perm (Dunes)	0	0.05	
Perm (light soil)	25	0.10	
Semi (most soils)	25	0.20	
Imperm (rock, paving)	50	0.30	
	Cp	100	0.23
Vegetal growth Cv	%		
Dense bush, forest	35	0.05	
Cult land, sparse bush	30	0.15	
Grassland	0	0.25	
Bare Surface	35	0.30	
	Cv	100	0.17
Rural coeff	Total (Ct)	0.50	
Rural coeff Ct = Cs+Cp+Cv			

POST/URBAN Runoff Coefficient		
URBAN	%	
Lawn sandy<2%	0	0.08
Lawn sandy>7%	0	0.18
Lawn heavy<2%	0	0.15
Lawn heavy>7%	10	0.30
Residential single	30	0.40
Flats/dense townships	25	0.60
Industry , light	0	0.65
Paving	0	0.85
Business local	0	0.60
Business CBD	5	0.85
Streets	30	0.95
Total	100	0.63

AREA WEIGHTING FACTORS		
	%	DWA
RURAL	20	0.50
URBAN	80	0.63
LAKES	0	0.00
C_{design}	100	0.60

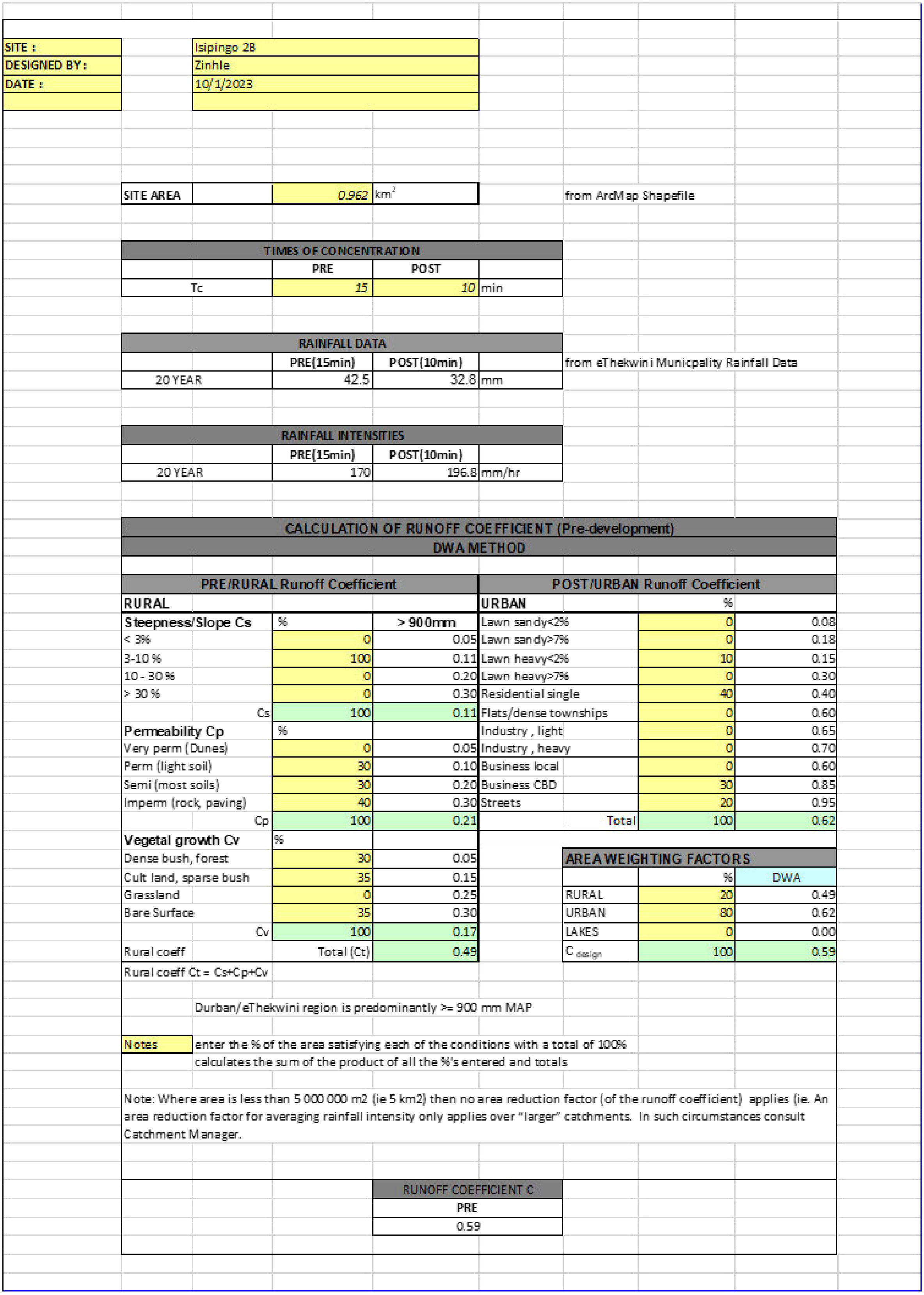
Durban/eThekwini region is predominantly >= 900 mm MAP

Notes: enter the % of the area satisfying each of the conditions with a total of 100%
calculates the sum of the product of all the %'s entered and totals

Note: Where area is less than 5 000 000 m2 (ie 5 km2) then no area reduction factor (of the runoff coefficient) applies (ie An area reduction factor for averaging rainfall intensity only applies over “larger” catchments. In such circumstances consult Catchment Manager.

RUNOFF COEFFICIENT C	
PRE	**POST**
0.50	0.60

Table 32: Isipingo 2b pre-development calculations



SITE :	Isipingo 2B
DESIGNED BY :	Zinhle
DATE :	10/1/2023

SITE AREA	0.962	km^2	from ArcMap Shapefile

TIMES OF CONCENTRATION			
	PRE	POST	
Tc	15	10	min

RAINFALL DATA			
	PRE(15min)	POST(10min)	
20 YEAR	42.5	32.8	mm

from eThekwini Municpality Rainfall Data

RAINFALL INTENSITIES			
	PRE(15min)	POST(10min)	
20 YEAR	170	196.8	mm/hr

CALCULATION OF RUNOFF COEFFICIENT (Pre-development)

DWA METHOD

PRE/RURAL Runoff Coefficient

RURAL		
Steepness/Slope Cs	%	> 900mm
< 3%	0	0.05
3-10 %	100	0.11
10 - 30 %	0	0.20
> 30 %	0	0.30
Cs	100	0.11
Permeability Cp	%	
Very perm (Dunes)	0	0.05
Perm (light soil)	30	0.10
Semi (most soils)	30	0.20
Imperm (rock, paving)	40	0.30
Cp	100	0.21
Vegetal growth Cv	%	
Dense bush, forest	30	0.05
Cult land, sparse bush	35	0.15
Grassland	0	0.25
Bare Surface	35	0.30
Cv	100	0.17
Rural coeff	Total (Ct)	0.49

Rural coeff Ct = Cs+Cp+Cv

POST/URBAN Runoff Coefficient

URBAN	%	
Lawn sandy<2%	0	0.08
Lawn sandy>7%	0	0.18
Lawn heavy<2%	10	0.15
Lawn heavy>7%	0	0.30
Residential single	40	0.40
Flats/dense townships	0	0.60
Industry , light	0	0.65
Industry , heavy	0	0.70
Business local	0	0.60
Business CBD	30	0.85
Streets	20	0.95
Total	100	0.62

AREA WEIGHTING FACTORS	%	DWA
RURAL	20	0.49
URBAN	80	0.62
LAKES	0	0.00
C_{design}	100	0.59

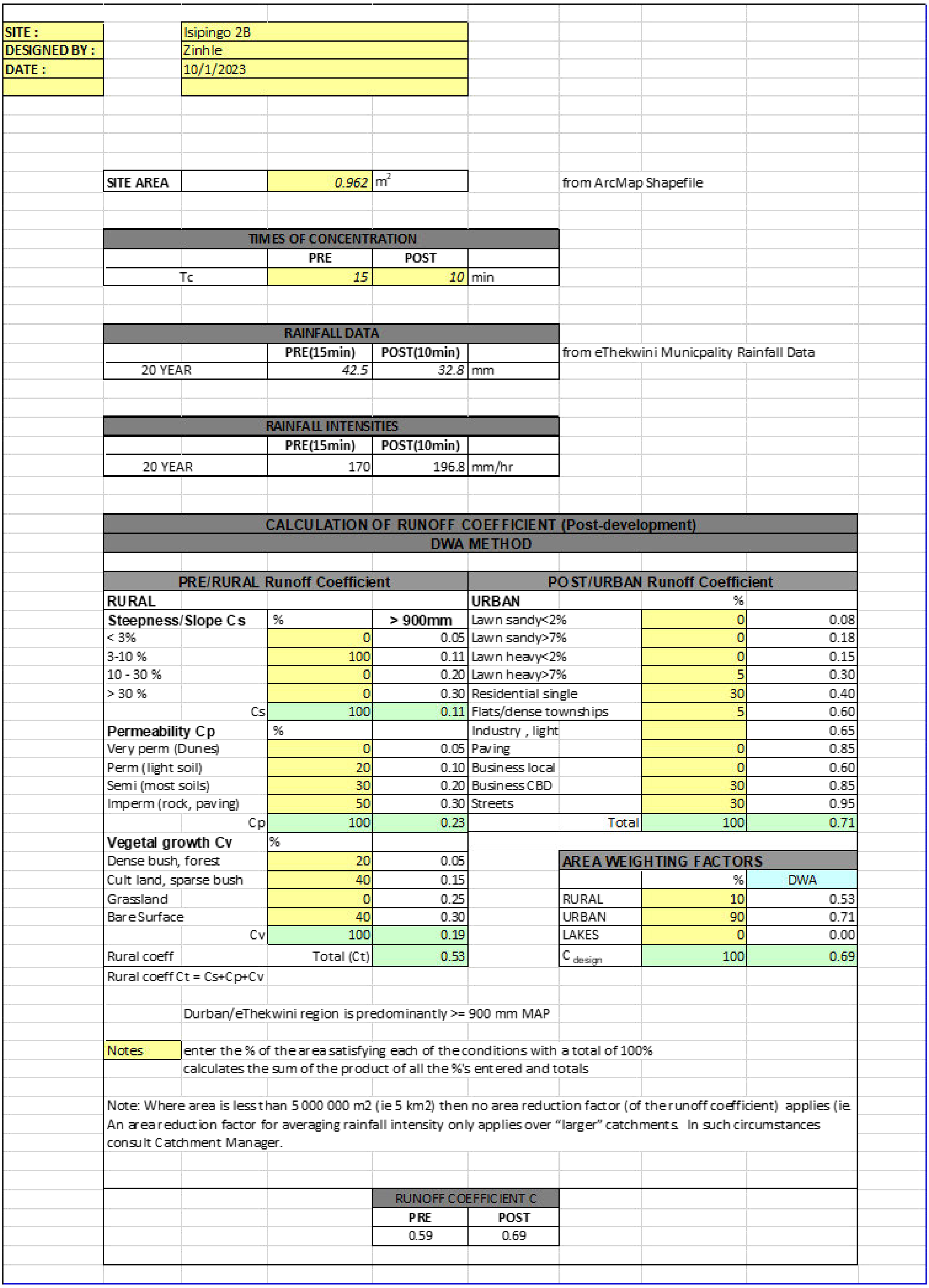
Durban/eThekwini region is predominantly >= 900 mm MAP

Notes enter the % of the area satisfying each of the conditions with a total of 100%
calculates the sum of the product of all the %'s entered and totals

Note: Where area is less than 5 000 000 m2 (ie 5 km2) then no area reduction factor (of the runoff coefficient) applies (ie. An area reduction factor for averaging rainfall intensity only applies over "larger" catchments. In such circumstances consult Catchment Manager.

RUNOFF COEFFICIENT C
PRE
0.59

Table 33: Isipingo 2b post-development calculations



SITE :	Isipingo 2B
DESIGNED BY :	Zinhle
DATE :	10/1/2023

SITE AREA	*0.962*	m^2	from ArcMap Shapefile

TIMES OF CONCENTRATION			
	PRE	POST	
Tc	*15*	*10*	min

RAINFALL DATA				
	PRE(15min)	POST(10min)		from eThekwini Municpality Rainfall Data
20 YEAR	*42.5*	*32.8*	mm	

RAINFALL INTENSITIES			
	PRE(15min)	POST(10min)	
20 YEAR	170	196.8	mm/hr

CALCULATION OF RUNOFF COEFFICIENT (Post-development)
DWA METHOD

PRE/RURAL Runoff Coefficient			POST/URBAN Runoff Coefficient		
RURAL			**URBAN**	%	
Steepness/Slope Cs	%	**> 900mm**	Lawn sandy<2%	0	0.08
< 3%	0	0.05	Lawn sandy>7%	0	0.18
3-10 %	100	0.11	Lawn heavy<2%	0	0.15
10 - 30 %	0	0.20	Lawn heavy>7%	5	0.30
> 30 %	0	0.30	Residential single	30	0.40
Cs	100	0.11	Flats/dense townships	5	0.60
Permeability Cp	%		Industry , light		0.65
Very perm (Dunes)	0	0.05	Paving	0	0.85
Perm (light soil)	20	0.10	Business local	0	0.60
Semi (most soils)	30	0.20	Business CBD	30	0.85
Imperm (rock, paving)	50	0.30	Streets	30	0.95
Cp	100	0.23	Total	100	0.71
Vegetal growth Cv	%				
Dense bush, forest	20	0.05	**AREA WEIGHTING FACTORS**		
Cult land, sparse bush	40	0.15		%	DWA
Grassland	0	0.25	RURAL	10	0.53
Bare Surface	40	0.30	URBAN	90	0.71
Cv	100	0.19	LAKES	0	0.00
Rural coeff	Total (Ct)	0.53	C_{design}	100	0.69

Rural coeff Ct = Cs+Cp+Cv

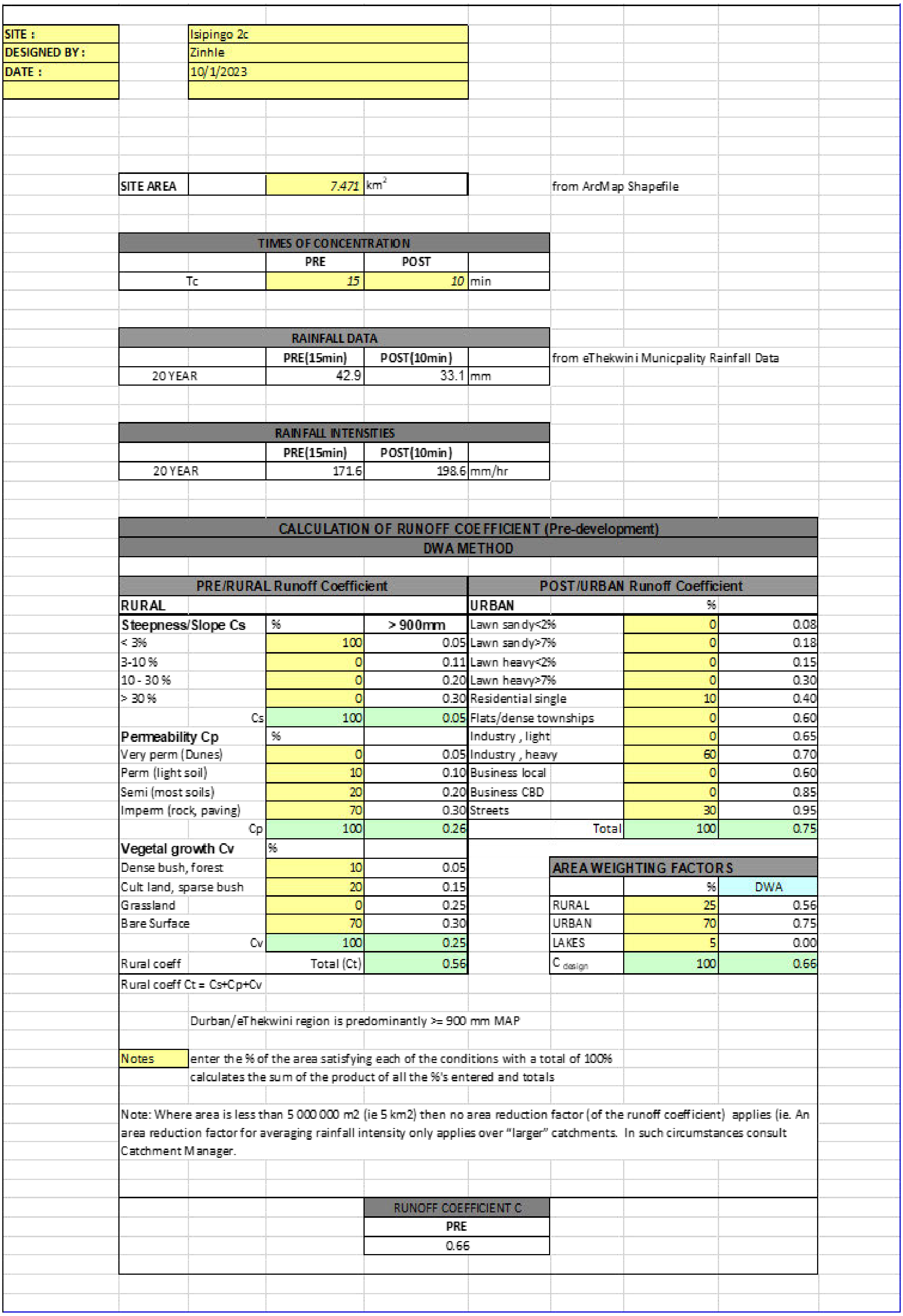
Durban/eThekwini region is predominantly >= 900 mm MAP

Notes: enter the % of the area satisfying each of the conditions with a total of 100%
calculates the sum of the product of all the %'s entered and totals

Note: Where area is less than 5 000 000 m2 (ie 5 km2) then no area reduction factor (of the runoff coefficient) applies (ie An area reduction factor for averaging rainfall intensity only applies over "larger" catchments. In such circumstances consult Catchment Manager.

RUNOFF COEFFICIENT C	
PRE	POST
0.59	0.69

Table 34: Isipingo 2c pre-development calculations



SITE :	Isipingo 2c
DESIGNED BY :	Zinhle
DATE :	10/1/2023

SITE AREA	*7.471*	km^2

from ArcMap Shapefile

TIMES OF CONCENTRATION			
	PRE	POST	
Tc	*15*	*10*	min

RAINFALL DATA			
	PRE(15min)	POST(10min)	
20 YEAR	42.9	33.1	mm

from eThekwini Municpality Rainfall Data

RAINFALL INTENSITIES			
	PRE(15min)	POST(10min)	
20 YEAR	171.6	198.6	mm/hr

CALCULATION OF RUNOFF COEFFICIENT (Pre-development)

DWA METHOD

PRE/RURAL Runoff Coefficient

RURAL		
Steepness/Slope Cs	%	> 900mm
< 3%	100	0.05
3-10 %	0	0.11
10 - 30 %	0	0.20
> 30 %	0	0.30
Cs	100	0.05
Permeability Cp	%	
Very perm (Dunes)	0	0.05
Perm (light soil)	10	0.10
Semi (most soils)	20	0.20
Imperm (rock, paving)	70	0.30
Cp	100	0.26
Vegetal growth Cv	%	
Dense bush, forest	10	0.05
Cult land, sparse bush	20	0.15
Grassland	0	0.25
Bare Surface	70	0.30
Cv	100	0.25
Rural coeff	Total (Ct)	0.56

Rural coeff Ct = Cs+Cp+Cv

POST/URBAN Runoff Coefficient

URBAN	%	
Lawn sandy<2%	0	0.08
Lawn sandy>7%	0	0.18
Lawn heavy<2%	0	0.15
Lawn heavy>7%	0	0.30
Residential single	10	0.40
Flats/dense townships	0	0.60
Industry , light	0	0.65
Industry , heavy	60	0.70
Business local	0	0.60
Business CBD	0	0.85
Streets	30	0.95
Total	100	0.75

AREA WEIGHTING FACTORS		
	%	DWA
RURAL	25	0.56
URBAN	70	0.75
LAKES	5	0.00
C_{design}	100	0.66

Durban/eThekwini region is predominantly >= 900 mm MAP

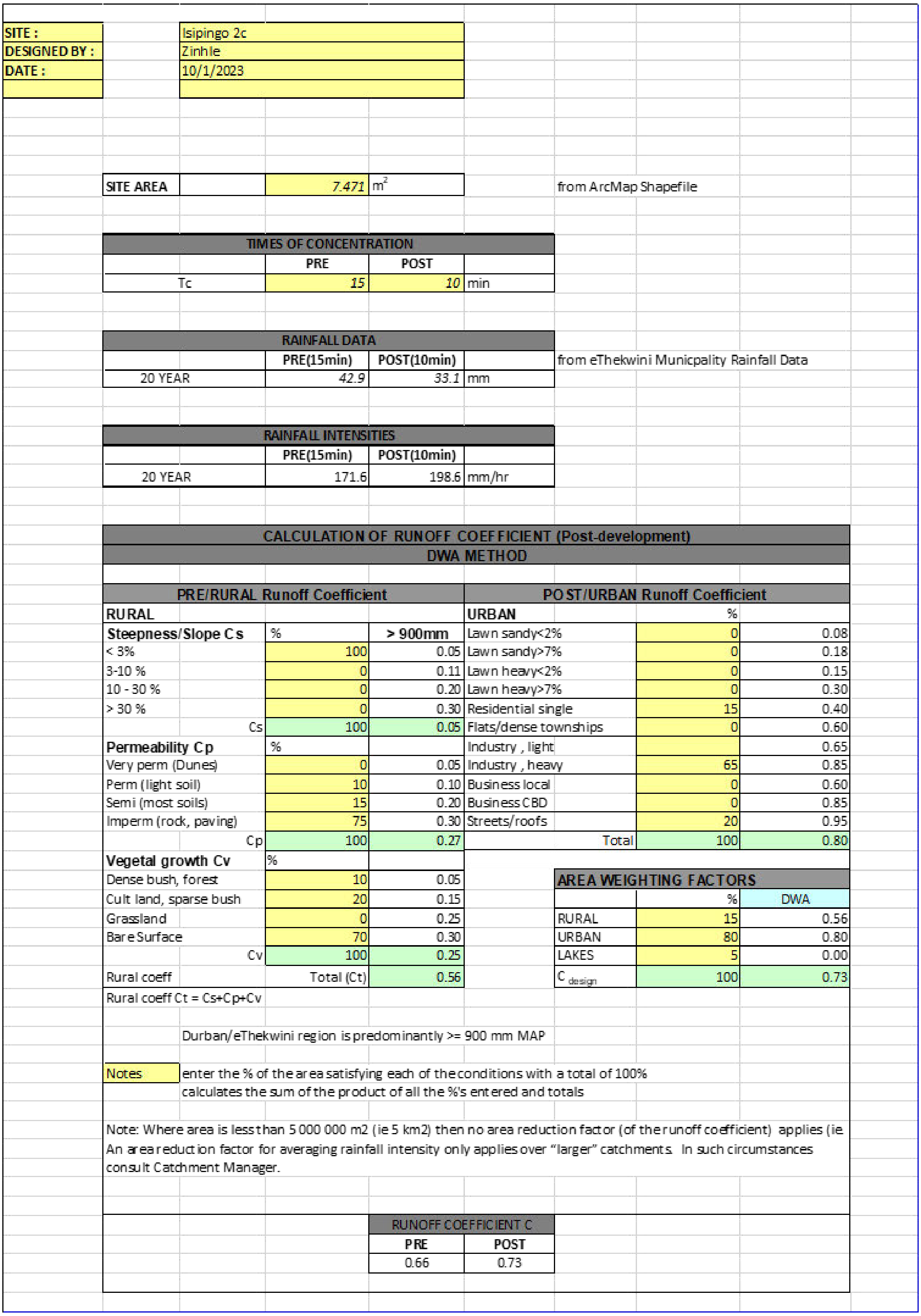
Notes: enter the % of the area satisfying each of the conditions with a total of 100%

calculates the sum of the product of all the %'s entered and totals

Note: Where area is less than 5 000 000 m2 (ie 5 km2) then no area reduction factor (of the runoff coefficient) applies (ie. An area reduction factor for averaging rainfall intensity only applies over "larger" catchments. In such circumstances consult Catchment Manager.

RUNOFF COEFFICIENT C
PRE
0.66

Table 35: Isipingo 2c post-development calculations



SITE :	Isipingo 2c
DESIGNED BY :	Zinhle
DATE :	10/1/2023

SITE AREA	*7.471*	m^2	from ArcMap Shapefile

TIMES OF CONCENTRATION			
	PRE	POST	
Tc	*15*	*10*	min

RAINFALL DATA			
	PRE(15min)	POST(10min)	
20 YEAR	*42.9*	*33.1*	mm

from eThekwini Municpality Rainfall Data

RAINFALL INTENSITIES			
	PRE(15min)	POST(10min)	
20 YEAR	171.6	198.6	mm/hr

CALCULATION OF RUNOFF COEFFICIENT (Post-development)
DWA METHOD

PRE/RURAL Runoff Coefficient			POST/URBAN Runoff Coefficient		
RURAL			**URBAN**	%	
Steepness/Slope Cs	%	**> 900mm**	Lawn sandy<2%	0	0.08
< 3%	100	0.05	Lawn sandy>7%	0	0.18
3-10 %	0	0.11	Lawn heavy<2%	0	0.15
10 - 30 %	0	0.20	Lawn heavy>7%	0	0.30
> 30 %	0	0.30	Residential single	15	0.40
Cs	100	0.05	Flats/dense townships	0	0.60
Permeability Cp	%		Industry , light		0.65
Very perm (Dunes)	0	0.05	Industry , heavy	65	0.85
Perm (light soil)	10	0.10	Business local	0	0.60
Semi (most soils)	15	0.20	Business CBD	0	0.85
Imperm (rock, paving)	75	0.30	Streets/roofs	20	0.95
Cp	100	0.27	Total	100	0.80
Vegetal growth Cv	%				
Dense bush, forest	10	0.05			
Cult land, sparse bush	20	0.15			
Grassland	0	0.25			
Bare Surface	70	0.30			
Cv	100	0.25			
Rural coeff	Total (Ct)	0.56			

AREA WEIGHTING FACTORS		
	%	DWA
RURAL	15	0.56
URBAN	80	0.80
LAKES	5	0.00
C_{design}	100	0.73

Rural coeff Ct = Cs+Cp+Cv

Durban/eThekwini region is predominantly >= 900 mm MAP

Notes: enter the % of the area satisfying each of the conditions with a total of 100%
calculates the sum of the product of all the %'s entered and totals

Note: Where area is less than 5 000 000 m2 (ie 5 km2) then no area reduction factor (of the runoff coefficient) applies (ie
An area reduction factor for averaging rainfall intensity only applies over “larger” catchments. In such circumstances consult Catchment Manager.

RUNOFF COEFFICIENT C	
PRE	POST
0.66	0.73

APPENDIX B

APPENDIX C

Table 36: Isipingo 1 PCSWMM results

Isipingo 1

SURCHARGING

Surcharging occurs when water rises above the top of the highest conduit.

MH	Type	Hours Surcharged	Max. Height above crown (m)	Min Depth below Rim (m)
E5576	Junction	0.53	0.75	0
ED275	Junction	0.61	0	0
ED278	Junction	0.77	0.704	0.389
ED299	Junction	0.29	0.284	0.956
ED300	Junction	0.52	0.589	0.411
ED301	Junction	0.46	0.519	0.431
ED303	Junction	0.41	0.244	0.756
ED304	Junction	0.36	0.159	0.791
ED310	Junction	0.13	24.905	0
ED337	Junction	0.58	0.809	0.041
ED340	Junction	0.32	0.85	0
ED352	Junction	0.74	0.239	0.661
ED440	Junction	0.64	0.606	0.964
ED506	Junction	0.34	0.613	0.062
F7859	Junction	0.7	0.825	0
F8042	Junction	0.31	0.825	0
F8052	Junction	0.21	0.825	0
F8061	Junction	0.41	0.103	0.347
M0429	Junction	0.35	0.975	0
ZC002	Junction	0.22	0.04	0.785
ZC020	Junction	0.26	0.304	0.446

FLOODING

Flooding refers to all water that overflows a node, whether it ponds or not.

MH	Hours Flooded	Max. Rate CMS	Total flood volume	Max. Ponded Depth (m)
E5576	0.53	0.001	0.002	0
ED275	0.61	0.083	0.035	0
ED310	0.11	0.002	0.001	0

ED340	0.31	0.005	0.003	0
ED506	0.01	0.013	0	0
F7859	0.7	0.001	0.002	0
F8042	0.3	0.004	0.004	0
F8052	0.01	0.003	0	0
M0429	0.33	0	0.001	0

Table 37: Isipingo 2a PCSWMM results

<table>
<tr><th colspan="5">Isipingo 2a</th></tr>
<tr><th colspan="5">SURCHARGING</th></tr>
<tr><td colspan="5">Surcharging occurs when water rises above the top of the highest conduit.</td></tr>
<tr><td>MH</td><td>Type</td><td>Hours Surcharged</td><td>Max. Height above crown (m)</td><td>Min Depth below Rim (m)</td></tr>
<tr><td>BH683</td><td>Junction</td><td>0.13</td><td>0.05</td><td>1.024</td></tr>
<tr><td>BH748</td><td>Junction</td><td>0.57</td><td>0.773</td><td>1.06</td></tr>
<tr><td>BH749</td><td>Junction</td><td>0.65</td><td>0.865</td><td>0.035</td></tr>
<tr><td>BH750</td><td>Junction</td><td>0.7</td><td>0.9</td><td>0</td></tr>
<tr><td>BH751</td><td>Junction</td><td>0.53</td><td>0.645</td><td>0.255</td></tr>
<tr><td>BH759</td><td>Junction</td><td>0.38</td><td>0.593</td><td>1.538</td></tr>
<tr><td>BL870</td><td>Junction</td><td>0.73</td><td>1.114</td><td>1.038</td></tr>
<tr><td>E5563</td><td>Junction</td><td>0.02</td><td>0.096</td><td>0.704</td></tr>
<tr><td>E6552</td><td>Junction</td><td>0.53</td><td>0.448</td><td>1.062</td></tr>
<tr><td>E6553</td><td>Junction</td><td>0.59</td><td>0.554</td><td>0.919</td></tr>
<tr><td>G0334</td><td>Junction</td><td>0.34</td><td>0.399</td><td>0.221</td></tr>
<tr><td>G0335</td><td>Junction</td><td>0.35</td><td>0.59</td><td>0</td></tr>
<tr><td>G7031</td><td>Junction</td><td>0.67</td><td>0.45</td><td>0</td></tr>
<tr><td>JV713</td><td>Junction</td><td>0.54</td><td>1.094</td><td>0.024</td></tr>
<tr><th colspan="5">FLOODING</th></tr>
<tr><td colspan="5">Flooding refers to all water that overflows a node, whether it ponds or not.</td></tr>
<tr><td>MH</td><td>Hours Flooded</td><td>Max. Rate CMS</td><td>Total flood volume</td><td>Max. Ponded Depth (m)</td></tr>
<tr><td>BH750</td><td>0.51</td><td>0.01</td><td>0.016</td><td>0</td></tr>
<tr><td>G0335</td><td>0.33</td><td>0.002</td><td>0.003</td><td>0</td></tr>
<tr><td>G7031</td><td>0.62</td><td>0.008</td><td>0.012</td><td>0</td></tr>
</table>

Table 38: Isipingo 2b PCSWMM results

Isipingo 2b				
SURCHARGING				
Surcharging occurs when water rises above the top of the highest conduit.				
MH	Type	Hours Surcharged	Max. Height above crown (m)	Min Depth below Rim (m)
BI067	Junction	0.62	0.013	0.935
BI172	Junction	0.62	0.201	1.782
BI480	Junction	0.71	0.904	0.911
BI652	Junction	0.54	0.428	1.183
BJ236	Junction	0.58	0.683	0
BJ240	Junction	0.62	0.005	0.864
ED495	Junction	0.62	0.139	1.356
ED566	Junction	0.57	0.728	0.364
ED567	Junction	0.64	0.97	0.507
ED604	Junction	0.13	1.38	0
ED688	Junction	0.35	0.173	0.591
ED702	Junction	0.01	0.01	1.333
ED703	Junction	0.06	0.041	1.27
ZC016	Junction	0.69	0.764	0.658
ZC029	Junction	0.54	0.524	0.807
FLOODING				
Flooding refers to all water that overflows a node, whether it ponds or not.				
MH	Hours Flooded	Max. Rate CMS	Total flood volume	Max. Ponded Depth (m)
BJ236	0.58	0.003	0.006	0
ED604	0.01	0.008	0	0

Table 39: Isipingo 2c PCSWMM results

Isipingo 2c				
SURCHARGING				
Surcharging occurs when water rises above the top of the highest conduit.				
MH	Type	Hours Surcharged	Max. Height above crown (m)	Min Depth below Rim (m)
AG441	Junction	0.28	0.132	0.618
AG442	Junction	0.34	0.261	0.489
AG443	Junction	0.37	0.315	0.54
AG444	Junction	0.15	0.02	0.73
AG449	Junction	0.57	0.4	0.809
AG466	Junction	0.29	0.171	0.949
AG548	Junction	0.62	0.028	0.572
AG566	Junction	0.65	0.185	0.81
AG567	Junction	0.66	0.315	0.65
CE456	Junction	0.23	0.324	0.426
CE459	Junction	0.39	0.498	0.252
CE460	Junction	0.39	0.75	0
CL829	Junction	0.08	1.679	1.679
CL843	Junction	0.57	0.912	0.912
CL962	Junction	0.57	0.962	0.27
CL964	Junction	0.4	1.323	0.597
CL965	Junction	0.33	1.02	0.624
E4032	Junction	0.72	0.9	0
E4039	Junction	0.36	0.9	0
E4243	Junction	0.48	0.525	0
E4346	Junction	0.52	0.158	0.67
E4354	Junction	0.46	0.189	0.815
E5067	Junction	0.48	0.543	1.213
E7188	Junction	0.51	0.326	0
E7189	Junction	0.21	0.131	1.171
E9442	Junction	0.41	0.161	1.001
ED002	Junction	0.61	0.7	0.609
ED088	Junction	0.57	0.596	0
ED089	Junction	0.53	0.482	0.147

ED094	Junction	0.77	0.28	0
ED095	Junction	0.74	0.273	3.257
ED100	Junction	0.74	0.051	0.424
ED112	Junction	0.76	0.225	1.094
ED143	Junction	0.73	0.23	0.03
ED145	Junction	0.66	0.089	0
ED167	Junction	0.4	0.03	0.886
ED169	Junction	0.42	0.074	0.52
ED192	Junction	0.71	0.351	2.479
ED199	Junction	0.71	0.486	0.214
ISI2c_OP_32	Open Channel	0.61	0	0
ISI2c_OP_38	Open Channel	0.33	0	0
ISI2c_OP_61	Open Channel	0.17	0	0
ISI2c_OP_76	Open Channel	0.75	0	0
ISI2c_OP_79	Open Channel	0.8	0	0
W3084	Junction	0.57	0.058	1.153
Y4508	Junction	0.86	0.156	0.669

FLOODING

Flooding refers to all water that overflows a node, whether it ponds or not.

MH	Hours Flooded	Max. Rate CMS	Total flood volume	Max. Ponded Depth (m)
CE460	0.01	0.007	0	0
E4032	0.01	0.002	0	0
E4039	0.35	0.002	0.003	0
E4243	0.47	0.027	0.045	0
E7188	0.27	0.026	0.014	0
ED088	0.43	0.02	0.018	0
ED094	0.77	0.007	0.017	0
ED145	0.64	0.011	0.014	0
ISI2c_OP_32	0.61	0.009	0.018	0
ISI2c_OP_38	0.33	0.023	0.019	0
ISI2c_OP_61	0.17	0.001	0.001	0
ISI2c_OP_76	0.75	0.003	0.006	0
ISI2c_OP_79	0.8	0.016	0.034	0