AN ANALYSIS ON OPTIMIZING THE USE OF SUSTAINABLE URBAN DRAINAGE SYSTEMS TO PROVIDE NON-POTABLE WATER SUPPLY IN THE ISIPINGO REGION.

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13/11/2019

DR M. Kumarasamy (Supervisor)

EXAMINER'S COPY

As the candidate's Supervisor I agree to the submission of this thesis.

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Supervisor's Signature

DECLARATION 1 - PLAGIARISM

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ABSTRACT

Population growth and urbanisation lead to increased water demand and stress on water resources. The increased demand implies an increased water treatment cost, utilities therefore charge higher tariffs consequently reducing consumer affordability and accessibility. Furthermore, many countries experience drought and intermittent water supply, low revenue collections and high operational costs. The National Water Act (Act 36, 1998) endeavours to find a balance between water conservation or demand management, water safety, affordability and accessibility. Potable water in many countries, including South Africa, is being used for non-potable purposes which is wasteful and threatens the exhaustion of potable water reserves. This research looks at sustainable urban drainage systems as a possible solution for providing an alternative water supply. The methodological approach involves setting up a PCSWMM model to investigate the optimal use of SUDS systems in the Isipingo region. Required data such as monthly water supply volume, GIS information for characteristics of the region, water supply pipe network was collected from eThekwini municipality data base. Weather data such as rainfall, temperature and humidity were collected from South African Weather Services. The current System input Volume (SIV) in Isipingo region was estimated as 11 780 000 Kilo Litres per year from logged data between July 2018 and July 2019. The water treatment costs required by the utility for Isipingo baseline volume is R5.33 /KL according to eThekwini municipality's master plans. A water balance model was constructed to illustrate the existing scenario. Different SUDS controls were then added onto the existing scenario to analyse the SUDS impact on the water balance components such as the baseline supply volume, water treatment cost and non -potable water demand. Results show that the municipal water supply demand reduces by an average of 74% across the use of the different SUDS scenarios. The water treatment costs reduce from R62 787 400 per year to an average of R 25 057 409,59 which is the treatment cost saving due to the SUDS interventions. The challenges with SUDS include initial installation and maintenance costs, the lack of adequate utility planning and design standards. However, SUDS reduce the risk of flooding, water pollutants, stress on potable water supply and contributes to the tourism economic activity through pleasing aesthetics for recreational areas and job creation. Therefore, the use of SUDS in diverting storm water for alternative non-potable usage is a viable option.

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1 INTRODUCTION

1.1 General description

The National Water Conservation/Water Demand Management (WC/WDM) proposals currently underway throughout the country are present to regulate the responsible use of natural water supplies due to the rapid depletion of water as a resource across the world. A lot of water is received from the rains but due to industrialization and human developments the water cycle is adversely disturbed yielding low levels of potable runoff. This research will explore the efficiency of using sustainable urban drainage systems (SUDS) and their related costs to divert storm water into water channels that are currently used for non-drinking purposes. The results of this initiative will therefore be key in providing engineers with a decision-making tool for designing potable and non-potable water systems, the SUDS techniques will be considered as an alternative for non-potable water supply based on cost and efficiency.

The SUDS concept is fairly new in South Africa with current pilot SUDS designs functioning in Gauteng, KwaZulu Natal and the Western Cape provinces. These provinces are examples of efforts to use SUDS systems in South Africa but they have been done on a pilot basis and to a small scale, the case study in this research will focus on the retrofitting of SUDS on an already existing portable water network, furthermore examples from Europe shall be analysed as part of the Literature review since this is the leading continent in SUDS and water loss management. The examples of the use of SUDS will help on feasibility analysis of SUDS systems in redirecting storm water for household non-potable uses, furthermore the choice of which material will be used as a medium to reduce the levels of toxic material metals in the storm water runoff destined for human use. This study will focus on the feasibility of diverting stormwater quantity for non-potable supply and as such water quality is standardized to one filtration medium for all the SUDS techniques in order to hold the water quality variable as constant for appropriate water quantity analysis. However, the Literature review discusses the options available for water quality analysis, Sedimentation is a common treatment process used to separate metals from water and sand is usually the most effective filtering medium used to enhance water quality.

A South African precinct in KwaZulu Natal, Durban, is to be used to gather field data patterning to the investigations of an existing stormwater and potable water network designed to eThekwini water design standards. Retrofitting of Umlazi, a particular sub catchment within eThekwini municipality, will be used as a case study in order to fulfil the paramount goal of this research. The chosen site has existing storm water network, the scenario analysis will therefore be generated by the use of different SUDS components analysed on the PCSWWM software to produce different volumetric results which can then be compared. The preliminary inputs are attributes of the different scenarios to be simulated and as such are to be collected from site research.

The outputs of interest in this study are the quantity outputs which are the municipal potable water supply volume, Potential water savings and the Cost of water treatment after SUDS implementation. A water balance is also a major output of this analysis, this tool is widely accepted mechanism to check the balance between water supply and water losses as per International water association's standards. The cross comparison of the SUDS scenario analyses and the portable water balance before and after retrofitting the SUDS is the endeavour to answer the research question.

1.2 Motivation

Potable Water is a scarce commodity worldwide, population growth and the lack of sustainable water management are a major contributing factor to water scarcity. Potable water is currently used to flush toilets and irrigation, only approximately 30 percent of the supplied water is used for potable purposes, this is wastage of the scarce water resource. Utilities incur the very high potable water treatment costs from water service authorities, households therefore pay higher tariffs due to the high consumption.

This research will focus on analysing the feasibility of using Sustainable urban drainage systems as a solution for water conservation and supply for non-potable purposes such as flushing toilets and irrigating, this is in order to save water and reduce potable water demand on utilities thereby saving water treatment costs. Saved water treatment costs translate to savings for both the utility, water service provider, and the households benefit by paying lower utility bills. Furthermore, water conservation is enhanced. There has also been a very slow uptake of SUDS into government's water conservation policies and Master plans. The research's findings will therefore be a government awareness tool for SUDS inclusion into government masterplans and budget, the financial aspects have slowed down the implementation of SUDS in South Africa. The research will also provide a SUDS criteria design tool for the engineers, the storm water stored per year can be used for many other emergency waters needs that do not necessarily fall under irrigation and flushing toilets but such as drought relief solutions. A further study into water quality would be required for drinking purposes and showering.

1.3 Research Question

What is the relative efficiency of Sustainable urban drainage systems (SUDS) controls in supplying non-potable storm water for non-potable purposes and reducing the current potable water supply in the Isipingo region?

1.4 Aims and Objectives

To investigate the use of Sustainable Urban drainage systems through the use of PCSWMM in providing an alternative water supply for flushing toilets and irrigation. The Results would raise government awareness and provide Engineers a guideline for designing and validating SUDS suitability in existing and new developments cited for sustainable water management.

2 LITERATURE REVIEW

2.1 Introduction

Sustainable Urban Drainage Systems (SUDS) is commonly known as a tool for urban storm water drainage, pursuing sustainability by replicating, as closely as possible, the natural drainage patterns and managing storm water runoff closer to its source (Kennedy and Lewis, 2007). The use of SUDS has to be properly planned for, there are many SUDS options but, in this research, only a certain number of SUDS systems will be employed for the task of retrofitting the potable water network for non -portable usage. Therefore, the choice of SUDS will depend on volume retention capacities. Efficient SUDS planning depends on a holistic approach which usually combines into a coherent system several small-scale structures, such as pervious pavements, green roofs, soakaways, infiltration trenches, retention and infiltration basins. (Sousa,2008).

The heavy metals in water can be very toxic, one of the non-portable uses is water used to bath, if the storm water is inadequately treated this may be a cause of concern, Previous studies have revealed that continued urbanisation of catchments does mean increased surcharge, flooding and pollution of the storm water effluent (Armitage,2009). As the storm water flows over impervious surfaces it picks up different pollutants depending on the type of surface. For example, runoff from highways has metal contaminants primarily emanating from vehicle related activities and components such as vehicle exhaust, lubricants, brake materials and tyres. Alongside these metals, residential areas generate storm water that might contain pollutants such as nitrates, pesticides, other organics, and phosphates.

Environmental Quality Standards (EQS) require that storm water must be treated before it is discharged into water bodies. (Hobart City Council ,2006). Table 2-1 shows these Standards for the metals which might be contained in storm water runoff, these standards are applied to this study as a quality validation for retrofitted SUDS mechanisms for human non-portable usage.

Table 2-1: Environmental Quality Standards (EQS) for accepted proportions of metals in runoff discharged to water bodies

(Source: McCuen, 2005)

Metal	EQS type	Hardness, mg/L $CaCO_3$						Coastal and estuarine, µg/L
		0 – 50	50 – 100	100 – 150	150 – 200	200 – 250	>250	
Freshwaters, µg/L, suitable for all fishlife								
Copper (dissolved)	Annual average	1	6	10	10	10	28	5
Freshwaters, µg/L , suitable for Cyprinid (coarse) fish								
Zinc (total)	Annual average	75	175	250	250	250	500	40
Iron (dissolved)	Annual average	1000 (not related to hardness)						1000

There are many techniques for treating storm water but the most common and simple method is sediment and metal removal bound to particulate matter using water detention units or gulley pots. However, the sedimentation process is less effective for removing metals in the soluble form (Baltrenas and Brannvall, 2006). Therefore, there are a number of different types of filter media that can be used for storm water treatment and removal of metals. These filtering media include sand, gravel, coated sand, crushed glass, leaf compost, perlite, peat, mulch, granular activated carbon. Zeolite, and other filtering media.(Stahre ,2006).

Table 2-2: Metal removal abilities of different filtering media

(Source: David, 2005)

Pollutant	Percent removal			
	Urbonas (1999)*	Barrett (2003)*	Ray et al. (2006)	Baltrenas and Brannval (2006)
	sand	sand	hardwood mulch**	zeolite and vermiculite
TSS	80 - 94	90	No data	No data
Copper total	20 – 40	50	No data	No data
Copper dissolved	No data	6	0 – 87	86.5
Zinc total	80 – 90	80	No data	No data
Zinc dissolved	No data	36	43 – 81	81.8
Lead total	No data	80	No data	No data
Lead dissolved	No data	39	84 – 92	98.6
Chromium (Cr^{6+})	No data	No data	0 – 68	No data
Cadmium dissolved	No data	No data	86 – 100	No data
Nickel dissolved	No data	No data	No data	81.8

* modified from Davis and McCuen (2005). ** - shredded peat, mixture of wet straw and leaves.

Table 2-2 shows the different media that can be used for filtration purposes from another study, for the purposes of this research sand will be used for all the SUDS techniques to standardize the water quality and focus on the water quantity for analysis. Furthermore, studies show that sand is very effective in the removal of metals associated with particulate matter such as suspended solids than when compared to that of metals in the dissolved form. (Clean Washington Centre (CWC), 1995).

2.2 SUDS overview

Sustainable urban drainage systems, SUDS, are techniques used to closely mimic the natural storm water flow of water before any development is done to a site. The natural storm water flow scenario is referred to as the pre development state of a catchment. (Ballard, 2007). The post development scenario is the developed state of a catchment where storm water pipes and other conventional designed water management tools are used. The pre development and post development states are both shown on Figure 2-1.

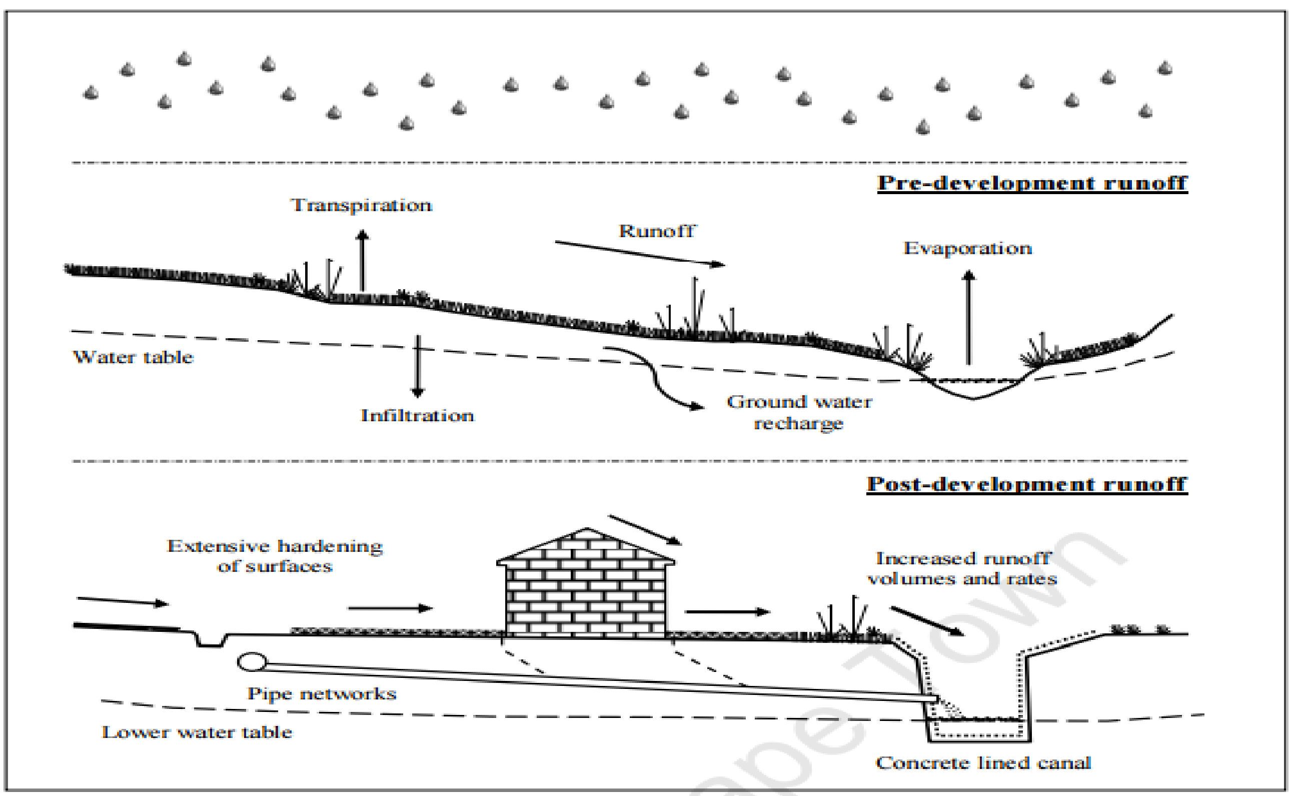

Figure 2-1:Storm water flow in Pre and Post developed sites

(Source: Ballard, 2007)

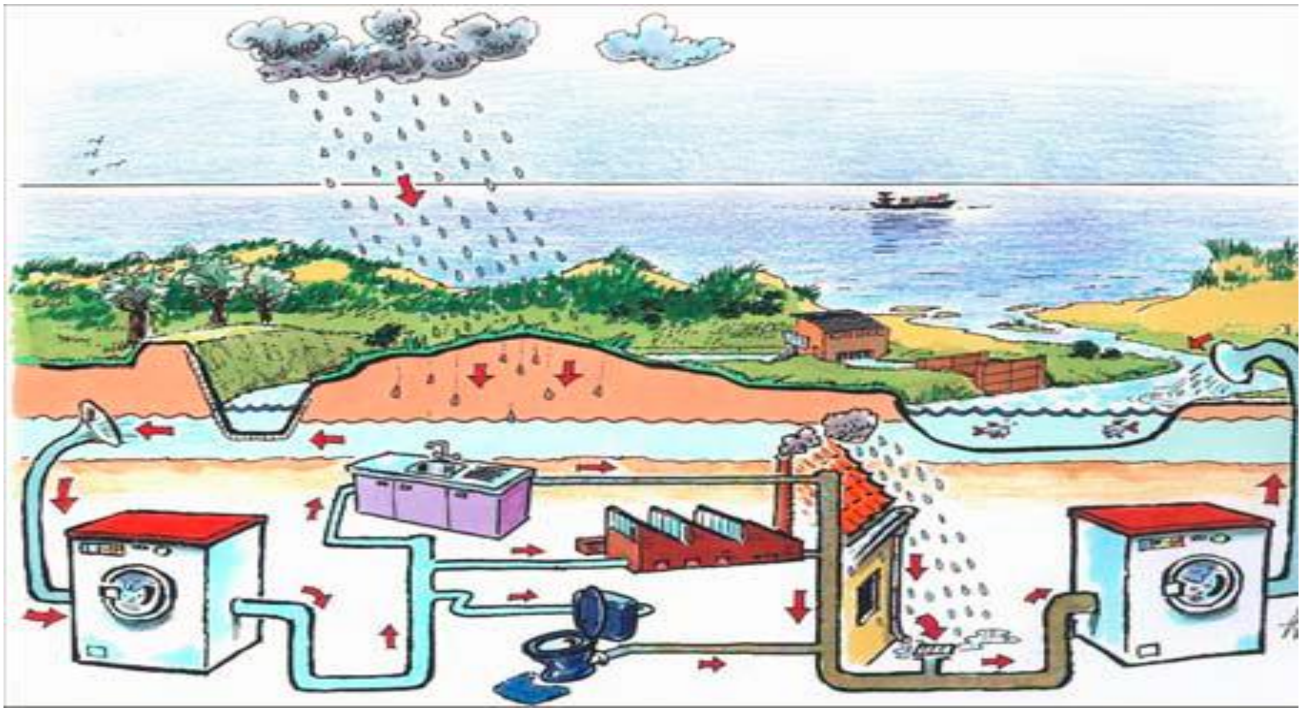

Figure 2-2:Water cycle and human usage

(Source: Uvini, 2008)

Figure 2-2 shows the interaction of humans with the water cycle. Prior studies have shown that the use of SUDS is an effort to mimic the predevelopment phase on Figure 2-1 which is reduced runoff and increased infiltration. This research further explores the interaction of the water cycle and human usage, the research is based on the possibilities of retrofitting storm water onto existing portable water pipes for non – portable human usage as depicted on Figure 2-2, this illustration of all the different components of the water cycle and their interaction with human usage is derived from work done in Netherlands where preliminary efforts to manage storm water, ground water ,waste water and drinking water have been holistically commenced. The holistic approach is important as all these components of the water cycle affect one consumer, the household occupant.

SUDS generally manage water quality, quantity and improve environmental amenity and biodiversity. (Taylor ,2003). The SUDS treatment train is defined by using the order of management which is categorized as the regional, site management, local, house site and source controls.

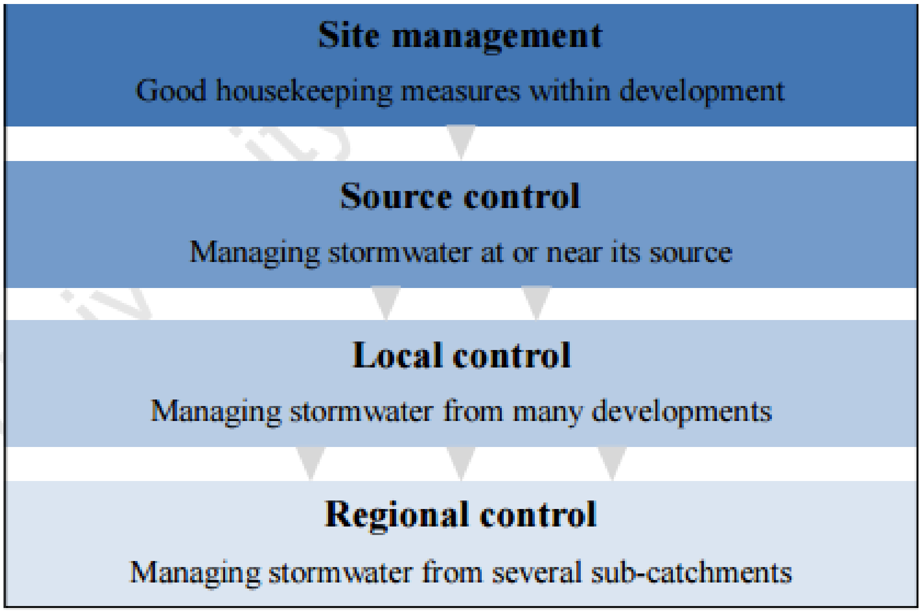

Figure 2-3: Order of SUDS management

(Source: Woods, 2004)

The SUDS order of management shown on Figure 2-3 is used for designing complete SUDS systems from source to water bodies. The examples of the SUDS management hierarchy as depicted by Figure 2-3 are as follows:

- Site management or Preventive measures– Educating the community about the avoidance of utilizing products that contaminate surface runoff and SUDS preventive practices (Wilson et-al, 2004)
- Source Controls – Use of Soakaways, rain harvesting and green roofs, in this study these could be retrofitted onto the portable water network for analysis.
- Local controls- Refers to the use of Vegetative swales and rain gardens.
- Regional controls- infiltration trench and Bio retention ponds as SUDS measures.
- SUDS Treatment Train- A combination of the different SUDS techniques.

Figure 2-4: SUDS tools that can be used

(Source: Lewis, 2012)

Table 2-3: SUDS controls and applicable management zones

LID Alternative	Zones	Processes (besides ET)
Rain Barrel	Surface, Storage	Surface Overflow Storage Underdrain Flow
Porous Pavement	Surface, Storage	Surface Overland Flow Storage Infiltration*
Infiltration Trench	Surface, Storage	Surface Overflow Storage Infiltration
Vegetative Swale	Surface	Surface Overland Flow Surface Infiltration
Bioretention Cell	Surface, Soil, Storage	Surface Overflow Soil Infiltration Soil Percolation Storage Infiltration*

Figure 2-4 shows some of the SUDS controls that can be used as depicted on Figure 2-3, these are examples of the controls that this study will be focusing on to retrofit the potable water network for non-potable purposes. Table 2-3 shows these SUDS measures and their applicable management zones, for the purposes of this research the SUDS measures with high storage capabilities and closest to households are of paramount importance as they can be used to retrofit the potable water network.

2.3 Case studies

2.3.1 General International and European case studies

The new Amsterdam town was completed in 1998 and it was unique in that it was designed with rain water harvesting and green roofs for toilet flushing and other environmental goals. (Scholz, 2006). Figure 2-5 shows this town; it is an important case study to investigate for the purposes of this research since one of the reasons of the SUDS design is to divert storm water into the potable water network for non-potable purposes.

Figure 2-5:Green roofs and Rainwater harvesting in the new town Ecowijk in Amsterdam, Netherlands
(Source: Seven Revolutions to Sustainable Urban Drainage, 2008)

Nevertheless, despite many advances in sustainable water solution designs in Europe and some parts of Africa not much analysis has gone into the effects of such SUDS systems on the potable water network for non-potable purposes. (Schuetze ,2009). This research will endeavour to uncover the effects of these SUDS systems on the potable water network and form a base for the acceptance of systematic retrofitting of these SUDS controls considering their either adverse or beneficial effects on the potable water network for non-portable human usage. Another case study is that shown on Figure 2-6 of a school yard that has been retrofitted to act as a water retention facility.

Figure 2-6: Malmo, Sweden Water Storage on a schoolyard
(Schuetze ,2009).

Public participation in developing public areas has become common practice in Sweden, Netherlands and a whole lot more of other European countries. (Semple E. et al. ,2004). Public participation is required for effective implementation of Sustainable urban drainage systems. Another key factor is how water supply, water management, waste water and sewage treatment are organized to achieve a sustainable water cycle. Therefore, it is paramount to monitor sewage treatment capacity and drainage capacity. Portable water alterations of hardness also influence the copper quantities of water which can affect the properties waste water discharge. (Stovin V,2009).

Tokyo in Japan has about 1700mm annual average rainfall. After the Second World War the Japanese perceived rainwater as a problem that needs to be dealt with by discharging the water into drains as rapid as possible. However, in recent times the Japanese water bodies and the people of the land have realized it was a huge mistake to see rain water as a problem. (Tahir S., Marnierre G., Bell S., Smith D., Crooks A., Batty M. and Campos L, 2009). The realization of this mistake was due to extreme drinking water shortages and flooding. Furthermore, large scale earthquakes damaged piped water supplies and water shortages were enhanced. (Kuno K., Oohashi H., Kobayashi K. and Yokota M, 2008). These crises therefore led to the consideration of sustainable developments such as the Tokyo sky tree.

Figure 2-7:Rain water Harvesting in Tokyo, Japan
(Source: Google, 2020)

Figure 2-7 shows the rainwater harvesting museum in Japan. The building is 610 meters in height and the tank that collects the water has a capacity of approximately 2 mega litres. (Murase, 2012) Underneath the water collecting tank the buildings collect the water from the tank, this collecting tank could also be used by these basement buildings and buildings around as it now acts as a reservoir with sufficient head.

Figure 2-8:Principles of Rain Water harvesting

(Source: www.renewableenergyhub.co.uk/images/design/pages ,2019)

Figure 2-8 depicts the rain water harvesting principles which were employed at the Tokyo museum. The water is collected at the roof, it is then directed to flush toilets and irrigate sites close to the building holding the tank. (Tahir S., Marnierre G., Bell S., Smith D., Crooks A., Batty M. and Campos L,2009). The overflow of water received is stored underground and may be pumped back into the non-potable network within the building once the demand of irrigation and flushing toilets rises.

Northern Glasgow, the Ruchill park and hospital is a case study that provides a framework for which SUDS can be used on a particular site. Figure 2-9 shows the location of the Ruchill hospital site.

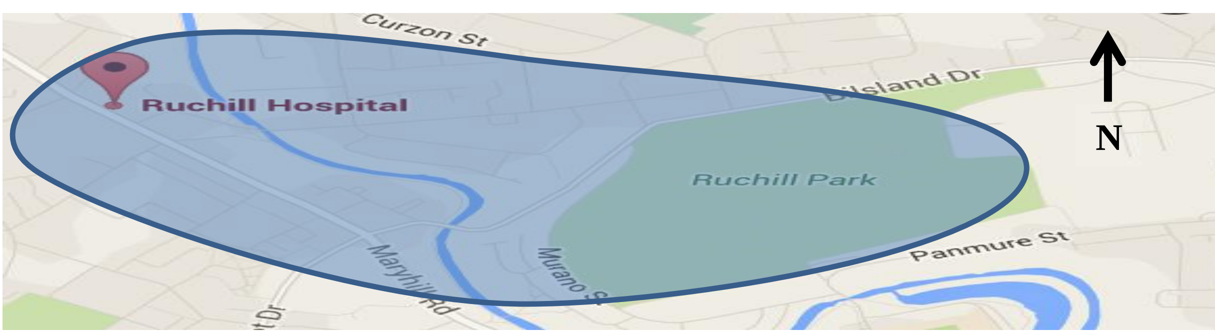

Figure 2-9: Ruchill park and hospital site location

(Source: Google maps, 2019)

Ruchill Park and hospital are in the same catchment and the decision-making tool that was used for the choice of SUDS management suitability was based on the following parameters:

- Catchment size;
- Runoff generated;
- Soil contamination levels;
- Ground water table level;
- Ecological impact potential;
- Soil Infiltration rates;
- Slope of the catchment;

These parameters were examined at the Ruchill park and were used to define the SUDS suitability for these sites. (Picher, 2004). The Glasgow site was therefore modelled and produce the results shown on Table 2-4 and 2-5, these results are important in defining SUDS suitability standards for specific sites and therefore are useful at the design staged of SUDS.

Table 2-4: SUDS modelling results

(Source: Picher, 2004)

SUDS option	Runoff	Catchment Size (m^2)	Area of for SUDS feature	Contamination	Land value
Wetlands	High	>50000	>5000	No	Low
Ponds	High	>15000	>50	No	Medium
Lined ponds	High	>15000	>50	Yes	Medium
Infiltration basin	High	>15000	>50	No	Medium
Swale	High	N/A	>200	No	Medium
Shallow swale	High	N/A	>200	No	Medium
Filter strip	High	>15000	>600	No	Medium
Soakaway	Low	>3000	>200	No	Medium
Infiltration trench	Low	>3000	>50	No	Medium
Permeable pavement	Low/High	N/A	N/A	No	N/A
Underground storage	Low/High	N/A	>40	Yes	N/A
Water playground	Low	>200	>10	No	N/A

.

Table 2-5: SUDS suitability conditions

(Source: Picher, 2004)

Area	Catchment	Wetland	Pond	Infiltration basin	Swale	Infiltration trench
Lillyburn Place	Entire area		X			XXX
Ruchill	Northeast				XX	
Hospital	Southeast				XX	
and	South		XXX		XX	
Park	West		XXX		XX	X

Area	Catchment	Soakaway	Filter strip	Permeable pavement	Underground storage	Water playground
Lillyburn Place	Entire area	X		X		X
Ruchill	Northeast			XX	XXX	
Hospital	Southeast			XX	XXX	
and	South			XX	X	XX
Park	West	X	X	XX	X	XX

Notes: X = possible option; XX = recommended option; XXX = predominant SUDS design feature.

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2.3.2 Case study of SUDS in South Africa

In 2004, eThekwini municipality launched the pilot green roof project as an initiative to fulfil the mandate of the municipal climate protection programme. (Greenstone ,2010). Figure 2-10 shows the green roof project done in Durban, South Africa.

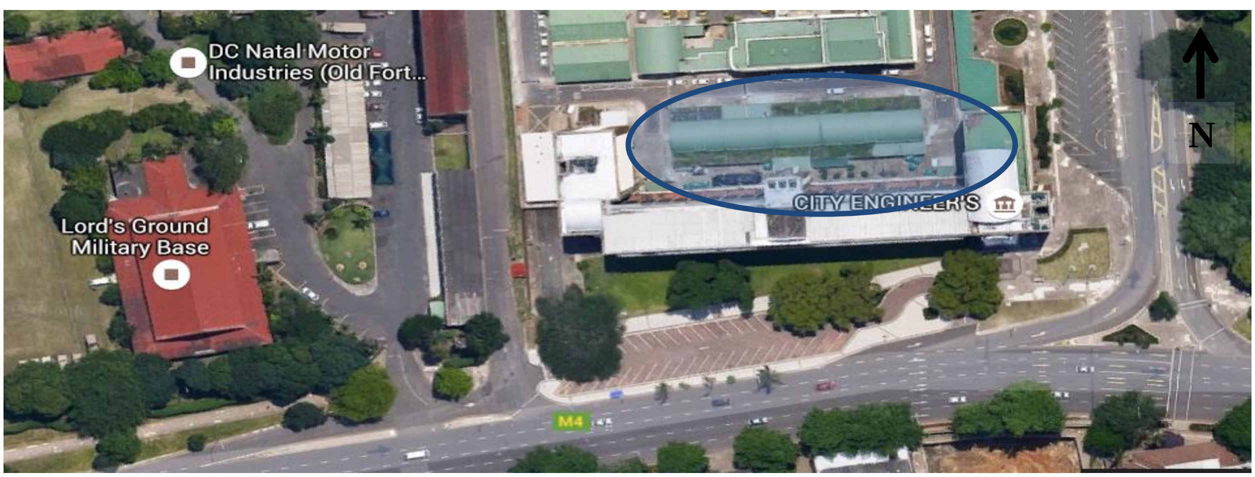

Figure 2-10: SUDS green roof layout in Durban, South Africa

(Source: Google maps, 2019)

The pilot green roof was split into different scenarios in order to analyse the direct and modular methods in the construction of the green roof, the rates of watering and the plant's reactions when placed on a rooftop. The roof area was categorized into five 55 m^2 modular types, and three 55 m^2 direct types. (Lewis, 2009) The modular types are characterized by individual containers with plants placed at the top, the direct types are the form of construction where the plants are placed directly on top of the roof. Figure 2-11 shows the before and after installation of the pilot green project in Durban, South Africa.

*Figure 2-11:*eThekwini pilot green project before and after construction.
(Meggan,2009)

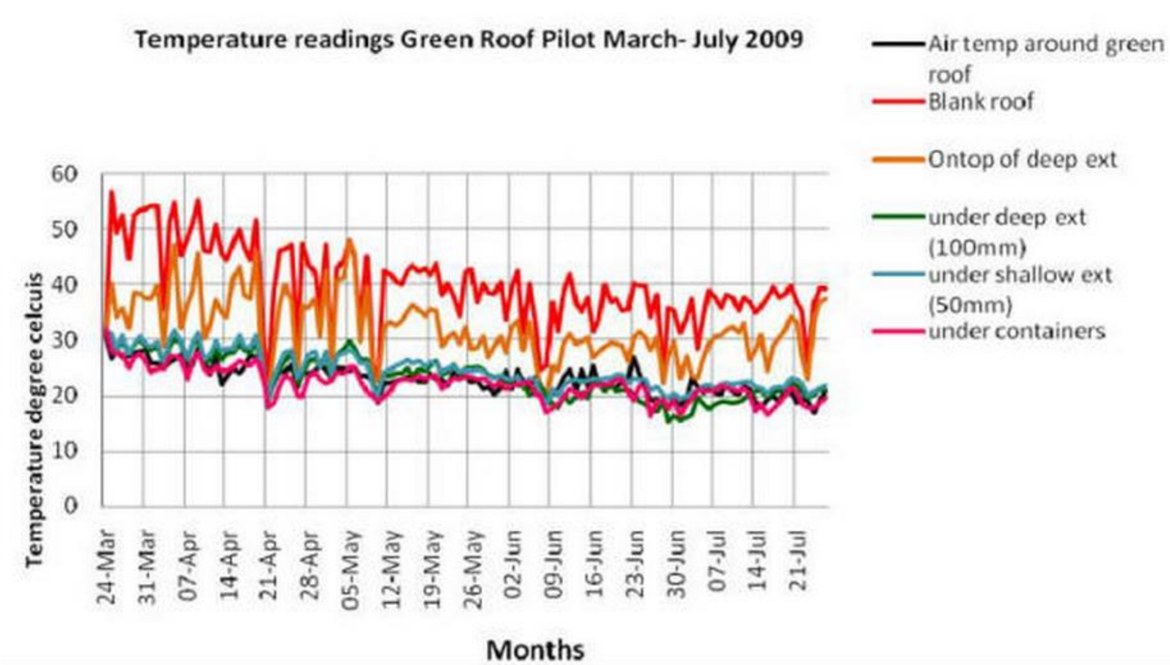

Figure 2-12: Effects of green roofs on temperature of a building
(Source: Greenstone, 2009)

Figure 2-12 depicts the resulting effects on temperature due to using green roofs on a building. The temperature inside the buildings with green roofs installed decreases.

Table 2-6: Table showing effects of green roofs on roof runoff

(Source: Greenstone, 2009)

L- litres					
	Rain Gauge (northside)mm	Rain Gauge (southside)	Drum under Blank Roof (L)	Drum under container roof (L)	Drum under deep (100mm) ext (L)
04-May	0.2	0.5	8	0	0
05-May	0.2	0.2	2	0	0
07-May	1	1.8	32	2.5	0
08-May	3.5	3.1	120	17.5	5
09-May	50	50	over 450	372	320
11-May	3	4	103	70	177
13-Jul	1	1.5	30	3	0
17-Jul	5	5	187	40	11

Table 2-6 shows that as the green roofs are installed the roof runoff significantly decreases, this is expected in theory since the introduction of storage with the use of green roofs reduces the peak runoff on the roof.

SUDS have also been employed in the city of Cape town in South Africa. In this particular case a SUDS treatment train was designed. The location and boundaries of the century city site are shown on Figure 2-13. The catchment area is 196 hectares and includes the surrounding towns, therefore the SUDS design included inter sub catchment t considerations. A SUDS treatment train was designed in Century city, Figure 2-14 shows the SUDS treatment train which included a constructed wetland, bio retention ponds and permeable pavements.

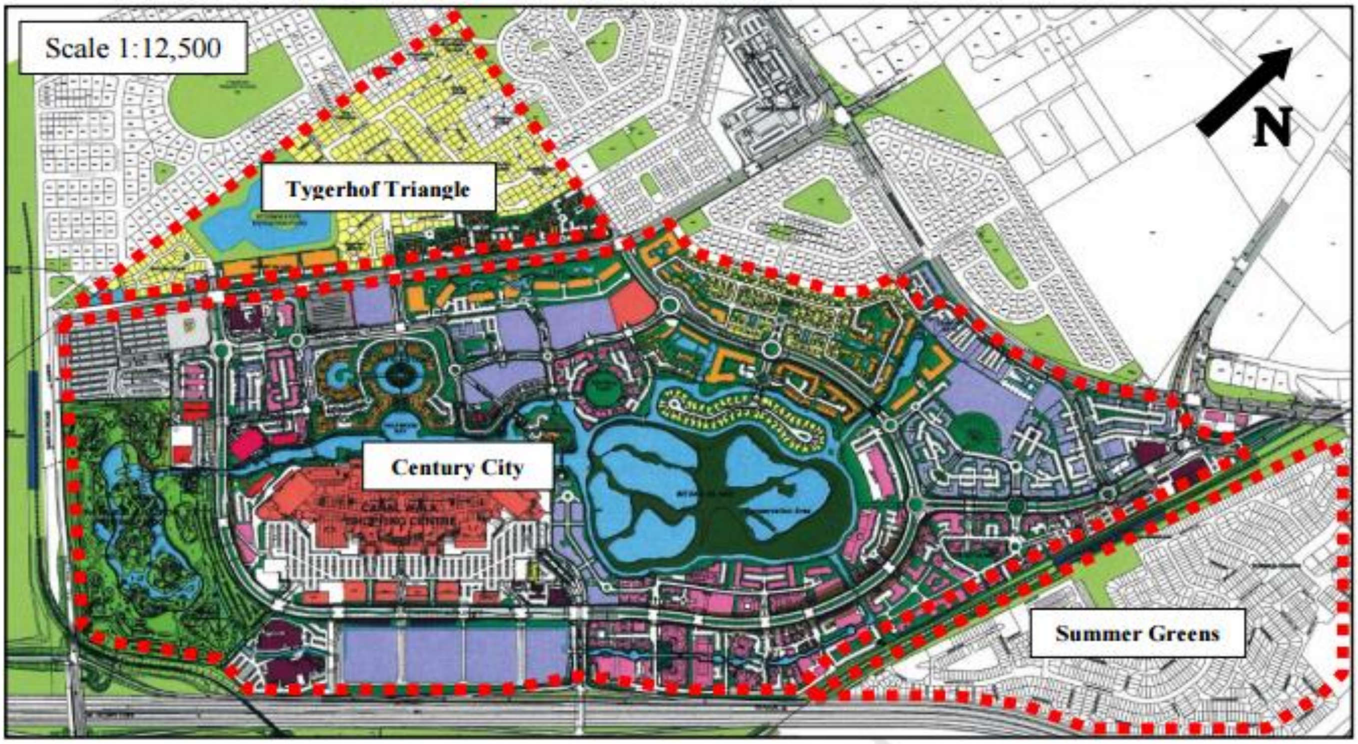

Figure 2-13: Century city location in Cape town, South Africa

(Source: Michael, 2010)

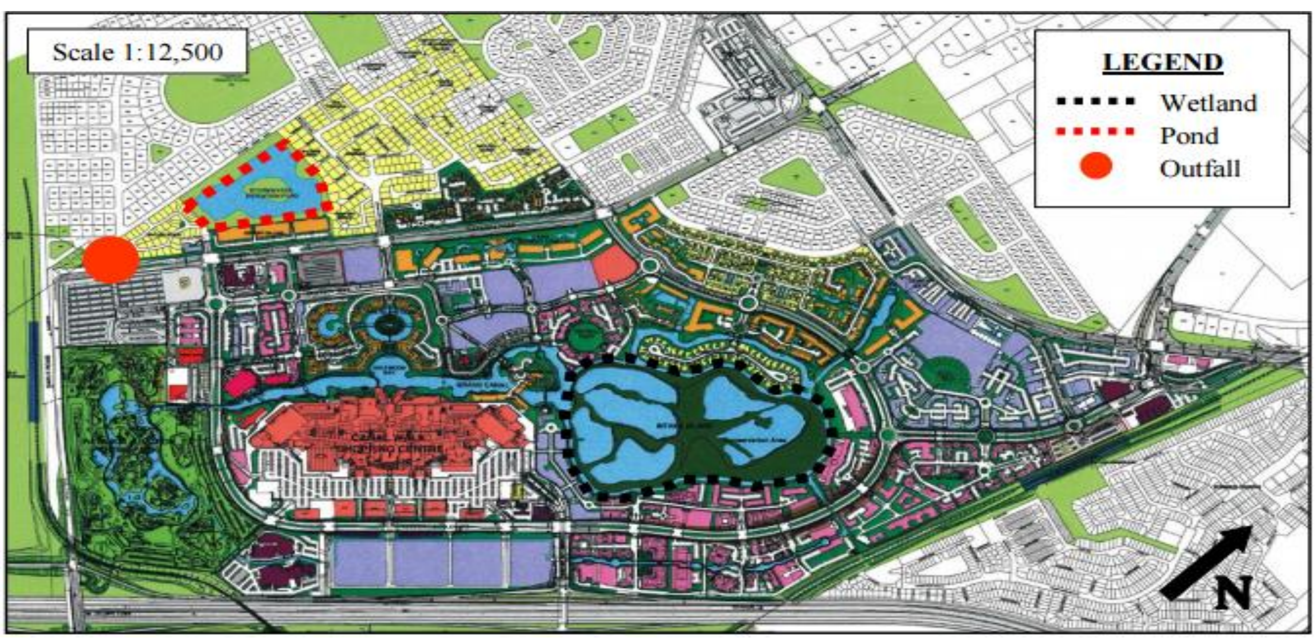

Figure 2-14:SUDS Treatment Train in Century city

(Source: Michael, 2010)

A 1 in a 100-year rainfall event and storage volume of 185 000 m^3 was used as the basis of designing the SUDS treatment train in Century City. A difference of 60 000 m^3 storage from the calculated storage volume was required and the SUDS treatment train was used to provide this difference. The different SUDS techniques used in century city are shown on Figures 2-15 and 2-16.

Figure 2-15: Wetland (Left) and Rain water collecting tank (Right)
(Source: Michael, 2010)

Figure 2-16: Vegetative Swale (Left) and Infiltration Trench (Right)
(Source: Michael, 2010)

Figure 2-22 and shows the location of each cell within the SUDS treatment train. Table 2-7 is a depiction of the modelling results for the SUDS treatment train after installation in Century city Cape town. The century city outfall has a low outfall volume after SUDS installation whereas Tygerhof and the canal have a storage of 273000 m^3 in total, this volume can be used for non-potable purposes by humans.

Figure 2-17: Cells within Century city SUDS treatment train

(Source: Michael, 2010)

Table 2-7: Storage differences between Century City and surrounding sites

(Source: HHO Africa, 2006)

Storm duration (hours)	Total precipitation (mm)	Volume required (m^3)			Peak discharge (m^3/s)	
		Canal	**Tygerhof pond**	**Total storage**	**Century City outfall**	**Flow to Wingfield outfall**
1.5	40.4	40135	65446	105581	3.10	0.45
2.0	43.9	42090	69900	111990	3.30	0.50
4.0	56	48615	86961	135606	3.75	0.57
6.0	63.0	50140	98950	149090	3.75	0.66
8.0	68	49335	108665	158000	3.70	0.68
10.0	70	44965	111888	156853	3.70	0.71
12.0	72	42320	114731	157051	3.30	0.72
24.0	93.6	38640	148425	187065	2.90	0.95
36.0	118.8	38180	181504	219684	2.85	1.13
48.0	144.0	37950	207568	245518	2.75	1.30
60.0	162.0	36455	218136	254591	2.75	1.38
72.0	172.8	34155	217331	251486	2.40	1.38
84.0	176.4	31165	207995	239160	2.10	1.31
Available Capacity		**83000**	**190000**	**273000**	**N/A**	**1.10**

2.4 Conclusion

An analysis of different SUDS techniques has been presented on the Literature review. This research focuses on possibilities of retrofitting SUDS systems and diverting these into water networks for human non-portable uses. The SUDS design parameters were clearly shown in the Glasgow, Durban and Century city case studies. More design tools will be generated from this research, such as a water balance which is required to visualise the effects of the addition of SUDS to drinking water networks. PCSWMM and Arc GIS will be used to integrate the Storm water and potable water network.

The comprehensive literature review therefore gives an idea of the SUDS systems that are more relevant to this research topic as SUDS is a broad topic, the source and Local controls will be explored mostly and their effects on the water balance of drinking water will therefore be key in determining the possibilities of diverting storm water for human non-portable use.

The National Water Act (Act 36 of 1998) aims to achieve the desired balance between the development, use, protection, conservation, management and control of water resources. This Water Conservation or Water Demand Management, WC/WDM, approach to be carried out comprises of a broad set of strategies that will be implemented to reconcile the available supply with the demand for water. Water conservation and managing the demand for water is key to ensure sustainable use of our water resources, and to ensure that sufficient water is available for current and future requirements. (Southeast Michigan Council of Governments ,2008). The intention of this research therefore correlates adequately with the Government's strategic direction in terms of water efficiency, as presented in Figure 2-18.

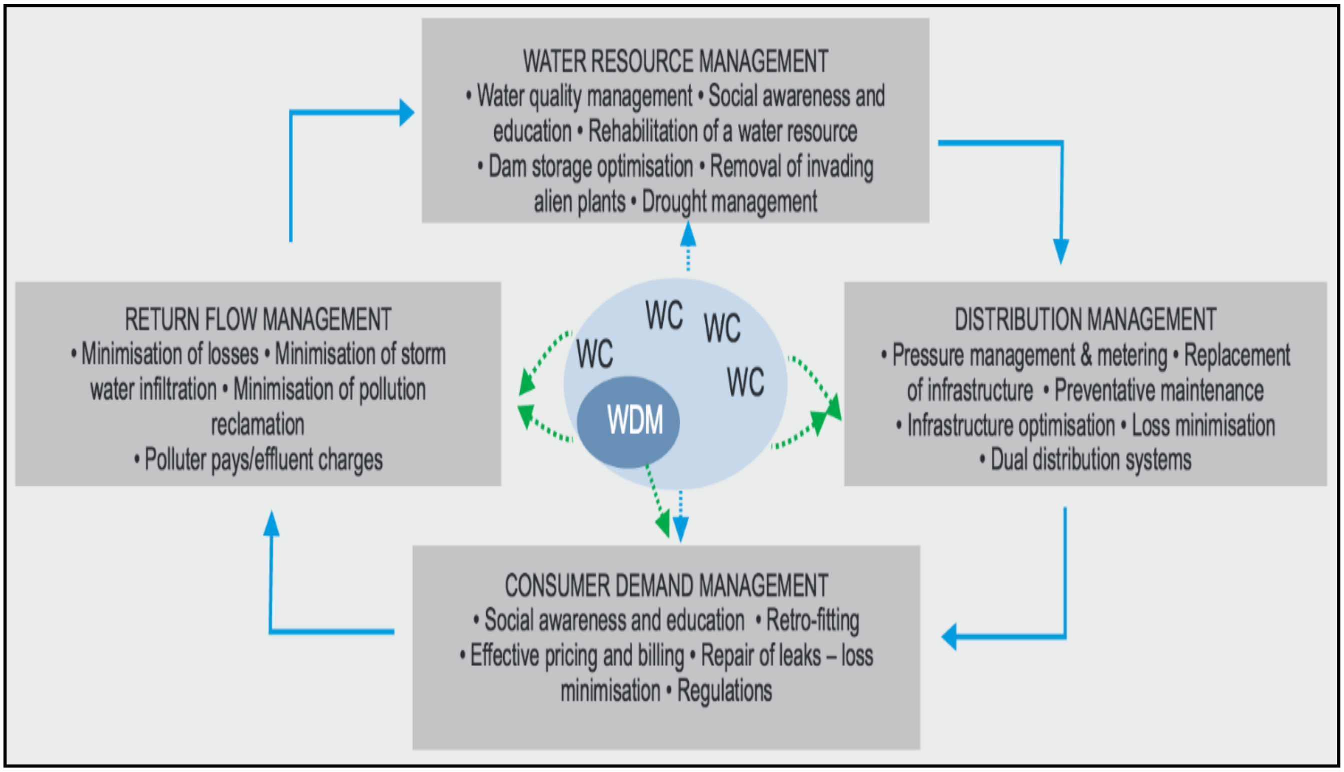

Figure 2-18:Elements of Water Conservation and Water Demand Management

(Source: Vishal, 2019)

In terms of the overarching strategy for WC/WDM, the following objectives are endorsed:

- Reduce water losses and increase water use efficiency;
- Promote water saving through incentive-based programmes;
- Fast-track implementation of WC/WDM; and

The onus therefore lies with the community in terms of managing their facilities to ensure that they plan for sustainable water use. Sustainable development has generally been defined in terms of water, energy and food security. Water security can be further defined by three elements:

- Water accessibility;
- Water safety; and
- Water affordability.

The purposes of fulfilling these three elements is to ensure that every person is able to lead a clean, healthy and productive life while ensuring that the natural environment is protected and enhanced. SUDS will be considered for the Isipingo region in this research as a means of reducing municipal water supply and increasing water conservation.

3 METHODOLOGY

3.1 Introduction

There is a large number of software available for storm water management modelling however PCSWMM has been reviewed well in terms of research precision and accuracy. PCSWMM can model SUDS systems both for continuous and single events. Figure 3-1 shows the parameters that SUDS measures which are mainly surface runoff, infiltration, overflow and evaporation.

PCSWMM categorizes the ground into the different layers of surface, soil and storage zone. The Green-Ampt equations or SCS Curve number method and Horton equations are used to calculate the infiltration losses for the different pervious and impervious zones of the ground. Manning's equations are used to calculate the surface runoff which is key to this study. is also able to define snow fall, snow melt and ground water levels.

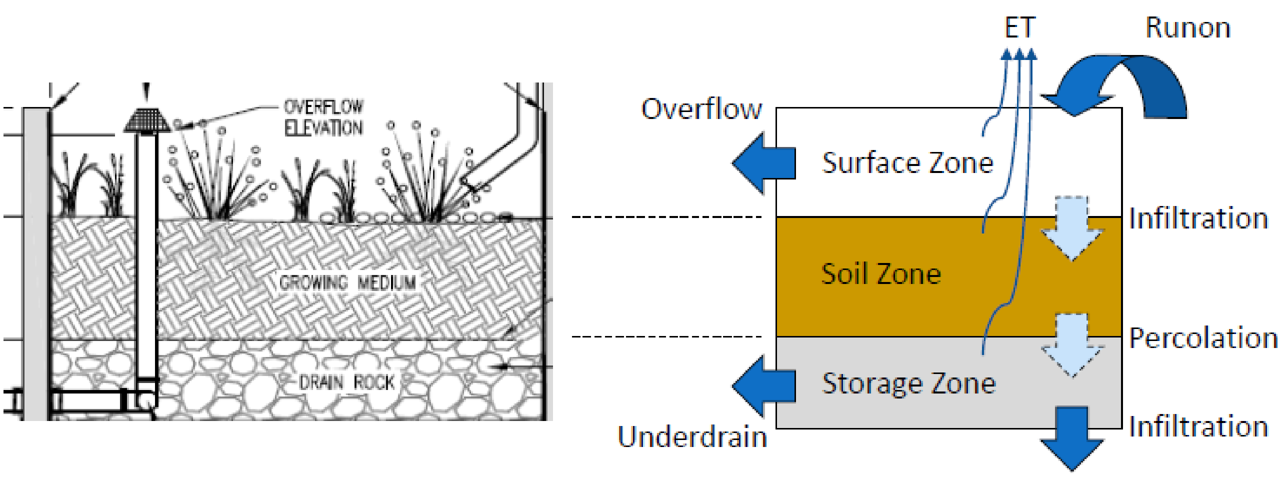

Figure 3-1:PCWMM SUDS modelling parameters
(Source: Rob, 2012)

3.2 Choice of methodology

The method used is sensitivity analysis and is usually governed by a number of constraints or settings. Some of the most common are:

- **Computational expense:** Sensitivity analysis is almost always performed by running the model a number of times, this can be a major problem if a single run of the model takes a huge amount of time, the model has a large number of uncertain inputs. Computational expense is a problem in many practical sensitivity analyses.
- **Correlated inputs:** Sensitivity analysis methods usually disregard interaction between model inputs yet sometimes inputs can be strongly correlated.

- **Nonlinearity:** In cases where the model output is nonlinear with respect to the inputs, linear regression methods can be an inaccurate measure of sensitivity and Variance based methods are preferred.
- **Model interactions:** Some input parameters interact and cause significant change to output results. Methods such as scatter plots and one factor at a time do not consider these interactions.
- **Multiple outputs:** It is a bit difficult to handle multiple outputs that are correlated, as in this research there are multiple outputs being analysed and as such if these inputs are correlated it is not easy to differentiate them but fortunately a sensitivity analyses of each output can be run simultaneously on the PCSWMM software. Considering the above review of methodologies, factors affecting the choice of each, the time allocation and the level of applicability to this research topic a combination of the screening methodology is used in the formulating of a methodology particular to this research.

The modeling criteria and the literature review were used to select the Isipingo Umlazi catchment as the SUDS case study site to be used for this research. The Isipingo catchment is chosen considering the literature review for SUDS suitability such as the catchment size and slope, all these are listed on Table 2-4. Table 2-5 shows the suitability of SUDS in accordance to catchment characteristics, Isipingo catchment is greater than 50 000 m^2 hence all the SUDS systems can be analyzed using the Isipingo catchment. The modelling criteria is also linked to the catchment characteristics therefore both the modeling criteria and catchment characteristics contribute to the choice of Isipingo catchment as an area of study.

3.3 Methodological approach

The approach hinges on the creation of scenarios compared to the existing status quo of the storm water network at the analysis precinct. The approach is as follows:

1) Select a precinct to be used as a case study using the SUDS suitability criteria cited in section 3.3 of this research.
2) Collect existing storm water network GIS data for the chosen precinct and input data into the PCSWMM software.
3) Rainfall – losses = Runoff (A), A is a representation of the existing scenario runoff.
4) Rainfall – losses - Harvested Volume (B) = Runoff (C), C is a representation of the SUDS scenarios runoff.
5) A - C = B, the harvested volume which is the interest of this study for potential water savings.
6) Harvested Volume (B) – Non-Potable Volume Used (D) = Remaining Volume Harvested (E), E is a representation of the SUDS scenarios after non-potable usage.
7) Setup parameters and simulate the precinct's existing scenario and analyse A, the existing scenario runoff.
8) Setup parameters and simulate the precinct's scenario 1 with SUDS source controls and analyse C1, the source control runoff. Calculate B1, the harvested volume in this scenario.
9) Setup parameters and simulate the precinct's scenario 2 with SUDS local controls and analyse C2, the local controls runoff. Calculate B2, the harvested volume in this scenario.
10) Setup parameters and simulate the precinct's scenario 3 with SUDS regional controls and analyse C3, the regional controls runoff. Calculate B3, the harvested volume in this scenario.
11) Setup parameters and simulate the precinct's scenario 4 with SUDS treatment train controls and analyse C4, SUDS treatment train runoff. Calculate B4, the harvested volume in this scenario.
12) Collect the precinct's GIS and potable water balance data to calculate X, the precinct's existing municipal water supply quantity per year.
13) Calculate X – B = Z, the difference between the existing municipal water supply volume and the storm water SUDS harvested volumes per year, B, for each scenario. If positive value, Z denotes the reduced municipal supply volume after SUDS savings over the year.
14) Calculate the actual savings per year considering that not all the harvested volume is used within the year. Consider the estimated non-potable usage and the remaining volume in the SUDS storage facilities.
15) A feasibility and cost benefit analysis considering rerouting of water from each of the SUDS storm water systems to the non-potable human supply systems.

4 PCSWMM MODEL

4.1 Introduction

As the study uses PCSWMM model to implement and analysis SUDS in a selected study area, the description of the methodological approach is extended in this chapter as well. The chosen precinct of analysis is based in Umlazi Durban area labelled ‘0’ on Figure 4-1, The Isipingo catchment was chosen for the purposes of this research considering section 3.3 outlining the SUDS suitability criteria. The approach hinges on the creation of scenarios compared to the existing status quo of the storm water and potable water networks at the analysis precinct.

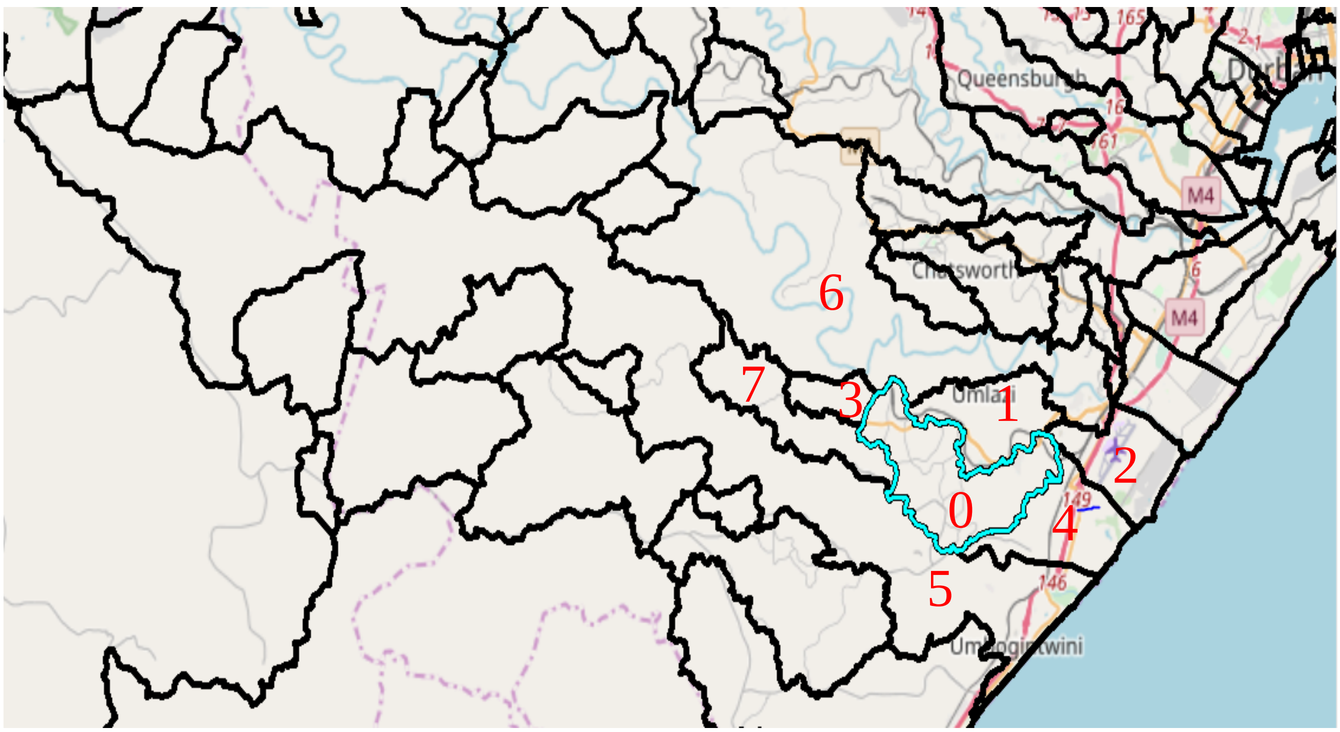

Figure 4-1: Site Description - Isipingo Catchment Area of analysis Highlighted

The potable water network has to be superimposed with the storm water catchment area in order for the analysis results to be closely comparable and for storm water retrofitting efficiency purposes, especially stormwater analysis which hugely relies on the catchment characteristics. Furthermore, many catchments around the Isipingo Catchment contribute to the runoff and consequent storage to be calculated in this research due to inter catchment transfer of water.

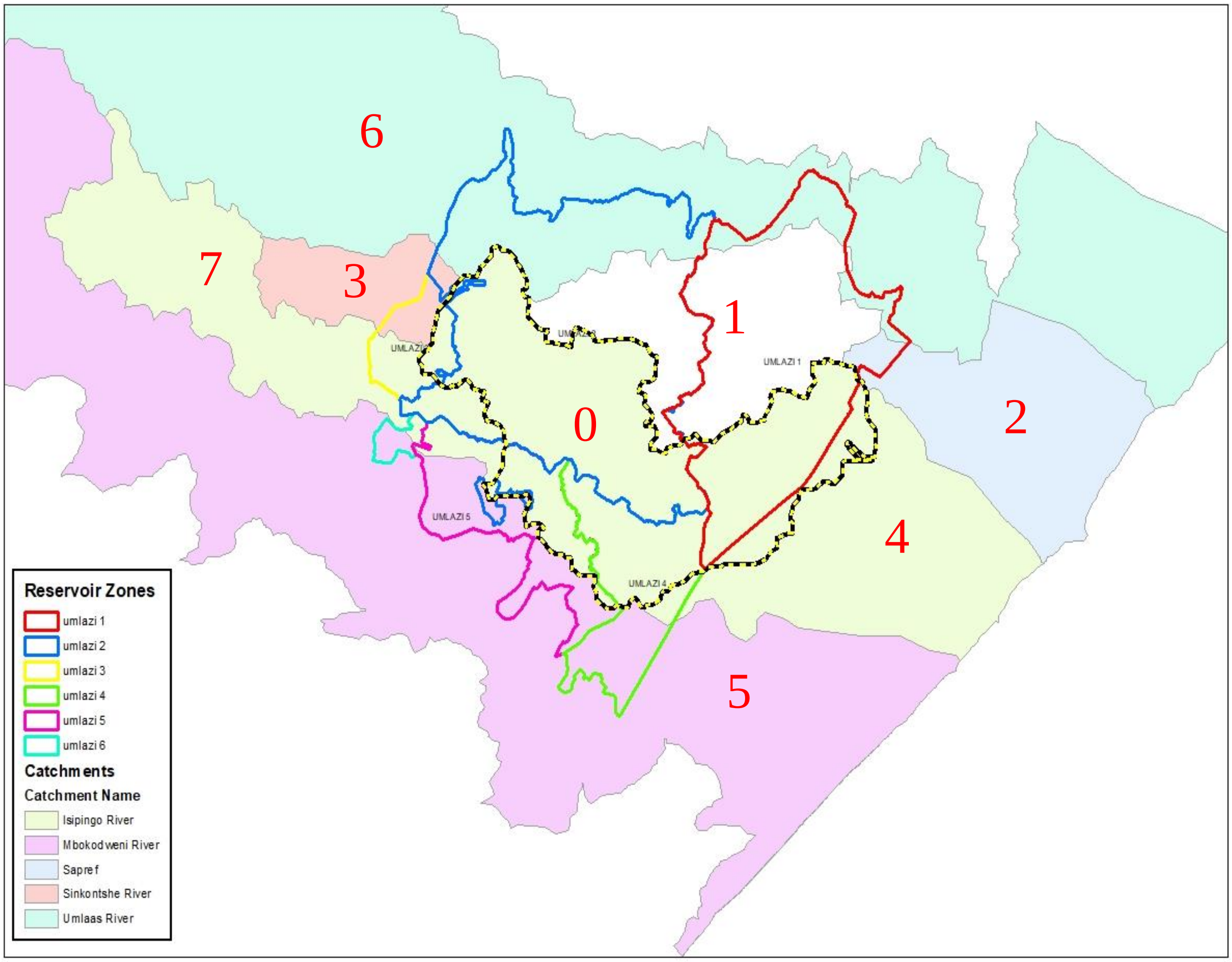

Figure 4-2: Isipingo Catchment Superimposed with the Potable Water Network in the form of reservoir zone polygons

As shown on Figure 4-2 the Isipingo catchment chosen for analysis interacts with all the 6 Umlazi potable water reservoir zones. Reservoir zone, Umlazi 2, has the highest interaction ratio with the Isipingo Catchment area of analysis catchment '0'. The six zones are not entirely discrete and supply each other, Therefore logging data for Umlazi 1 to Umlazi 6 is all analyzed giving preference to the Umlazi 2 which has the highest supply zonal area to Isipingo catchment area ratio.

4.2 GIS integration of potable network

The GIS data of potable water networks in eThekwini is all collected and using query functions of Arc GIS software the area of interest is zoned into and isolated for further analysis. The zone's pipe sizes are also obtained as shown on Figure 4-3. Furthermore, the zone has district metered areas with full PRV locations. These district metered areas are a means to accounting for water in the different district metered zones within the reservoir zone.

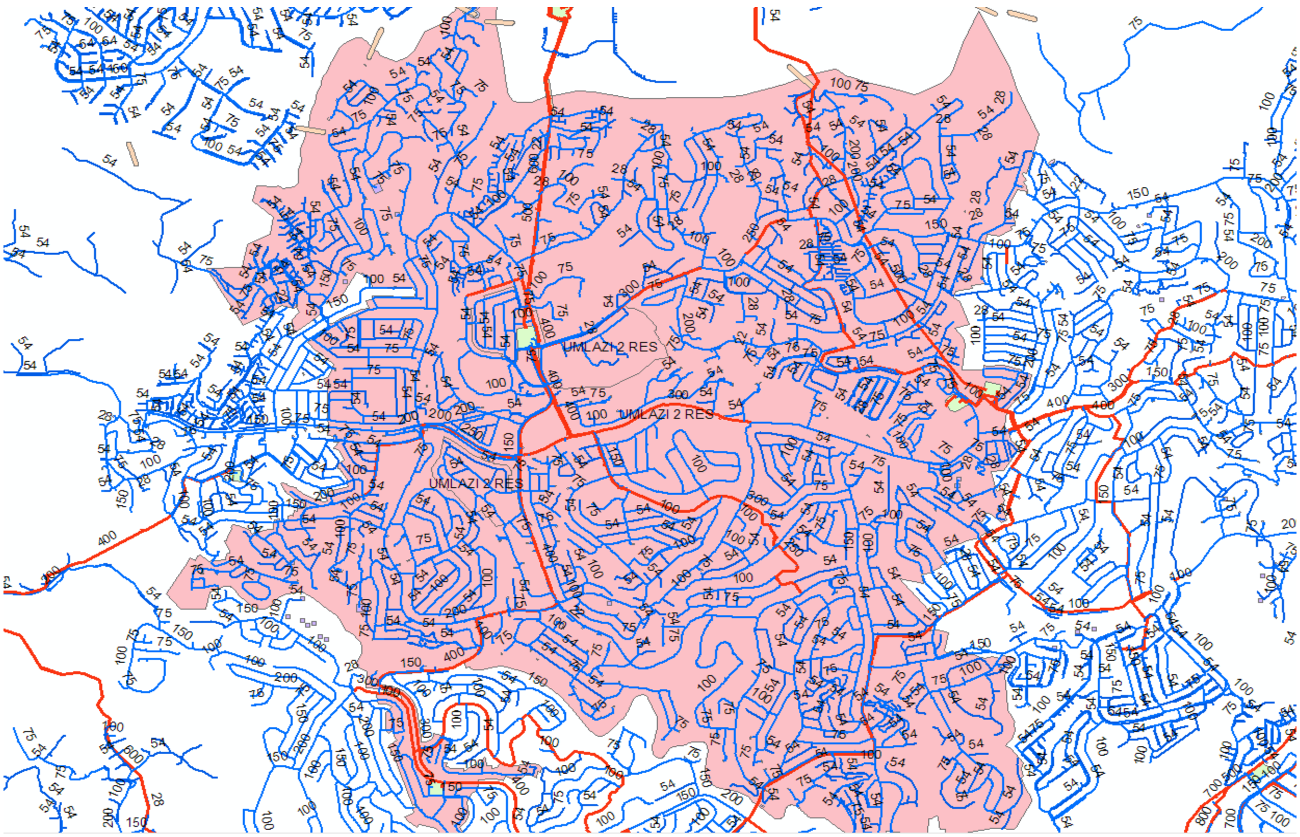

Figure 4-3: Reservoir Zone's Bulk pipe sizes within supply zone

There are many existing water metering points in the Umlazi region which are also pressure reducing valve locations. These metering points are critical for this research as they provide water logging points to obtain the system input volume required for this research. However as earlier alluded to these zones are not discrete, hence a zone close to discrete status is chosen for analysis using the zone's operations team knowledge in accordance to the as built maps. The water operators in this area usually exercise the valves and generally know the reaction of the system to valve exercising, over and above the GIS data and meter readings which are used for cross verification of the knowledge provided by the operators. Their knowledge is particularly important because the pipes may have been changed by different contractors over the years without updating the as built drawings and GIS information therefore the liaison with operators provides better results accuracy. Figure 4-4 shows the selected discrete zone for analysis and the corresponding pipe materials in this zone.

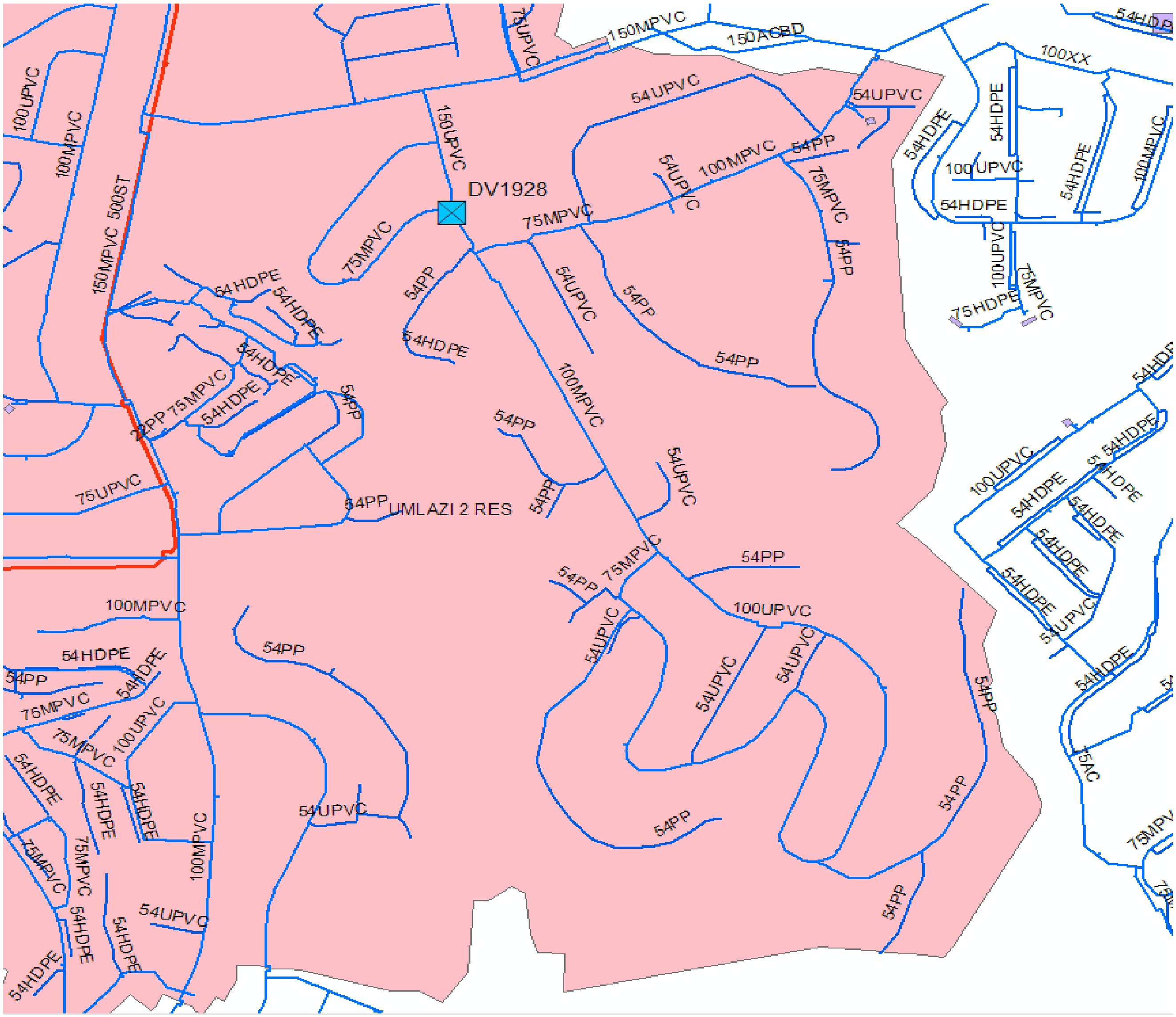

Figure 4-4: Metering Point DV1928 selected for this research

The water logging point DV1928, shown on Figure 4-4, is used to obtain the volume of water entering the discrete zone. The volume is only representative of the reservoir supply zone therefore a ratio of population to the volume obtained from logging is used to convert the volume to represent the catchment population of interest in this research. The population of Umlazi according to the census 2011 count is approximately 404 811 people.

4.3 GIS integration and modelling analysis

4.3.1 GIS integration of storm water network

The main focus of this research is around the computational modelling analysis of the stormwater network and the use of sustainable urban drainage systems to divert water into the potable water network for non-potable uses. The GIS shape file data of the storm water drains, pipes and the catchments are obtained and further Arc GIS querying is done before importing these shape files on the PCSWMM analysis package. Figure 4-5 shows the average slope verification process using google earth, this is very important especially for storm water analysis which is hugely affected by the catchment's characteristics

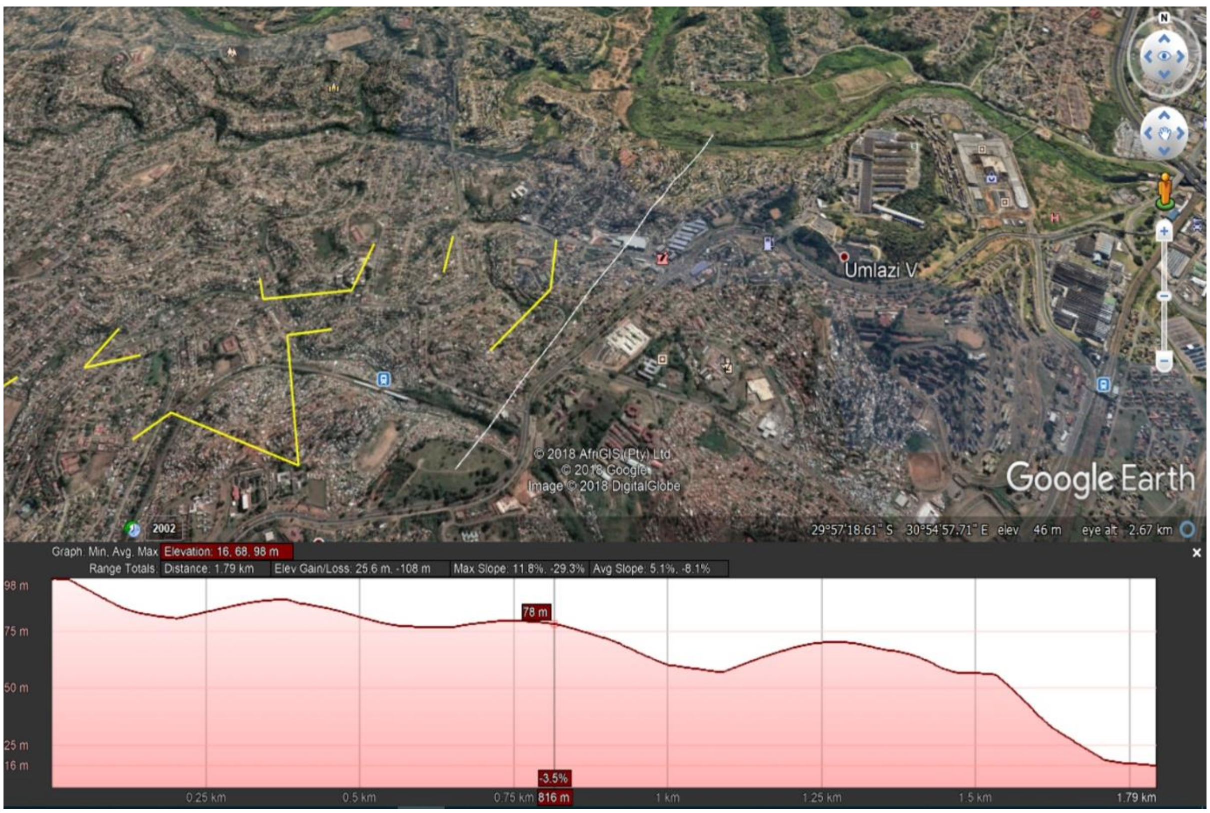

Figure 4-5: Google Earth Verification of slopes for Arc GIS and PCSWMM analysis (Source Google Earth)

An Arc GIS model of the Isipingo catchment pipes, stormwater drains and the catchment shapefile is produced for further exporting to PCSWMM software. These shapefiles are obtained through Arc GIS querry functions to zone into the Isipingo subcatchment area and its attributes.The attributes tables also assist in cleaning the data and identifying orphan junctions or junctions without invert levels, this can be done as a first manual check to eliminate the anomalies before exporting data into the PCSWMM software.

4.3.2 PCWMM modelling analysis setup

The PCSWMM software models both quantity and quality of stormwater, this research focuses mainly on the quantity of stormwater in the form of storage volumes, the cost benefit analysis of implementing these storm water storage technchniques in a sustainable manner, Sustainable urban drainage systems, and feasibility study of diverting this stormwater into potabe water networks for non potable uses. Figure 4-6 shows all the shapefiles that have been imported into PCSWMM for computational modeling analysis.

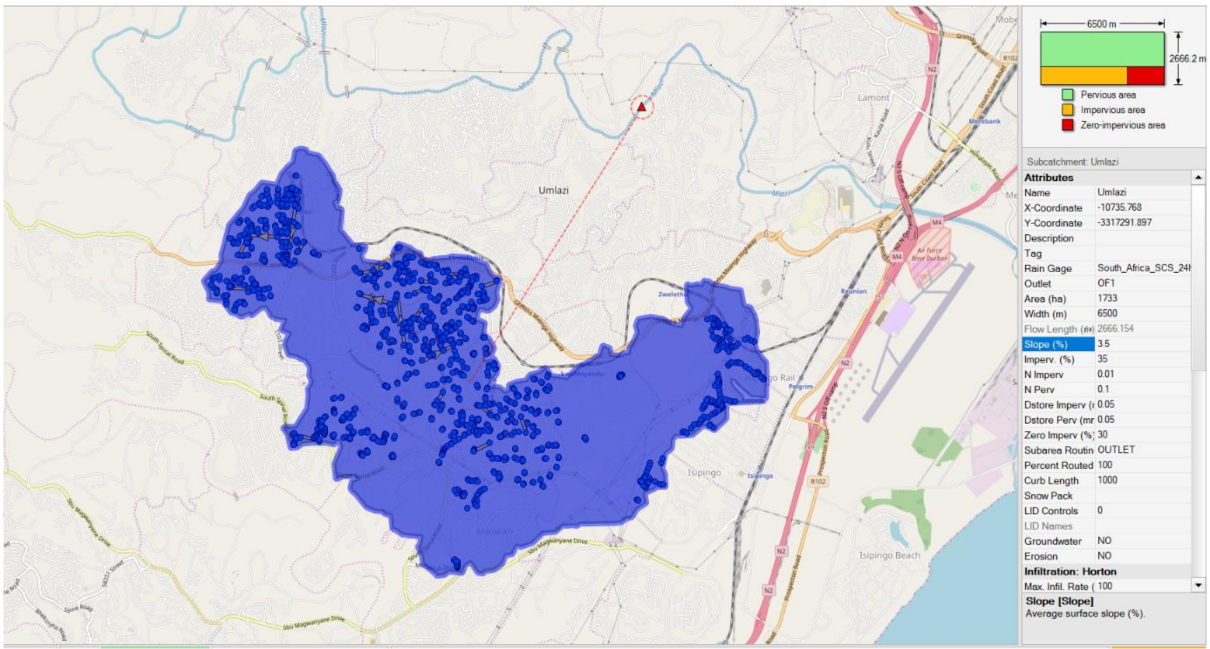

Figure 4-6:PCSWMM import of Arc GIS shape files for computational water modelling

A time series is chosen and in this case an interval of 1 year is selected as the simulation period.Futhermore the characteristsics such as percentage imperviosness are estimated from google earth as is the slope of the catchment. Figure 4-6 is representative of the current existing scenario; the current storm water network scenario which has no sustainable urban drianage techniques employed. Four scenarios are to be simulated according to the stormwater hierchal system which is as follows:

- Source Controls;
- Local controls;
- Regional Controls;
- SUDS Treatment Train Contol;

These controls are to be anaylsed interms of storage , the most effective and average storage value is obtained inorder to subtract it from the existing scenario's potable water system input volume which includes non potable demand, if positive then the result obtained is the reduced potable volume.Therefore the harvested non potable water is considered as potable water saving due to SUDS.

4.3.3 SUDS PCWMM modelling Inputs

4.3.3.1 SUDS inputs and parameters

The modelling inputs are mainly for the different Sustainable urban drainage systems, inputs and paramters vary for each storm water technique. The techniques are shown on the following Figures below:

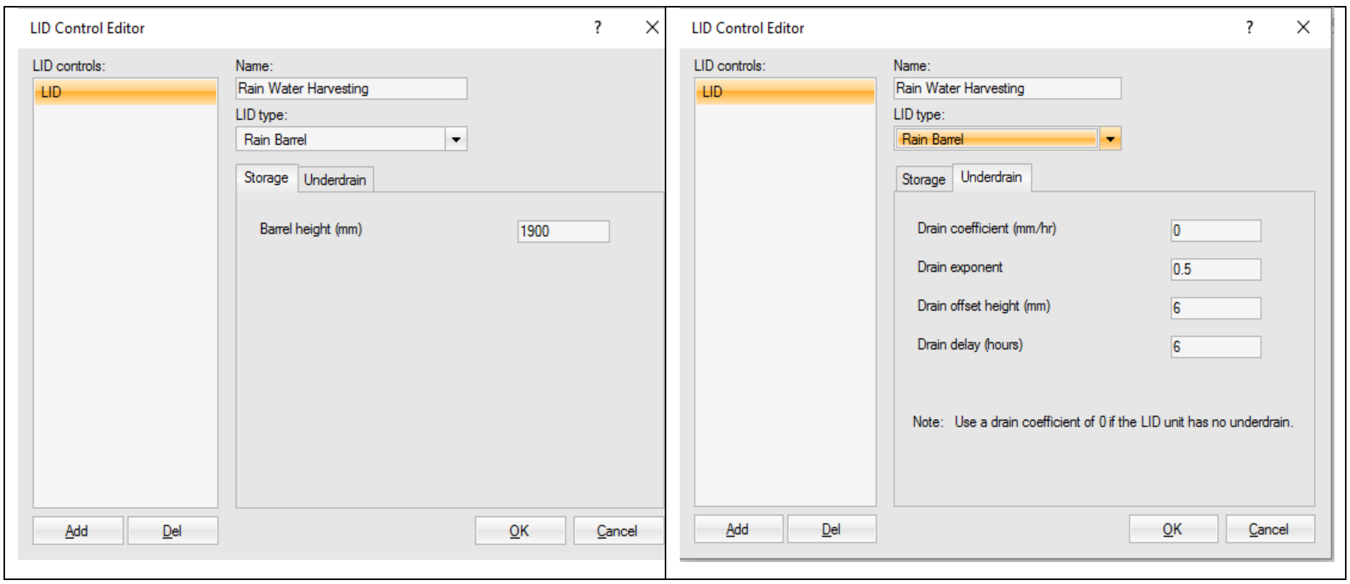

Figure 4-7: Rainwater Harvesting and corresponding Source Control Inputs (Rain Water Barrel Input Parameters into the PCSWMM Software)

The rain water harvesting input has two tabs , storage and underdrain. The storage tab defines the height of the barrel.The second tab is the underdrain , Underdrains are either recommended or required when the natural soil infiltration rate is insufficient to prevent the LID unit from flooding. The drain coefficient, exponent offset and delay are provided on the SWMM GIS addon tab for the area of study. The underdrain applies for rainwater harvesting, Infiltration trench and the bioretention cells. The drain coefficient determines the rate of flow through the drain as a function of height of stored water above the drain bottom. For Rooftop Disconnection it is the maximum flow rate in mm/hour that the roof's gutters and downspouts can handle before overflowing. The exponent determines the rate of flow through the drain as a function of height of stored water above the drain outlet. Offset height of the drain line above the bottom of the storage layer or rain barrel mm.

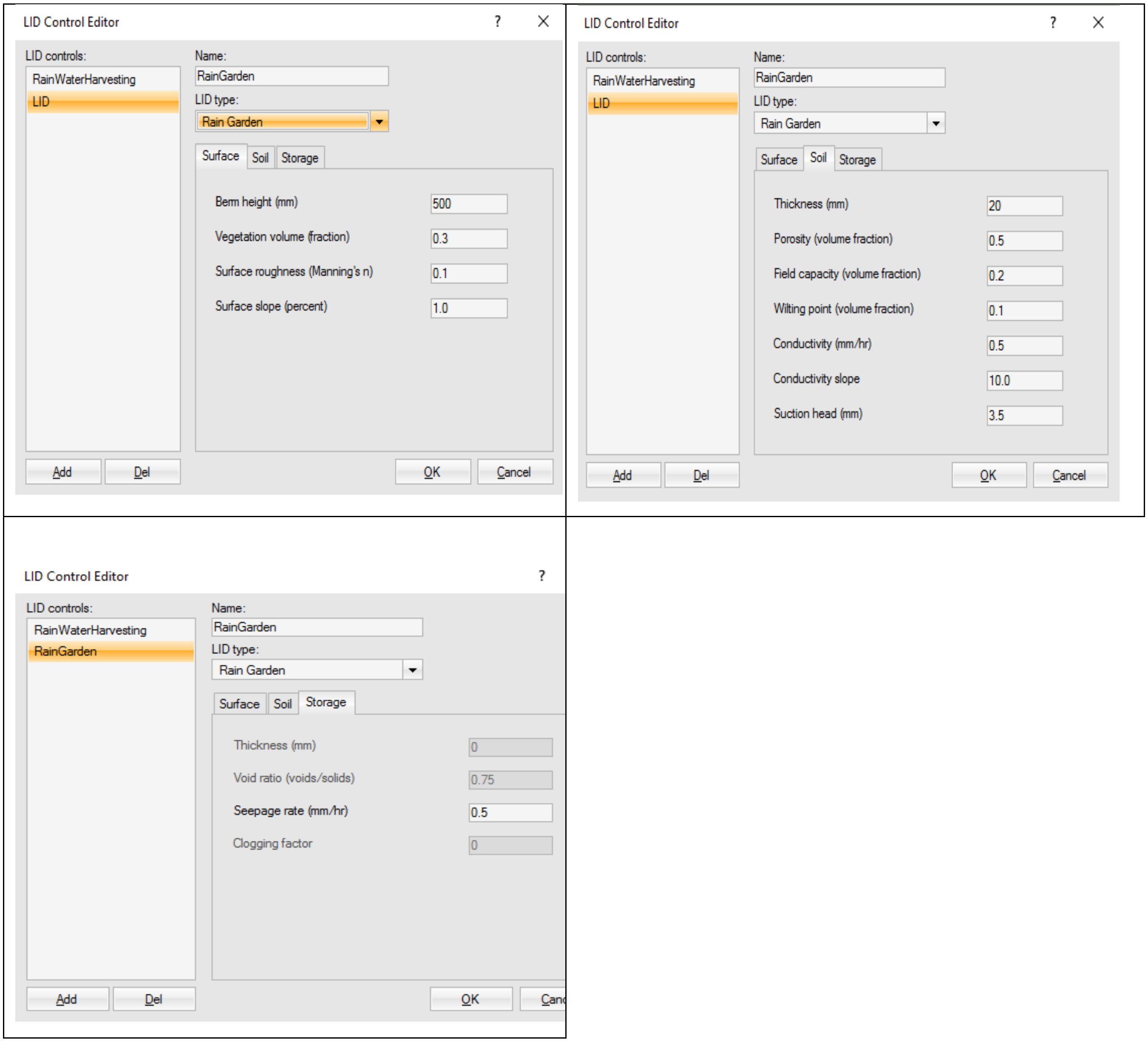

Figure 4-8: Rain Garden and corresponding source Control Input (Rain Garden on site Input Parameters into the PCSWMM Software

The rain garden input has three tabs , surface , soil and storage. For the surface tab when confining walls or berms are present this is the maximum depth to which water can pond above the surface of the unit before overflow occurs in mm. For low impact designs that experience overland flow it is the height of any surface depression storage. For swales, it is the height of its trapezoidal cross section. The vegetation fraction is a representation of the surface storage volume that is filled with vegetation. Rough Manning's n is for overland flow over surface soil cover, pavement, roof surface or a vegetative swale. Surface slope is the slope of a roof surface, pavement surface or vegetative swale as a function of percentage.

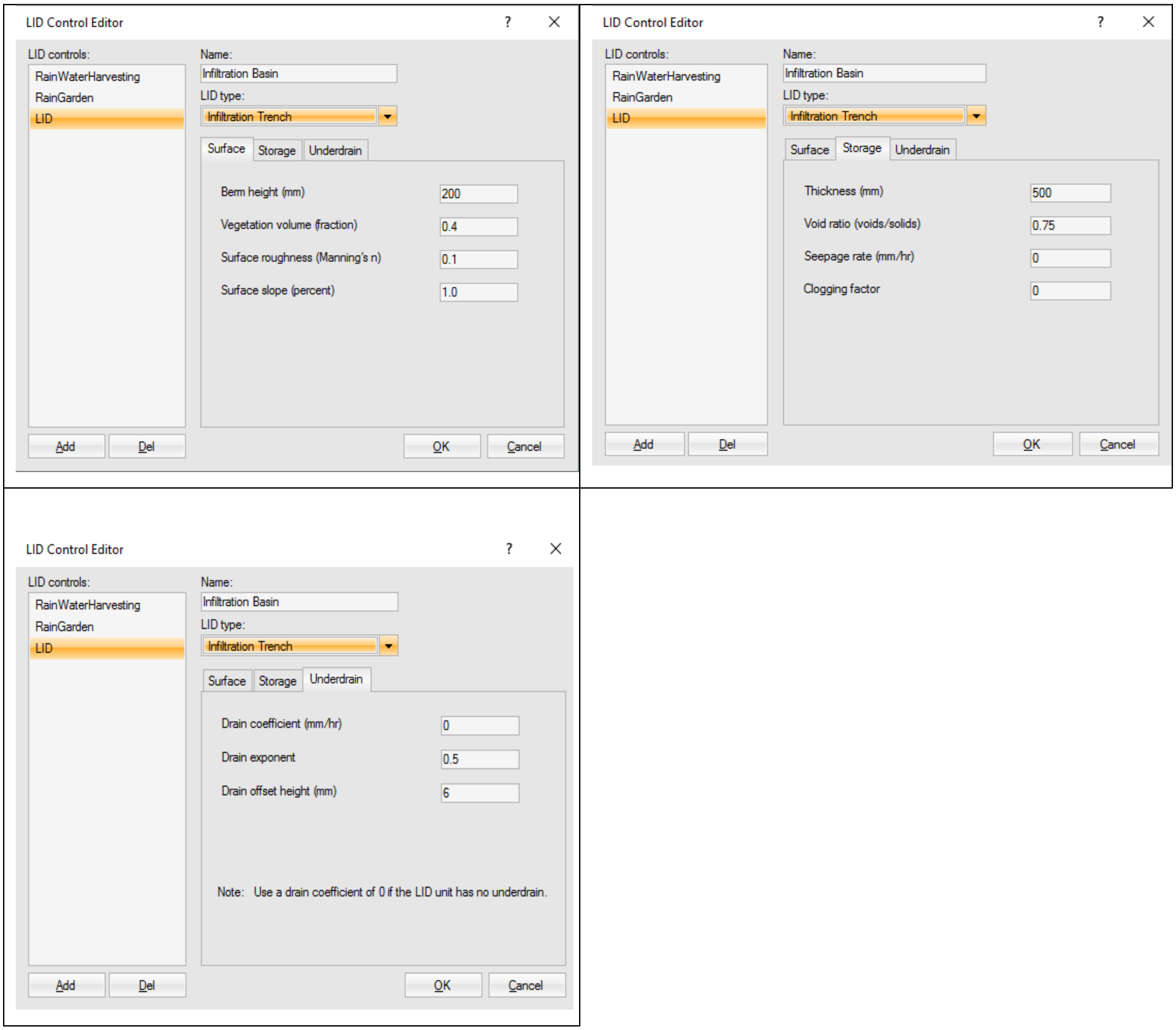

Figure 4-9: Infiltration Basin and corresponding Local Control Input (Infiltration Trench Input Parameters into the PCSWMM Software)

The infiltration trench shown on Figure 4-9 input aslo has three tabs , surface , storage and underdrain. The Biorentention pond shown on Figure 4-10 has four tabs surface, soil, storage and underdrian. The storage for the rain garden, infiltrtion trench and the bioretention pond has height which is the thickness of the storage layer. The void ratio is the volume of void space relative to the volume of solids in the layer. The porosity = void ratio / (1 + void ratio). Seepage is the rate at which water seeps from the layer into the underlying native soil when first constructed in mm/hr. The clogging value is the number of storage layer void volumes of runoff treated it takes to completely clog the layer.

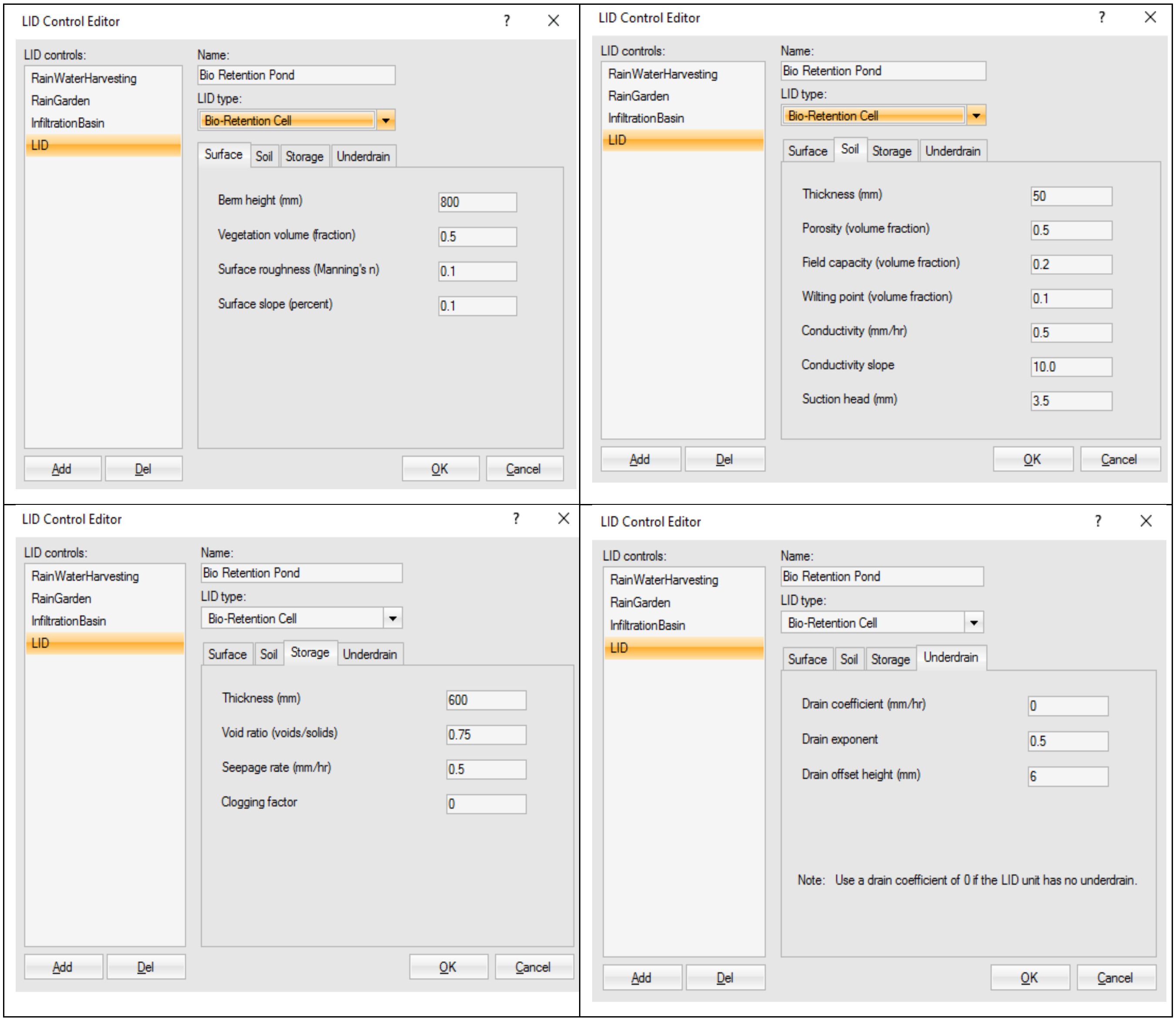

Figure 4-10: Bio Retention Pond and corresponding Regional Control Input (Bio Retention Cell Input Parameters into the PCSWMM Software)

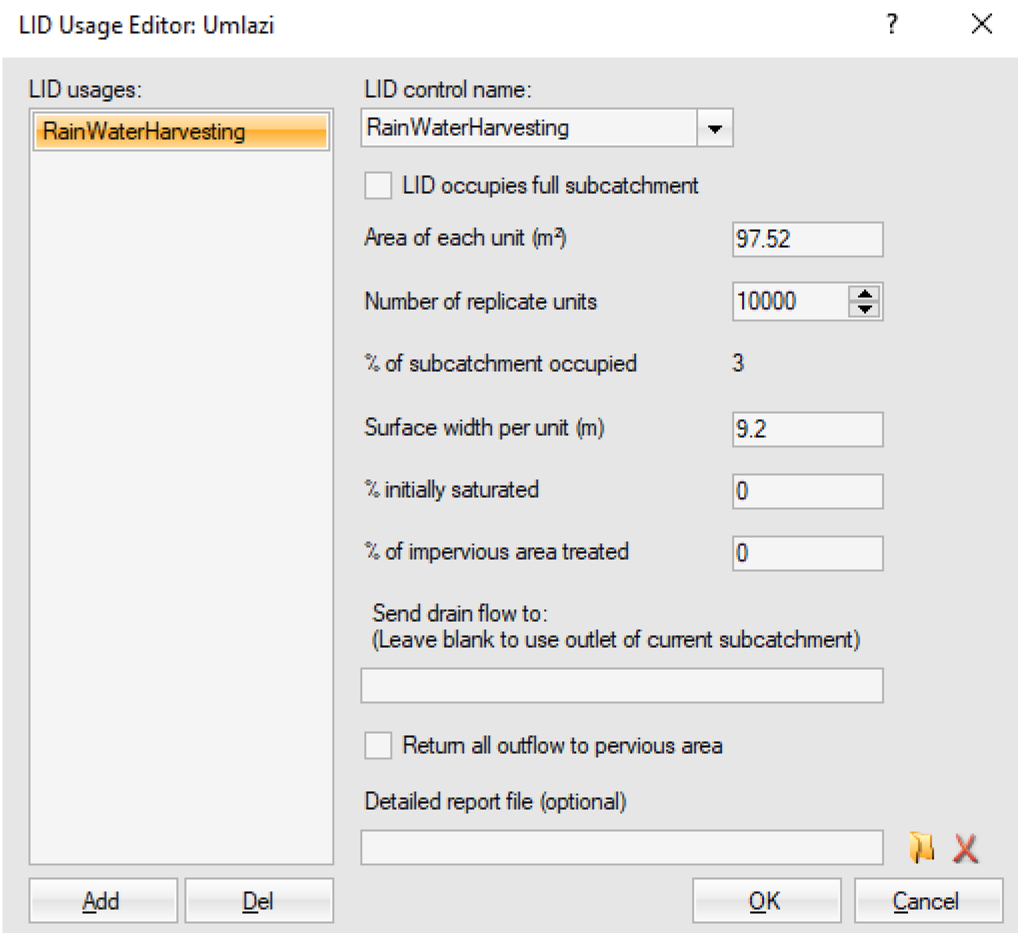

Figure 4-11: LID Usage Editor for Umlazi Isipingo Catchment area.

The Low Impact Design (LID) controls shown from Figure 4-7 to 4-10 are used to model different scenarios for the same Isipingo catchment. For the purposes of this study the source control used is rainwater harvesting. A combination of these controls yields a SUDS treatment train which is the most effective form of control, however due to the requirement of installination of these SUDS systems the costs of the SUDS treatment train are huge. Generally the costs of using source controls are low but their relative efficiency depends on the cathment area's characteristics.The SUDS systems are interchanged to produce different scenarios through a PCWSMM interface named the Low Impact design(LID) Usage editor shown on Figure 4-11 above. As Noted before the catchment charactreistsics are set according to imported and querried GIS data, the Isipingo raingauge and Time series are imported from Ethekwini raingauge data and used for the analysis input

.

4.3.3.2 Design return period

A return period is the probability of a flood's occurrence. The 2, 3, 5, 10, 20- and 50-year return periods are analysed for the Isipingo catchment site. A rain gauge in eThekwini municipality close to the Isipingo catchment analysed for rainfall intensity at two stations. Tables 4-1, 4-2 and 4-3 show the rainfall intensities as a function of time of concentration and return periods. The rational method is usually part of the storm water guidelines in determination of peak values. A rainfall intensity and run off coefficient are needed for the rational method using the following equation:

$$Q = f_t \times C \times I \times A/360 \text{ cumecs } (m^3/s)$$

Q = the maximum/peak rate of run off in cumecs

ft = an adjustment factor for the recurrence interval storm considered

C = run-off coefficient

I = rainfall intensity

A = Area of catchment in hectares

Table 4-1: Rainfall intensities at Tc=13 mins for station 1

(Source: Bulelani, 2015)

	Duration of Storm (minutes)					Tc
RP (Yrs.)	5	10	15	30	45	13
2	108.0	84.0	72.4	49.0	39.1	77.0
3	126	97.8	84.4	57.1329	45.5557	89.76
5	162.0	125.4	108.4	73.4	58.5	115.2
10	202.8	158.4	136.4	92.6	73.7	145.2
20	249.6	193.8	167.2	113.4	90.3	177.8
50	318.0	247.2	213.2	144.6	115.1	226.8

Table 4-2: Rainfall intensities at Tc=13 mins for station 2

(Source: Bulelani, 2015)

	Duration of Storm (minutes)					Tc
RP (Yrs.)	5	10	15	30	45	13
2	109.2	85.2	73.6	49.8	39.7	78.2
3	127.6	99.4	85.868	58.1332	46.3	91.28
5	164.4	127.8	110.4	74.8	59.5	117.4
10	206.4	160.8	138.8	94.2	74.9	147.6
20	253.2	196.8	170.0	115.4	91.9	180.7
50	322.8	251.4	216.8	147.0	117.1	230.6

Table 4-3: Average Intensity for Station 1 and 2 for Tc =13 minutes

(Source: Bulelani, 2015)

RP(Yrs.)	Station 1	Station 2	New Intensity
2	78.2	77.0	77.6
3	91.28	89.76	90.52
5	117.4	115.2	116.3
10	147.6	145.2	146.4
20	180.7	177.8	179.3
50	230.6	226.8	228.7

A 3-year return period is used for this research considering the recommendations of eThekwini storm water manual. Therefore 90.52 mm/hr is used as the rainfall intensity in accordance to Table 4-3. A runoff coefficient is to be calculated and the manning's equation can be used to validate the runoff results of this research.

4.3.3.3 Runoff coefficient

Table 4-4 shows the calculation of the runoff coefficient. The catchment area is about 1733 ha, 17 330 000 m^2 , the grassed area is about 173,3 ha, 1 730 000 m^2. Therefore, the percentage of grassed pervious areas is approximately 10 percent. 0.6092 is calculated as the runoff coefficient as shown on Table 4-4, the DWA method is used to calculate the runoff coefficient.

Table 4-4: DWA method (Isipingo Catchment Area and surrounding catchment runoff coefficient) (Source: Kasserchun, 2012)

Urban Runoff Coefficient		
Catchment Area Characteristics		
Lawn sandy < 2%	1%	0.08
Lawn sandy > 7%	0%	0.18
Lawn heavy < 2%	0%	0.15
Lawn heavy > 7%	1%	0.30
Residential single	20%	0.40
Flats/dense townships	10%	0.60
Industry, light	0%	0.65
Industry, heavy	0%	0.70
Business local	0%	0.60
Business CBD	9%	0.85
Streets/roofs	59%	0.95
Final C	**100**	**0,6092**

Table 4-4 and calculation of the run off coefficient is through the guidance of the eThekwini municipality storm water design guidelines, a percentage of the different catchment characteristics produce the final runoff coefficient.

4.3.3.4 Rainfall and time series

The PCSWMM software needs a time series for simulation. The rainfall depth, latitude and longitude of the rain gauge stations discussed in section 4.4.3.2 gives a basis for the time series input but is used as validation for the logged results that are to be input into the PCSWMM model. The model simulates the response of the Isipingo catchment area to a 2-hour design storm on particular days in the year. eThekwini Municipality has a rain gauge in the Isipingo catchment which is logged as shown on Figure 4- 12. There are approximately 90 significant rainfall events over the 365 days analysis period. The rainfall events range between 1 hour to about 3hours yielding an average of about 2 hours storm duration per day, therefore the storm duration over the year period of analysis is approximately 180 hours. The rain gauge inputs are imported from the logging data into the PCSWMM software through the import portal shown on Figure 4-13.

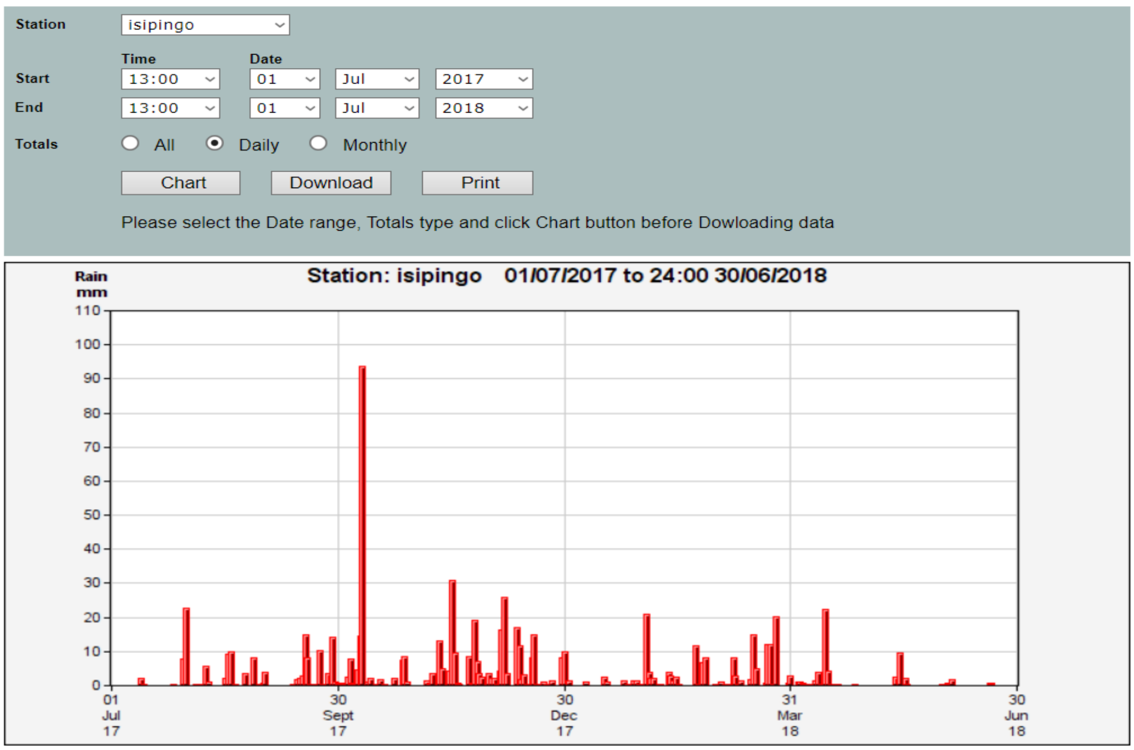

Figure 4-12: eThekwini Municipality Rain gauge live data (Source : eThekwini Municipality Online monitored rain gauge logging - http://www.dbnrain.co.za/showmodels.php)

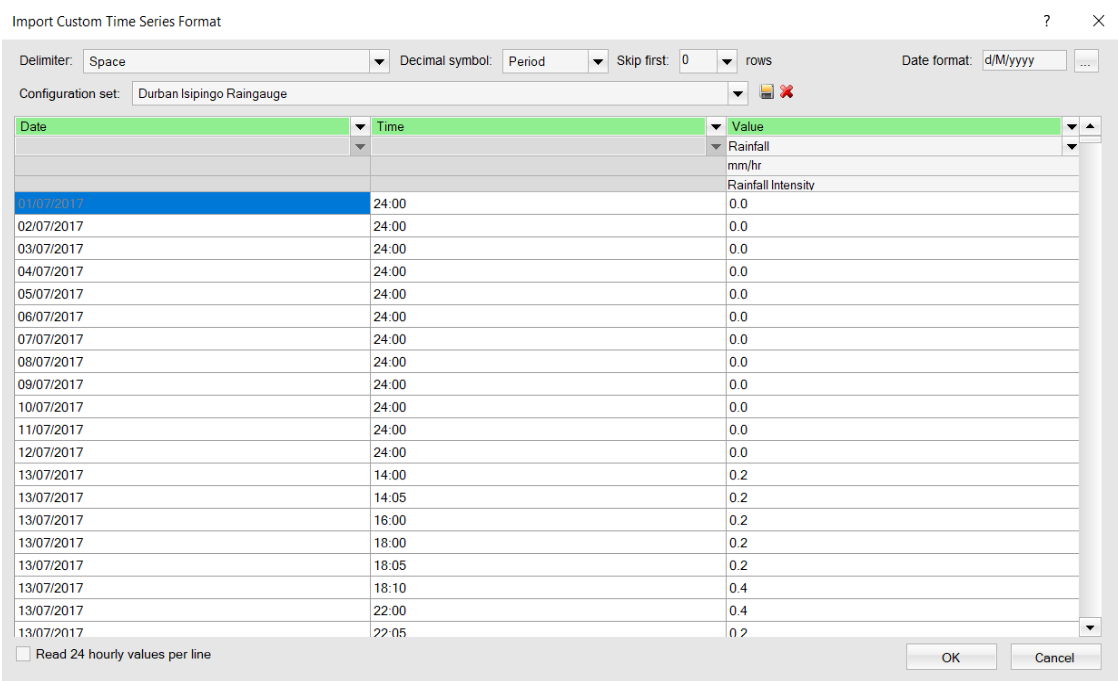

Figure 4-13: Rain gauge import into PCSWMM

5 RESULTS AND ANALYSIS

5.1 Potable water logging results

The seven-day profile for Umlazi DV1928 discrete zone yields an average of 47,18 m^3/hr as shown on Figure 5-1. This translates to 1132,32 m^3/day which is the average flow rate over a 24-hour period.

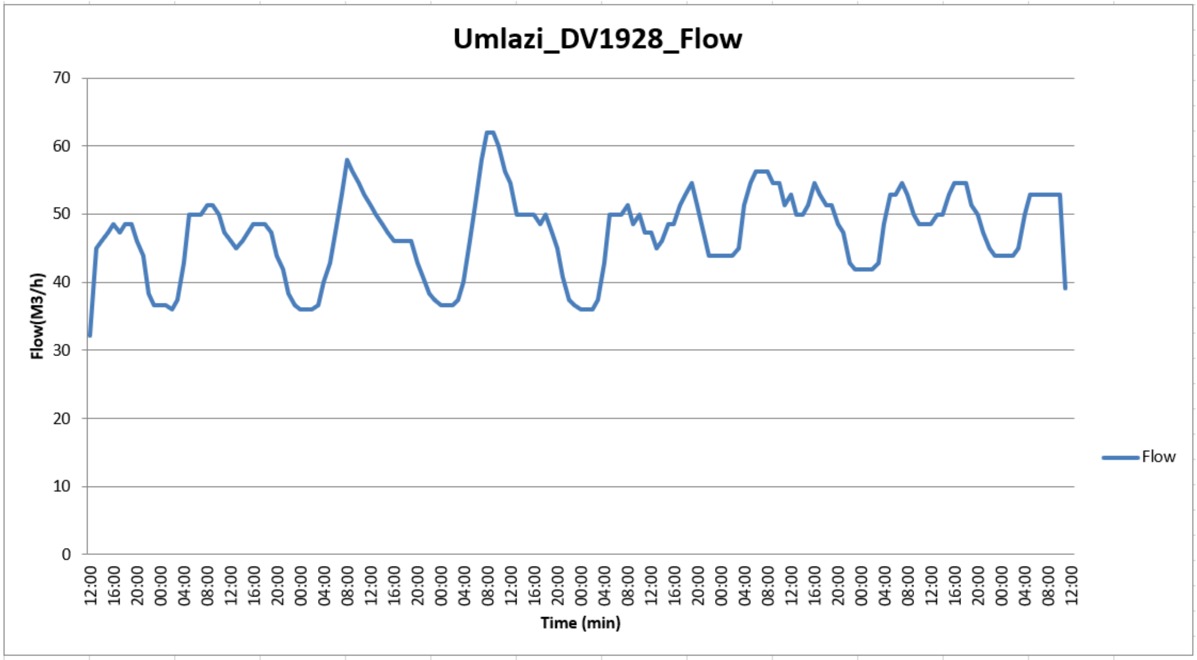

Figure 5-1: 7 Day Potable Water Flow Profile for Umlazi DV1928 Zone

The discrete zonal area and population are the adjustment factors used to estimate the usage of water in the entire Isipingo catchment with reference to the logged DV1928 zone consumption of 1132,32 m^3/day. The Umlazi 2 reservoir Zone has 19 identified subzones with DV1928 as one of these zones, The Isipingo Catchment is supplied by approximately a quarter of the 6 reservoir zones in and around the catchment. Therefore, the product of 1132,32 m^3/day, 19 zones and approximately a quarter of the 6 reservoir zones is 32 271,12 m^3/day and 11 778 958,8 m^3/Year which is used as the baseline potable system Input volume for the Isipingo catchment area as shown on the summary Table 5-1.

Table 5-1: Sensus CDLWin Summary Table of Flow Logging output for Umlazi DV1928 PRV

First measured value	2018/02/17 12:00
Last measured value	2018/02/24 12:00
Resolution	3600
Area	UML2-025
Site	DV1928
Logger-ID	104358
Logger commentary	7 Day Profile
Channel	FORWARD
Channel commentary	Digital for Flow Measurements
Channel mode A/D	D (Digital)
Impulse value	0,01
Impulse unit	m^3
Type of evaluation	Avg
Evaluation unit	m^3/h
7 Day Consumption	7885,164
Counter reading	0
Minimum	32.117
Maximum	62.019
Average Flow Rate (m^3/h) :	**47,18**
Total Isipingo System Input Volume (m^3/day)	**32 271,12**
Total Isipingo System Input Volume (m^3/Year)	**11 778 958,8**

5.2 Storm water PCSWMM simulation results

The storm water results are focused on the harvested volume stored by the different SUDS techniques employed for non-potable water supply; the harvested storage volumes are obtained from the PCSWMM runoff scenarios. The Existing scenario is used as a baseline with a SUDS harvested storage capacity of 0 m^3/hr since there are no SUDS systems employed on the scenario, the differences between the existing baseline runoff and the different scenarios gives an indication of the harvested water in the SUDS facilities. The area under the runoff graphs gives the volume of water runoff over a period of time, the runoff volume reduces as the catchment's harvesting storage capacity increases due to SUDS. The peak runoff also reduces for all of the SUDS employed scenarios. Figure 5-2 shows the baseline existing scenario without any SUDS techniques employed on the Isipingo catchment area. The peak runoff volume for the existing scenario is at approximately 18,86 m^3/s. The runoff volume is important for this research and is calculated as the area under the graph, over the year period the runoff volume is approximately 12 240 000 m^3/year. All the SUDS techniques are placed systematically across the whole area of study in order to produce the best-case scenario for modelling and the highest volumes achievable by each SUDS technique.

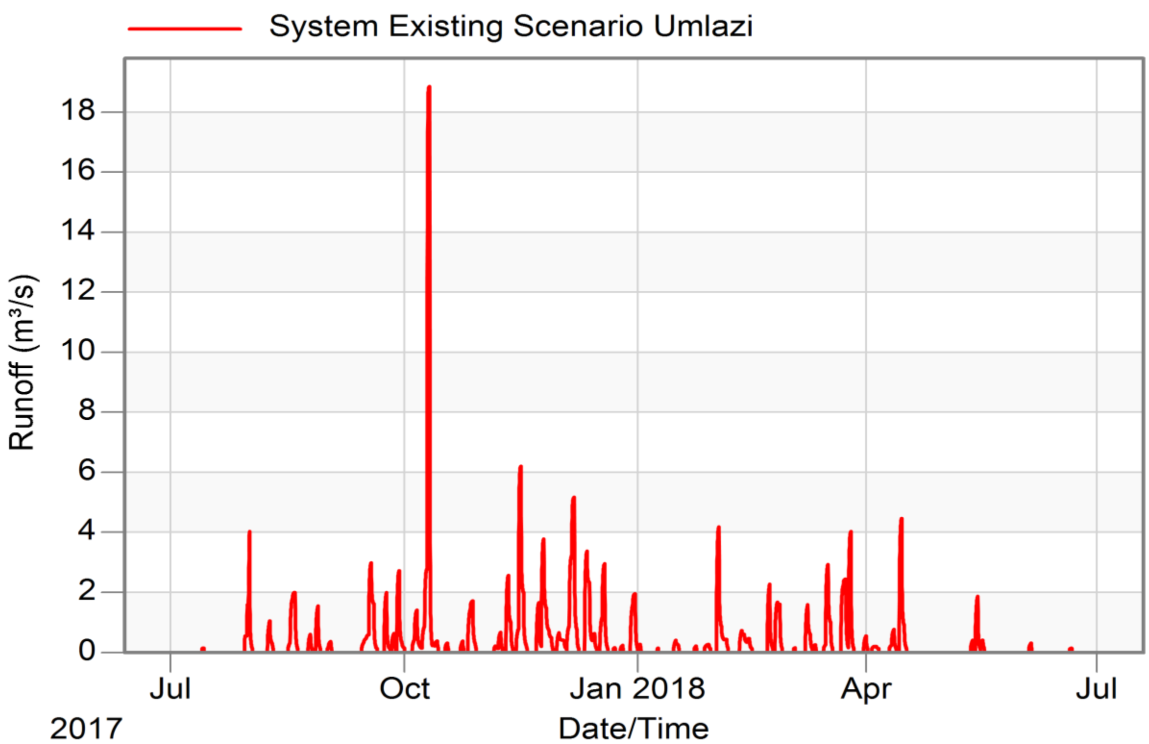

Figure 5-2: The Existing scenario Stormwater Runoff Results

Figures 5-3 5-4, 5-5, 5-6 and 5-7 show the different SUDS techniques runoff simulation results compared to the baseline existing scenario separately. Figure 5-3 shows that when a SUDS source control, Rainwater harvesting in this case study, is employed the peak runoff reduces from 18,86 m^3/s to approximately 16,97 m^3/s. The runoff volume reduces from 12 240 000 m^3/year to 10 970 000 m^3/year. The reduction in runoff volume translates to 1 270 000 m^3/year which is equivalent to the harvested storage volume per year, the water stored can therefore be used to supply the non-potable households demand within the Isipingo catchment area.

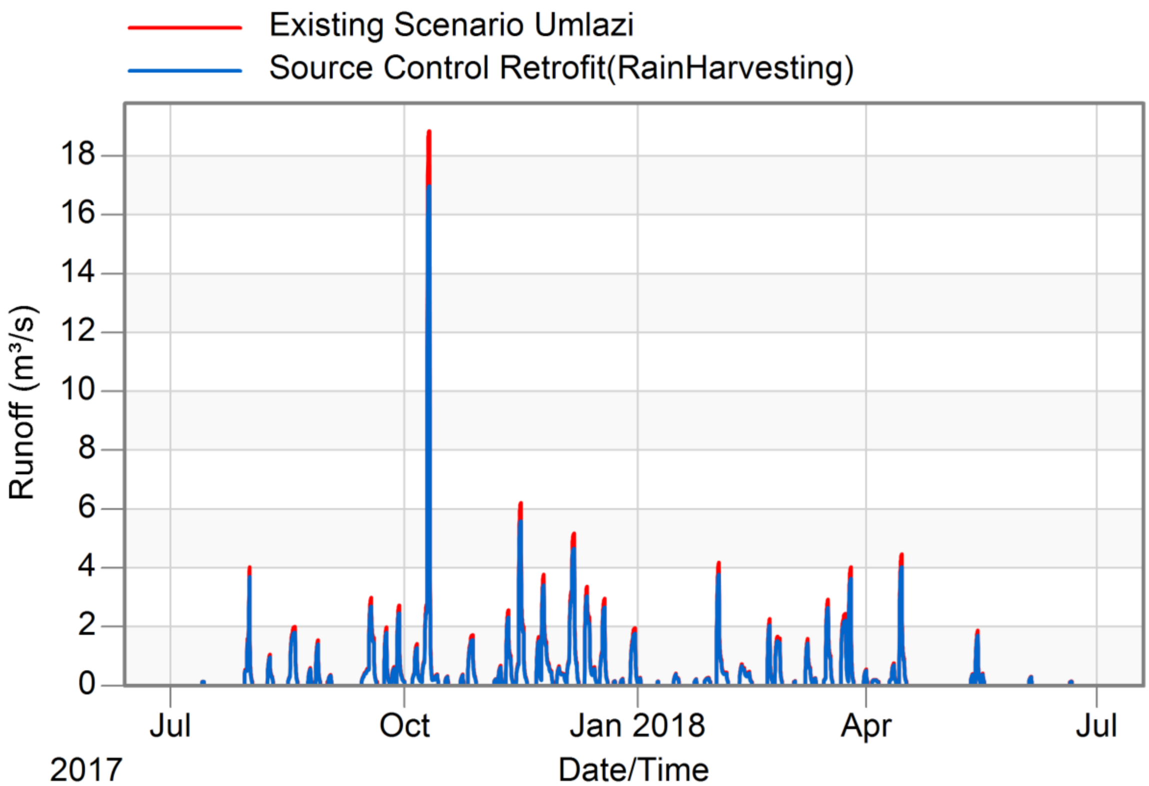

Figure 5-3: The Comparison of stormwater runoff between the Existing Scenario and Source Control scenario

Figure 5-4 shows that when a SUDS Local control, in this case study an infiltration trench, is employed the peak runoff reduces from 18,86 m^3/s to approximately 10,21 m^3/s. The total runoff volume over the year period of 2017/2018 reduces from 12 240 000 m^3/year to 831 800 m^3/year. The harvested storage is therefore 11 408 200 m^3/year for the local control SUDS which can be used to supply the non-potable demand in the Isipingo region. The non-potable SUDS reduce the municipal supply volumes across the different SUDS scenarios. The utilities therefore save on the amount of water bought from the water service authorities, as a service provider the utilities therefore reduce expenditure and increase revenue. An increased revenue assists the municipalities in reducing tariffs to their customers.

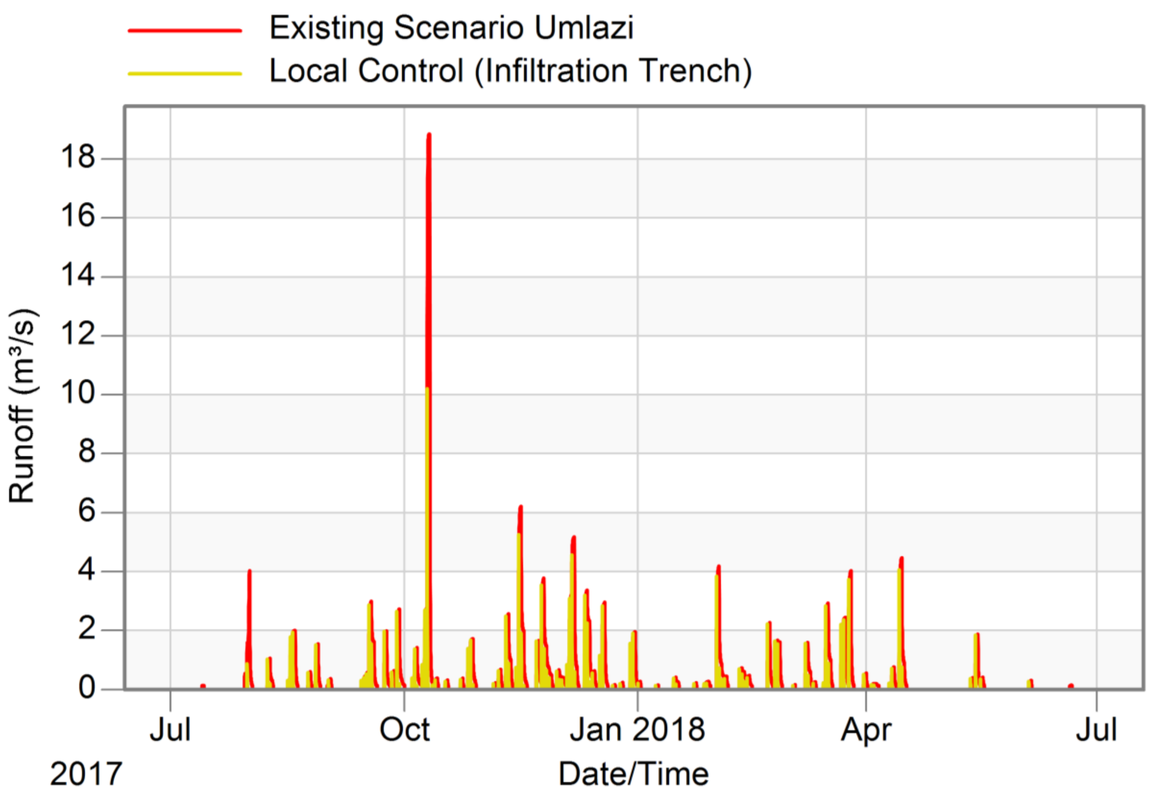

Figure 5-4: The Comparison of stormwater runoff between the Existing Scenario and Local Control scenario

The simulation for employing a regional control such as the Bioretention cells used for this analysis shows a decrease in peak flow from 18,86 m^3/s to approximately 5,76 m^3/s as illustrated on Figure 5-5. The total runoff volume decreases from a baseline volume of 12 240 000 m^3/year to 501 700 m^3/year. This result implies a harvested storage volume of 11 738 300 m^3/year which can be used for non-potable supply.

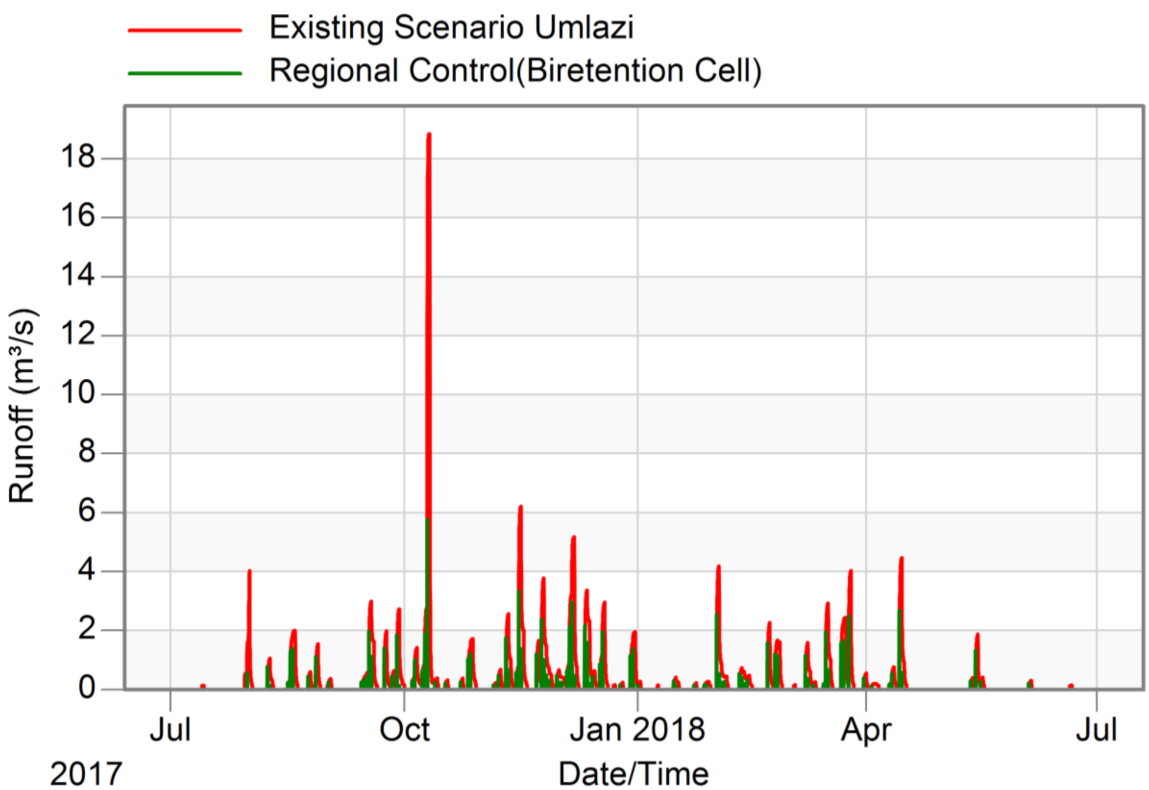

Figure 5-5: The Comparison of stormwater runoff between the Existing Scenario and Regional Control scenario

The combination of the SUDS techniques simultaneously is referred to as a SUDS treatment train, the simulation results for a SUDS treatment train scenario theoretically should provide the most harvested storage volume compared to all the other techniques with certain catchment conditions. The results on Figure 5-6 show that SUDS Treatment train for this particular site would significantly reduce the peak runoff from 18,86 m^3/s to approximately 2,54 m^3/s. In this case study the SUDS treatment train technique provides the most harvested storage volume than all the other techniques due to the combination of all the different techniques, the total runoff volume decreases from 12 240 000 m^3/year to 243 500 m^3/year. A harvested storage volume of 11 996 500 m^3/year can therefore be used to supply the non-potable demand in the Isipingo region. The harvested storage volumes can be viewed as potable water savings, however to calculate this appropriately the non-potable demand has to be calculated.

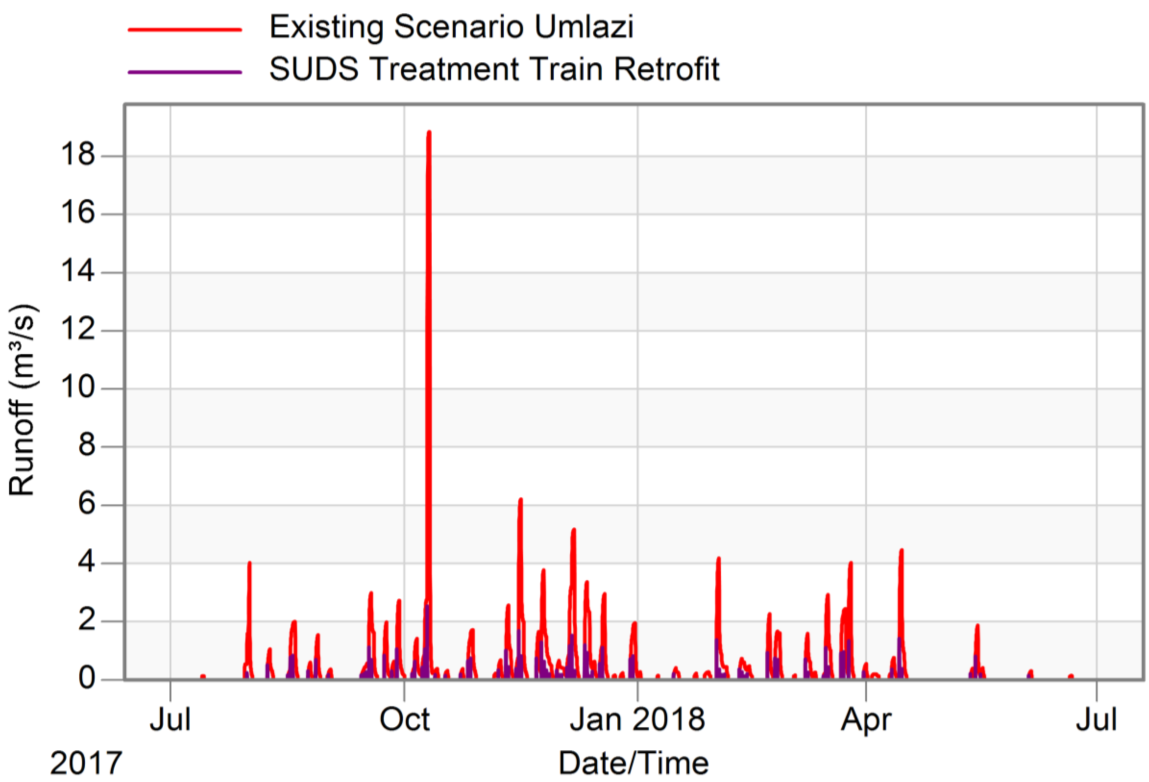

Figure 5-6: The Comparison of stormwater runoff between the Existing Scenario and SUDS Treatment Control scenario

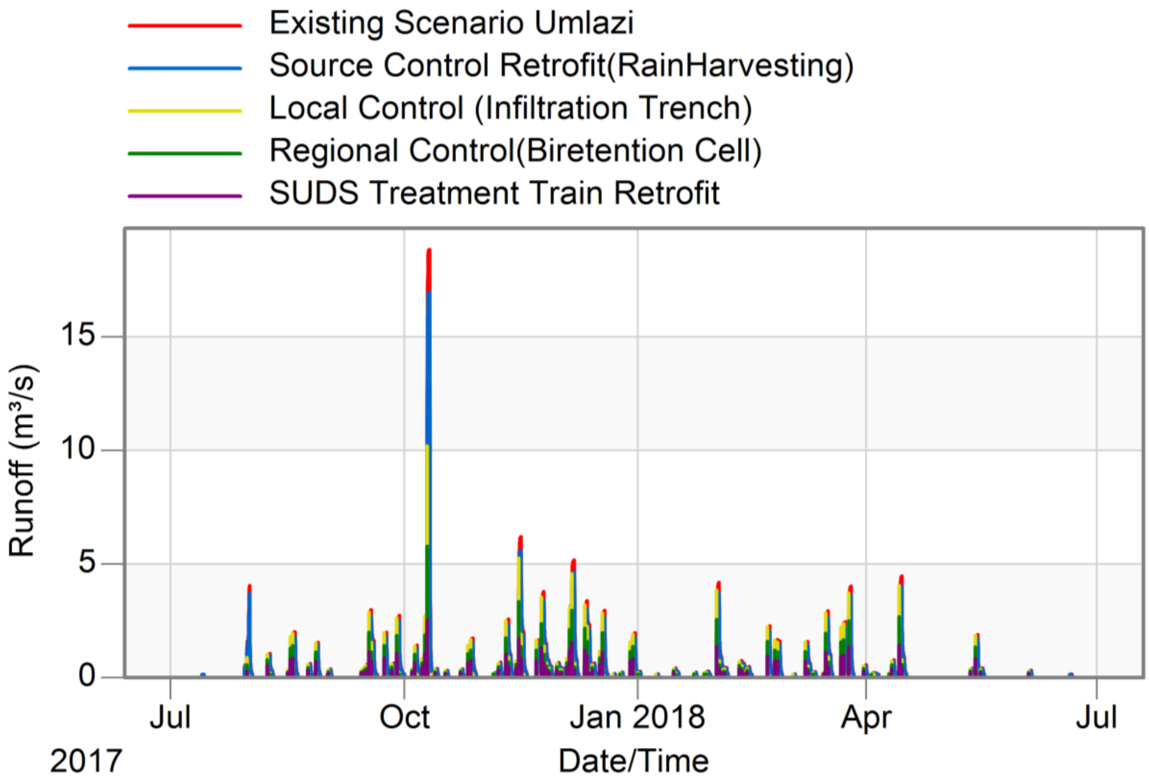

Figure 5-7: The Comparison of stormwater runoff between the Existing Scenario and all the other proposed scenarios

Figure 5-7 Shows the PCSWMM simulation results for all the different SUDS scenarios in reference to the baseline existing scenario, the baseline scenario has a peak runoff rate of 18,86 m^3/s and the relative efficiency of all the other SUDS scenarios is based on the comparison between the baseline scenario and the different SUDS runoff storage volumes. Figures 5-8 and 5-9 show that runoff volumes decrease across the different scenarios when compared to the increasing existing scenario runoffs. This is an important tool for design engineers, some SUDS techniques have a minimal effect on peak runoff due to low runoff scenarios analysed, higher baseline runoffs would have a different effect on the peak runoff across the different SUDS scenarios.

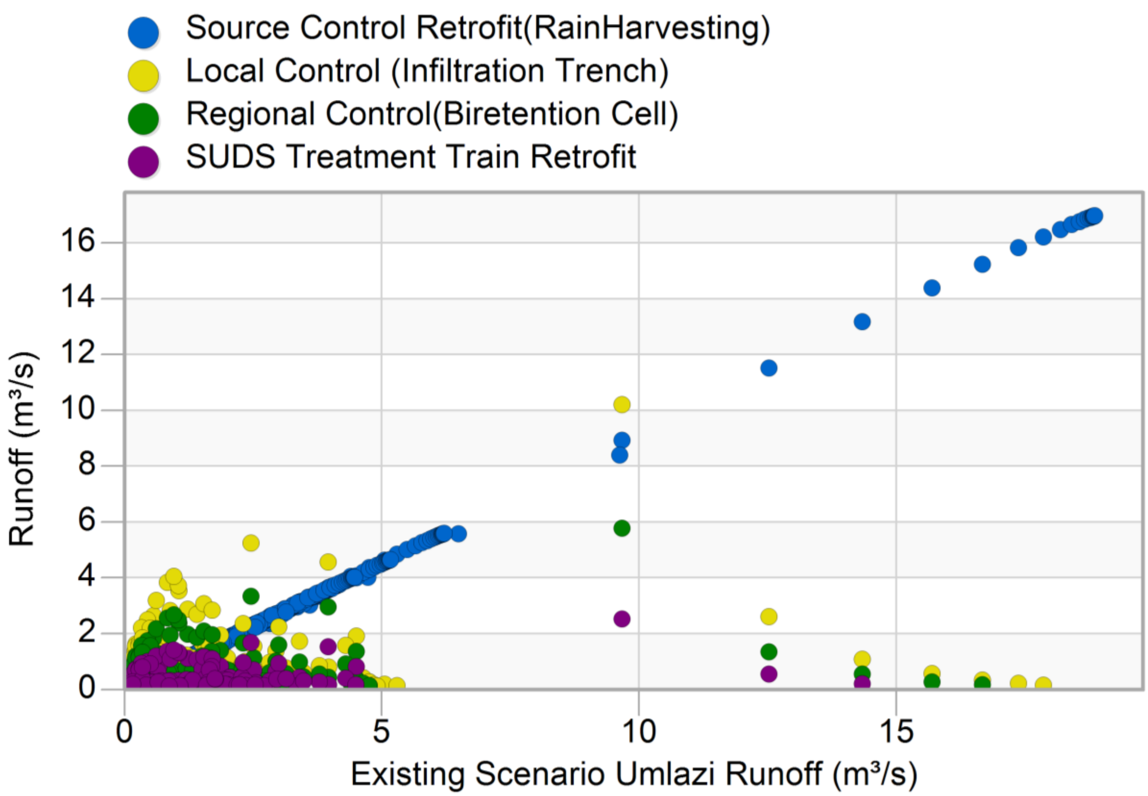

Figure 5-8: Scatter of the SUDS controls runoff relative to Existing Scenario Runoff

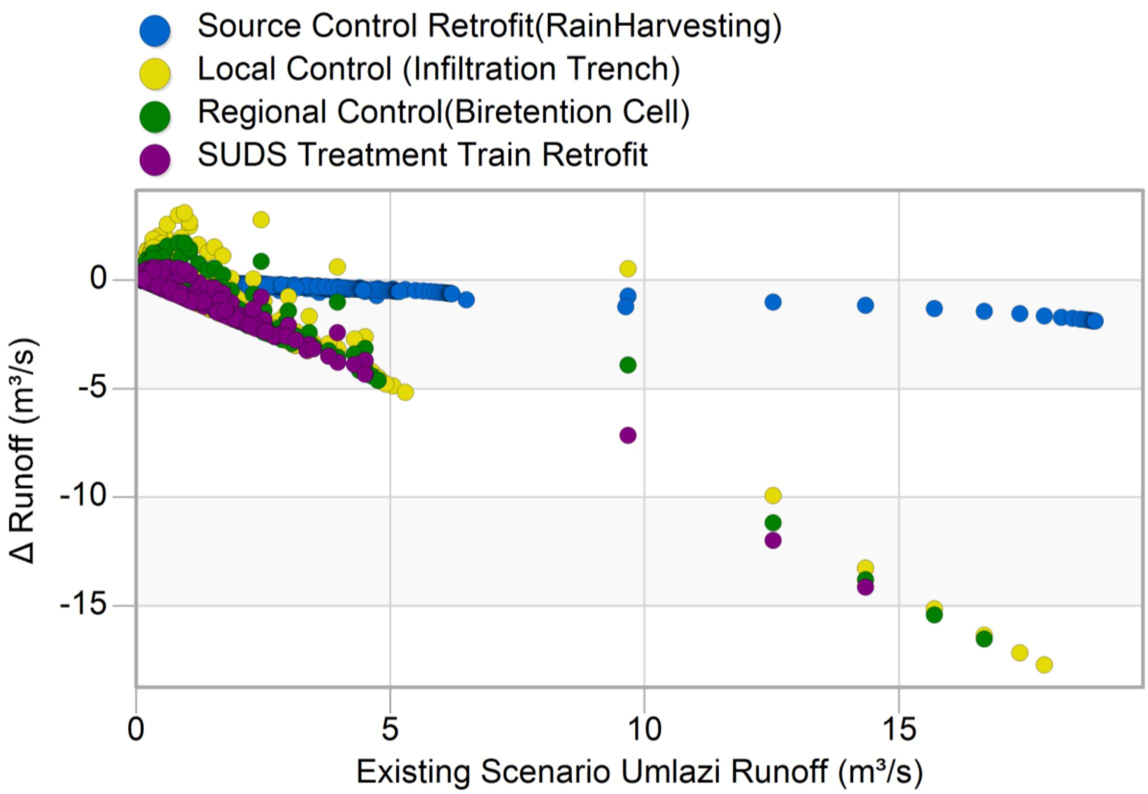

Figure 5-9: Graph of Percentage reduction of the different SUDS scenarios relative to the existing scenario.

A SUDS criterion is therefore developed from these results, for example Figure 5-9 shows that for a catchment with runoff between 0m^3/s and 5m^3/s the most effective SUDS tools would be the SUDS treatment train and source controls. The local and regional controls are more effective under conditions of baseline or existing runoff that is more than the 5m^3/s.

5.3 Effects of SUDS implementation on potable water balance

5.3.1 Non potable and potable water demand simulation

The International Water Affairs (IWA) has a standardized water balance which is modified for this research, the modified water balance of the existing scenario is shown on Figure 5-10. The potable and non-potable water demands are the areas of focus for this study, harvested storage volumes extracted from the PCSWMM SUDS analysis are cited on Table 5-3. The effects of the SUDS supply on the water balance are to be presented in the water balance format shown on Figure 5-11 for all the SUDS intervention scenarios.

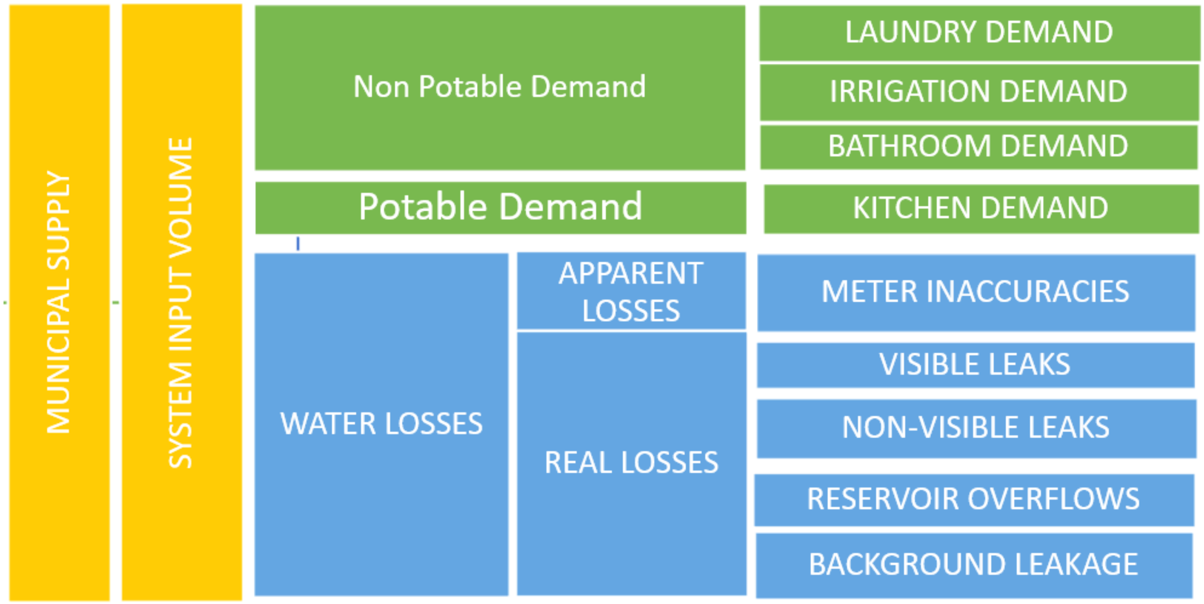

Figure 5-10: The Existing scenario Water Balance Before SUDS Interventions

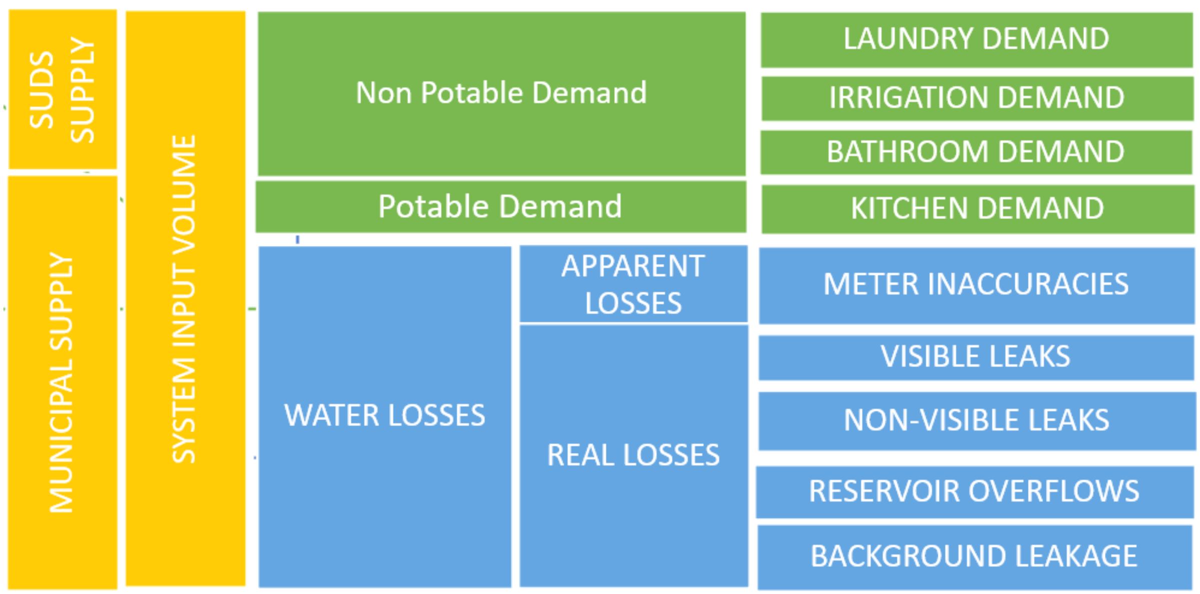

Figure 5-11: The Different SUDS Scenario Effects on the Water Balance.

The existing scenario water balance of the precinct and the general effects of employing the different SUDS systems are shown on Figures 5-10 and 5-11 respectively. The non-potable demand is broken down into laundry, irrigation and bathroom demand for the Isipingo region. The summary of the demands is shown on Table 5-2 in accordance to the Red Book, UK standards and Department of public works in South Africa.

The irrigation demand however has to be calculated specifically for the South African region as shown on Figure 5-12.

Catchment	Field requirement (mill. m^3/a)	Irrigated areas (ha)
Upper Orange (Reaches 1-14)	846.0	99 647
Lower Orange (Reaches 15-22)	818.0	63 109
Molopo	1.9	127
Lower Orange Tributaries	19.8	1320
Total Orange	1684.8	164 203
Eastern Cape	577.2	49 565
Total RSA	2262.0	213 763
Lesotho	20.6	2 640
Namibia Fish River	47.5	2 520
Namibia Orange River	35.2	2 961
Total demand	**2365.3**	**221 889**

Figure 5-12: Department of Water Affairs Irrigation Demand Estimations for South Africa

(Source: Department of Water Affairs Reports, 2013)

Considering Figure 5-12 the Upper Orange catchment is used which has an irrigation demand of 2262 X 10^6 m^3/Annum for an area of 213 763 hectares. The Isipingo catchment area is roughly 1733 hectares with 10 percent of the catchment area available for irrigation. Therefore, using ratios, the irrigation demand of the Isipingo region is 5024,19 m^3/day assuming irrigation everyday which is a worst case design approach. The population of the Umlazi region is 550 000, the Isipingo catchment population is approximately 137 500 which is a quarter of the Umlazi region therefore the Isipingo region's irrigation demand per capita is 36,5 l/c/day.

Table 5-2: Table of Non-Potable and potable water demands

Demand Description	References	
	EWS (2010)	DWA (2016)
Laundry	72 l/c/d	-
Kitchen*	15 l/c/d	-
Shower	65,1 l/c/d	
Toilets	6 l/c/d	
Irrigation		36,5 l/c/d

The non-potable water demand is the sum of the laundry, shower, toilet and irrigation demands which is a total of 179,6 l/c/d and 9 013 675 m^3/ Year, therefore the SUDS treatment train and regional control are the closest to supplying the actual non-potable demand. The kitchen demand contributes to the potable demand with a total of 752 812,5 m^3/year, the balance of the potable water is used for showering purposes to add up to the total of the measured volume of 11 778 958,8 m^3/year as shown on Table 5-1. Sensus loggers were used to measure the potable flow over the year as presented on Table 5-1.

5.3.2 SUDS effects on potable water demand

Table 5-2 summarises the harvested stormwater storage efficiency considering the existing scenario as the baseline, one of the key objectives of this study is to optimize the use of the different SUDS techniques for non-potable supply in the Isipingo area. The stored non-potable stormwater volume therefore contributes to the reduction of the baseline water supply volume from the municipality of 11 778 958,8 m^3/ Year shown on Table 5-1 and 5-3.

Table 5-3: Summary Table of Storage Volume and efficiency for the different SUDS Scenarios

Description	Existing Scenario Umlazi	Source Control Retrofit (Rain Harvesting)	Local Control (Infiltration Trench)	Regional Control (Bioretention Cell)	SUDS Treatment Train Retrofit
Maximum Runoff (m^3/s):	18,86	16,97	10,21	5,76	2,54
Minimum Runoff (m^3/s):	0	0	0	0	0
Total Runoff Volume (m^3/year):	12 240 000	10 970 000	831 800	501 700	243 500
Non-Potable Demand (m^3/Year)	9 013 675	9 013 675	9 013 675	9 013 675	9 013 675
Non-Potable Harvested Volume (m^3/year):	0	1 270 000	11 408 200	11 738 300	11 996 500
Non-Potable Harvested Volume efficiency (%):	0	14,09	126,57	130,23	133,09
Harvested Non-Potable Usage (m^3/Year)	0	1 270 000	9 013 675	9 013 675	9 013 675
Remaining Harvested Water (m^3/Year)	0	0	2 394 525	2 724 625	2 982 825
Municipal Supply (m^3/year):	11 778 958, 8	10 508 959	2 765 284	2 765 284	2 765 284

The SUDS treatment train control has the highest non-potable storage volume efficiency percentage of 133,09 % and a volume of 11 996 500 m^3/year can be harvested considering the infiltration losses. The non- potable water stored can be used to reduce the municipal water supply from 11 778 958,8 m^3/year to about 2 765 284 m^3/year. The non-potable demand of 9 013 675 m^3/year as calculated for the Isipingo region is supplied by part of the harvested water as shown on Table 5-3. Considering the SUDS treatment train scenario, the remaining harvested volume after non-potable usage for the year is 2 982 825 m^3. However, the source control scenario is different, the harvested volume is less than the yearly non-potable demand therefore the remaining volume after non-potable usage is 0m^3.

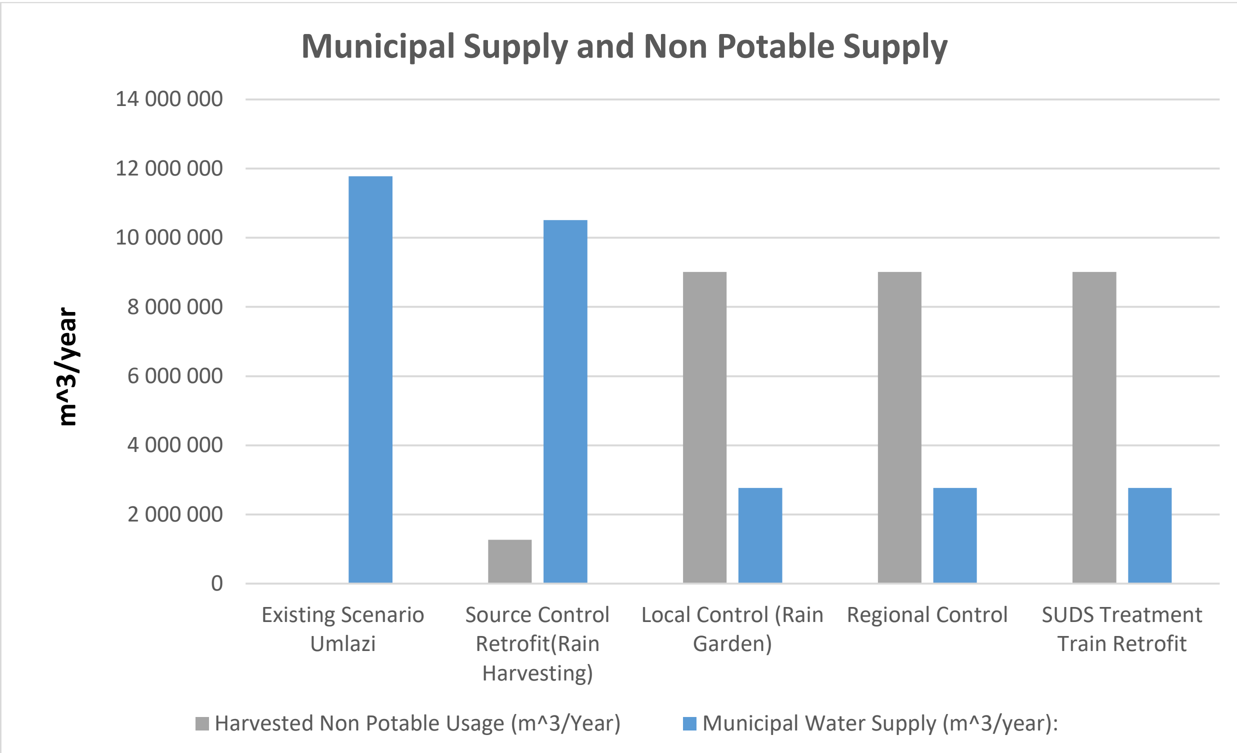

Figure 5-13: Graph of Isipingo Region Potable Water Demand reduction through the use of SUDS non-potable water

This research focuses on the possibilities of using stored SUDS non-potable water in the Isipingo region to reduce municipal water supply demand for non-potable purposes. In order to optimize which SUDS technique is suitable for implementation, the catchment's actual non-potable water demand within the potable network has to be taken into consideration as shown on Table 5-2 and 5-3, the difference between the harvested volume and the actual non-potable demand of the precinct gives the remaining harvested volume in the SUDS components at the end of the year. The remaining volume can be utilized in the following year. If the harvested volume per year is less than the non-potable demand therefore the SUDS facilities would be empty at the end of the year, this provides a design tool for engineers on which SUDS tools would be suitable for a specific precinct.

5.4 Utility financial implications of SUDS interventions

The cost of water to the utility is taken to be conservatively R5,33 as per eThekwini municipality's master plan tariff. The financial effects of SUDS use by utilities are shown on Table 5-4. The different SUDS controls have different financial consequences, the source controls yield the least savings but also cost less to build and maintain.

Table 5-4: Financial effects of using SUDS as an alternative for non-potable water supply

SUDS	**System Input Volume (KL/Year)**	**Utility Supply Volume (KL/Year)**	**SUDS Supply (kl/Year x10^6)**	**Utility Treatment and Supply Cost (R/Year)**	**SUDS Savings (R/Year)**	**Cost of SUDS and Maintenance (R/Year)**
Existing Scenario	11 778 958,80	11 778 958,80	0,00	**R62 781 850,40**	**R0**	**R0**
Source Controls	11 778 958,80	10 508 958,80	1 270 000,00	**R56 012 750,40**	**R6 769 100**	**R2 950 000**
Local Controls	11 778 958,80	2 765 283,80	9 013 675,00	**R14 738 962,65**	**R48 042 888**	**R8 490 000**
Regional Controls	11 778 958,80	2 765 283,80	9 013 675,00	**R14 738 962,65**	**R48 042 888**	**R19 030 000**
SUDS Treatment Train	11 778 958,80	2 765 283,80	9 013 675,00	**R14 738 962,65**	**R48 042 888**	**R22 540 000**
Pre-SUDS Average	11 778 958,80	11778958,80	0,00	**R62 781 850,40**	**R0**	**R0**
Post-SUDS Average	11 778 958,80	4 701 202,55	7 077 756,25	**R25 057 409,59**	**R37 724 441**	**R13 252 500**

The Post financial effects of using SUDS are summarized on Table 5-4, due to the variance between the SUDS controls an average is determined across all SUDS interventions explored within this research. SUDS can approximately save R37 724 441 over the course of the year in the Isipingo region, the average estimate cost to build and maintain the SUDS systems per year is approximately R 13 252 500 per year therefore 4 months return on investment period is anticipated from a build and maintain model rather than retrofitting.

The SUDS local, regional and treatment train controls yield a lower return on investment period than all the other SUDS interventions, therefore considering the budget, cost, return on investment and the volume required for non-potable usage in the Isipingo region the local controls would be a suitable option. However, the SUDS treatment train controls are the most feasible option for alternative water supply due to providing the most potable water volume saving and the third in terms of cost payback period. A reduced utility cost means a lower demand is created for potable water which in turn benefits the water customers by reducing their water tariffs and increasing water accessibility.

6 CONCLUSION

The use of sustainable urban drainage systems (SUDS) controls in supplying non-potable storm water for non-potable purposes and reducing the current potable water supply in the Isipingo region is relatively efficient, the research question is answered through this study. The SUDS treatment train controls are the most effective tool for the Isipingo region based on catchment characteristics, runoff volume, non-potable water supply volume capacity, water demand analysis and cost of installation as the key research performance indicators. The SUDS treatment train includes the source, local and regional controls, the stormwater stored in the bioretention ponds can be reused in the Isipingo area to supply the irrigation, toilet flushing and laundry demands. The kitchen and showering water demands would still be supplied from the potable municipal feed to avoid high stormwater treatment costs and health hazards associated with stormwater. Therefore, the aims and objectives of this research have been achieved, the investigation of the use of Sustainable Urban drainage systems in providing an alternative water supply for flushing toilets and irrigation are obtainable objectives. The results would raise government awareness and provide engineers a guideline for designing and validating SUDS suitability in existing and new developments cited for sustainable water management.

These results provide a clear design tool for engineers, some of these SUDS controls are not suitable for low runoff volumes, the amount of volume produced may also not meet the non-potable demand and also the cost is a factor in decision making and suitability criteria. All the SUDS may be used and are efficient but the goals to be achieved have to properly analysed.

The balance of SUDS use within the treatment train systems depends on the catchment characteristics and preferences by the utility managing the site. The rain water harvesting analyzed in this research is a source control, which contributes to community awareness and responsibility about water saving since the rainwater harvesting tanks would be installed at the individual households. The Rain gardens and bioretention ponds are the local and regional SUDS controls which contribute to good aesthetics, parks and recreational areas of a region. The good aesthetics and recreational areas provide an opportunity for tourism and economic growth within the Isipingo region, the SUDS maintenance requirements and tourism attractions created by the SUDS tools also provide job opportunities for the local Isipingo region inhabitants.

The water treatment supply cost and volume for the Isipingo region is currently approximately R62 787 400 and 11 780 000 kilo liters per year. The different SUDS systems employed have an average potable water volume saving of 7 077 756,25 kiloliters per year which translates to an average water saving amount of R37 724 441, The costs of installation of the SUDS systems has an average of R13 252 500 per year. Therefore, the use of the SUDS systems is in line with the National Water Act (Act 36, 1998) endeavors to find a balance between water conservation or demand management, water safety, affordability and accessibility. Some of the key challenges faced with the implementation of SUDS currently is the lack of national SUDS design standards, lack of government prioritization for funding, utility masterplans do not include extensive SUDS specification and the lack of community awareness and water saving responsibility. Furthermore, there is legislation in many countries that is against the collection of huge amounts of stormwater as it is seen to cause bad environmental impacts.

The future recommendations hinge on creation of more community awareness through the government organizations to promote water saving techniques and SUDS implementation advantages, the population of the regions need to be constantly alerted of the benefits of good water saving habits as opposed to wastage of water which leads to the detrimental effects of intermittent water supply and droughts. Furthermore, inclusion of the SUDS designs in the utility's master plans will assist in an effective worldwide implementation of the SUDS tools per utility. Another future research to be used in enhancing this research can be aligned to the water quality analysis produced by the different SUDS techniques and zooming into the impacts of SUDS implementation on the economy in terms of job creation. Potable water in many countries, including South Africa, is being used for non-potable purposes which is not sustainable, wasteful and threatens the exhaustion of potable water reserves. Despite the challenges around the implementation of SUDS this research has focused on the optimization of the different SUDS techniques and the results show that SUDS provide a feasible option for alternative non-potable water supply in the Isipingo region.

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8 APPENDIX A

8.1 SUDS Design Flow Chart

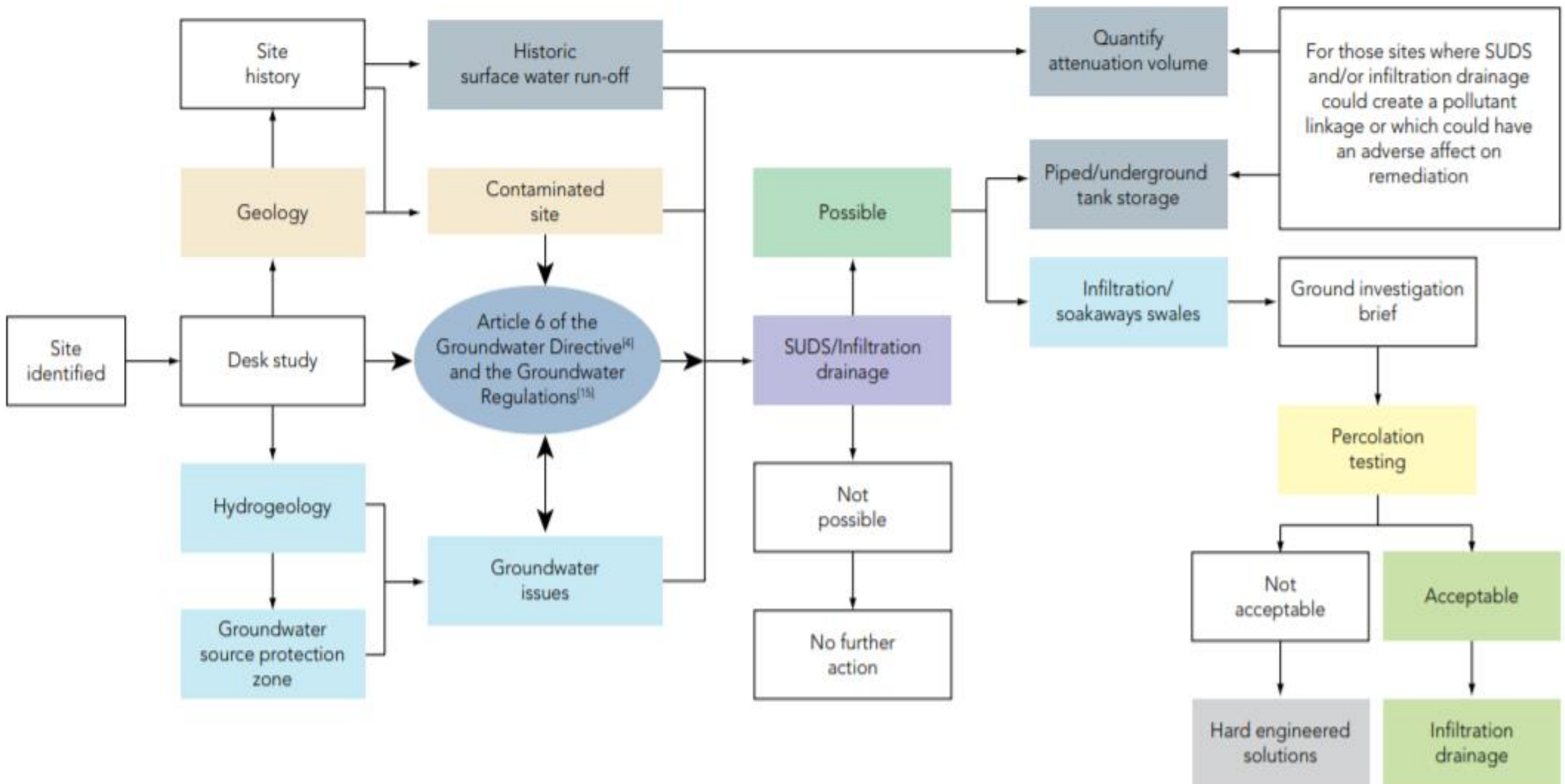


Figure 8-1:Conceptual Design Flowchart (Source: Miller Homes, 2011)

(Source: Woods,2011)

9 APPENDIX B

9.1 General Designs for SUDS Scenarios

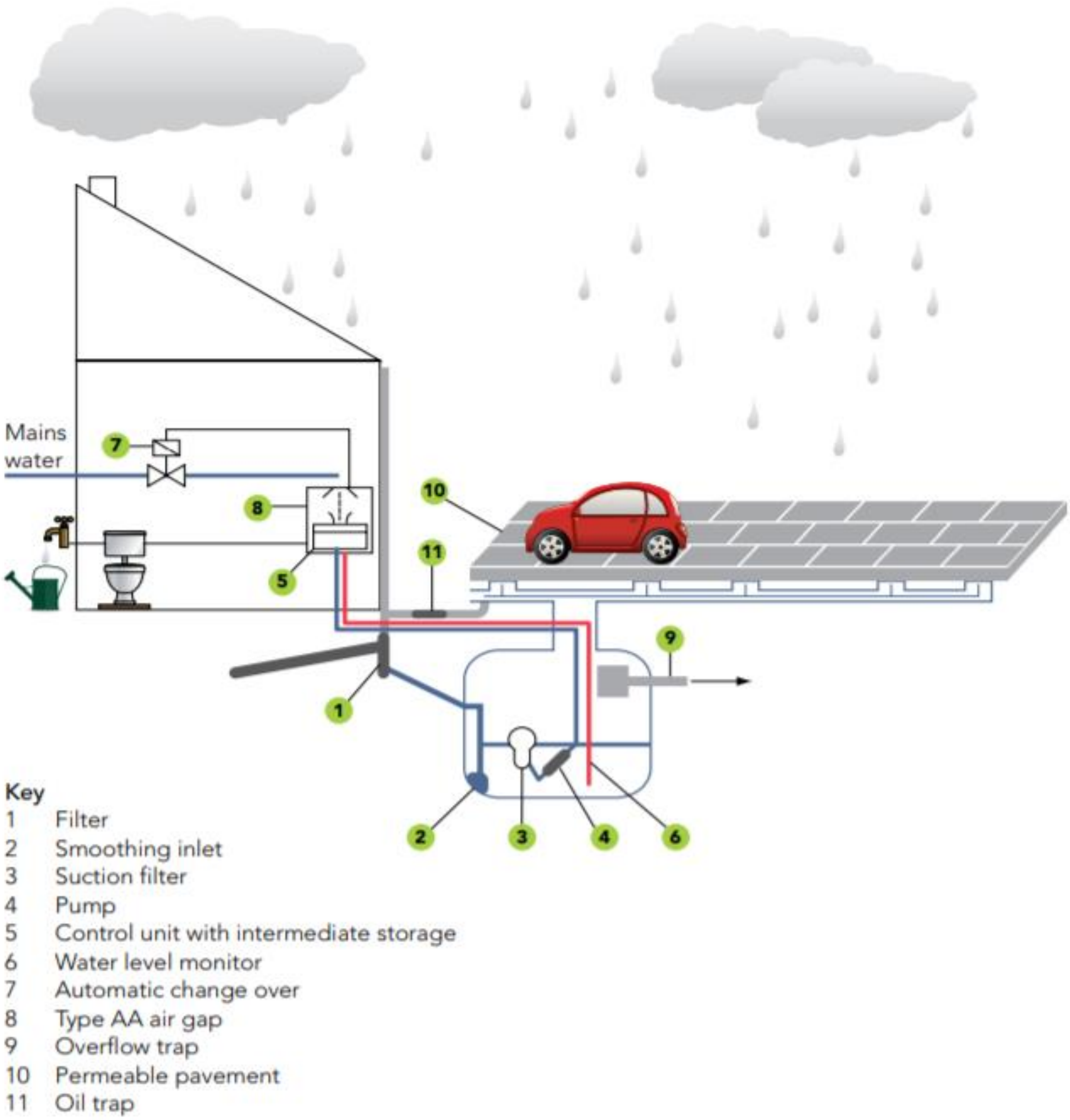


Figure 9-1:Rain Water Harvesting Components

(Source: Woods,2011)

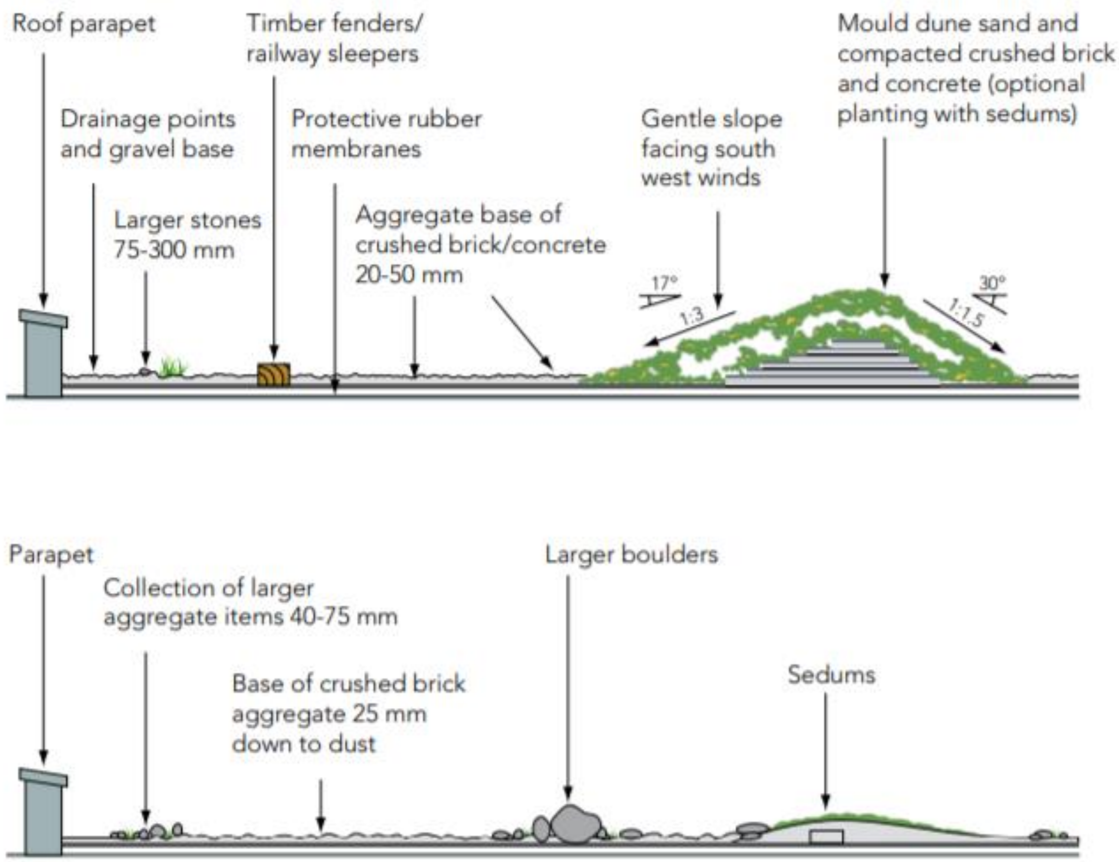
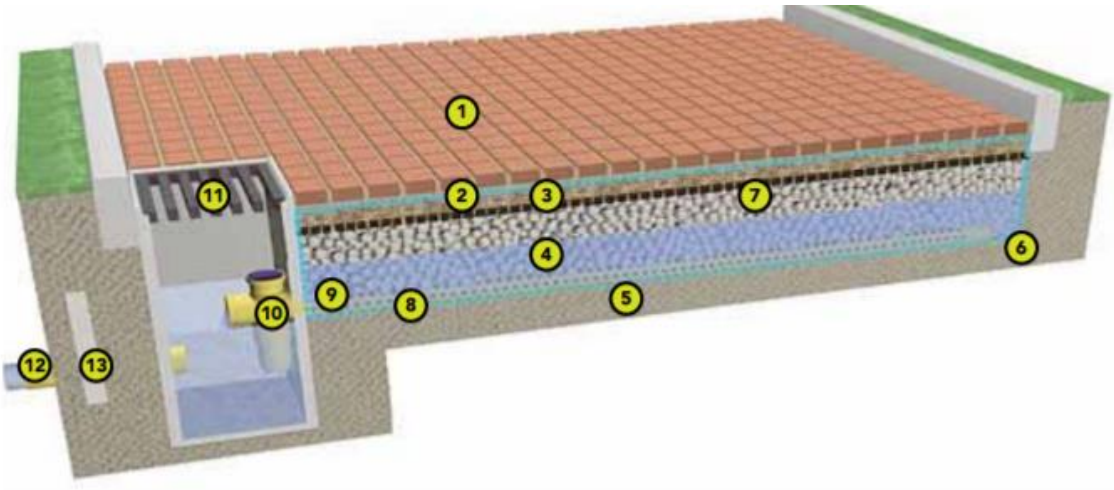


Figure 9-2: Green roof Components

(Source: Woods,2011)



1. Permeable paving (min. 80 mm thickness)
2. Aggregate bedding course – not sand (50 mm depth)
3. Open graded base (depth varies by design application)
4. Open graded sub-base (depth varies by design application)
5. Subsoil – flat and scarified in infiltration designs
6. Geotextile on all sides of reservoir
7. Optional reinforcing grid for heavy loads
8. Perforated drain pipe 150 mm diameter minimum
9. Geotextile adhered to drain at opening
10. Flow restrictor assembly
11. Secondary overflow inlet at catch basin
12. Outlet pipe to storm drain or swale system. Locate crown of pipe below open graded base to prevent heaving during freeze/thaw cycle
13. Trench dams at all utility crossings.

Figure 9-3: Infiltration Trench Components

(Source: Woods,2011)

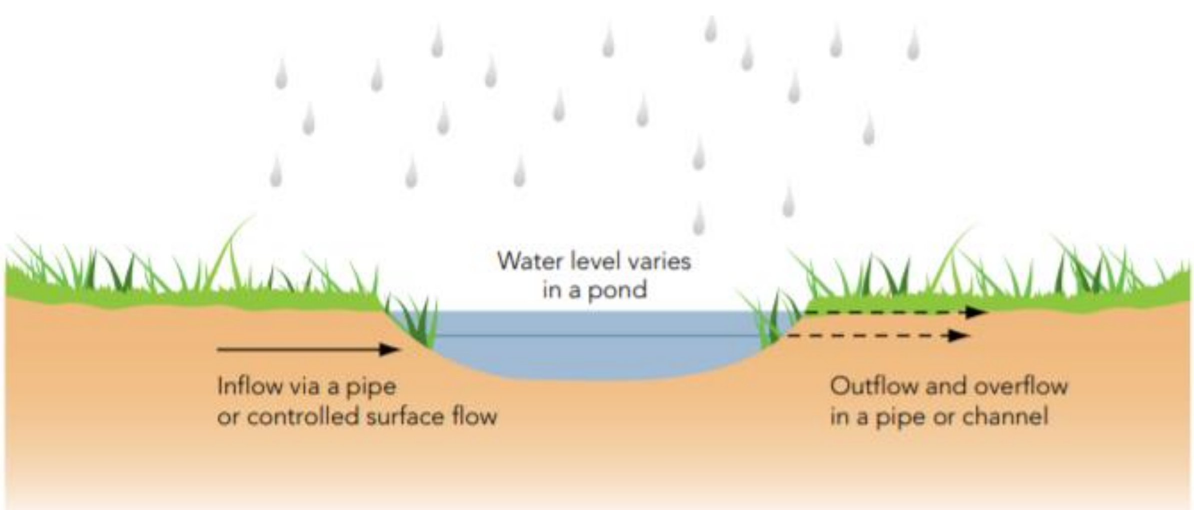


Figure 9-4: Bioretention Pond Components

(Source: Woods,2011)

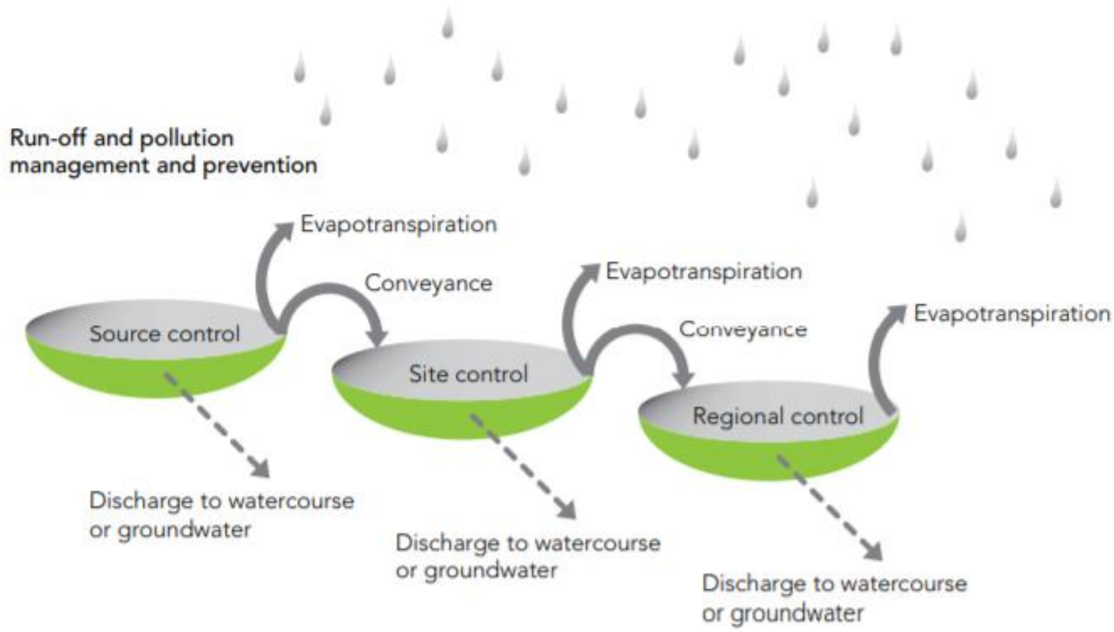


Figure 9-5: SUDS Treatment Train Components

(Source: Rob ,2012)