Department of Civil Engineering

Assessment of Infiltration Based Urban Stormwater Management for Residential Land Development

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DECLARATION

To the best of my knowledge and belief this thesis contains no material previously published by any other person except where due acknowledgment has been made.

This thesis contains no material which has been accepted for the award of any other degree or diploma in any university.

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Date: 20.10.2017

ABSTRACT

The main aim of this study was to establish a statistically significant broad approach to assess the infiltration based stormwater management concept and its application to urban land developments, taking infiltration rates, ground water and soil properties into account. Traditionally, stormwater runoff from several adjacent lots has been captured and stored temporarily in basins or sumps from which the water infiltrates into the surrounding soil. Due to the increasing housing densities within urban cities, there is a clear increment of stormwater runoff. Therefore, stormwater management authorities now require urban stormwater runoff to be retained or detained within each property and allow maximum reuse via infiltration to the groundwater resources. This valuable concept reduces stormwater runoff to urban drainage systems which are already operating beyond their capacity. In this concept, infiltration plays an important role as a best available onsite stormwater management technique. In an urban context, infiltration typically can be achieved in several ways such as perforated pipes, trenches, soak pits, leaky wells, swales and also rain gardens or vegetated bio-retention basins and pervious pavements. There are many factors that affect the infiltration process. It is very important to conduct research broadly about infiltration systems for maintaining a sustainable, environmental friendly stormwater management system in the future. Due to lack of information about local soil properties, especially permeability rates of the soils predominant in the infill and the green field development areas, it is difficult to accurately assess stormwater retention and detention requirements without t investigating on-site soil properties. Taking these facts into account, this study was able to introduce an effective methodology to identify the suitable soil types, based on their permeability capacities and to provide guidelines for the implementation of onsite infiltration based best management practises (BMPs) on urban areas aiming to minimize the peak flows and extreme floods.

This research has developed an inventory of basic geotechnical properties from several infill development areas using field and laboratory tests results. Therefore, it was considered essential to develop mapping of the soil characteristics pertaining to on-site disposal or retention of stormwater. This mapping would provide support for

land development by giving guidance on the implementation of drainage strategies based on the basic underlying parameters. Due to land use restrictions and maintenance difficulties, current best practices promote the infiltration of stormwater on residential lands. Onsite management of stormwater assists local authorities with sustainable strategies for stormwater management of urban densification and re-development areas, whilst ensuring ongoing functionality and satisfactory performance of the existing stormwater drainage systems.

The main study area of this research is the 64 housing precincts located in the City of Gosnells, where it has been identified that stormwater management is a challenge. The City of Gosnells' Local Housing Strategy is a strategic planning tool that identifies the capacity for increasing residential densities within the City to cater for population growth and change, whilst contributing to achieve the targeted objectives for a more sustainable form of housing strategy. This research investigates and examines soil infiltration levels and how it relates to stormwater drainage in the community. Thus, identifying stormwater drainage problems in existing residential housing lots was critical and justified the necessity of well-defined strategies in implementing sustainable stormwater management practices.

The research was focused on providing guidance on option evaluation and selection of the best stormwater management strategy. The selection of the best stormwater management requires consideration of multiple factors, such as soils permeability, catchment management objectives, site characteristics (scale factor), target pollutants, social values, and capital and operating costs to achieve a balance between quantity and quality management objectives and to create a sustainable outcome. Considering all these factors and the potential benefits and limitations of available stormwater management strategies, the research developed a decision-Support matrix for stormwater management strategy selection based on the infiltration capacity or soil properties of the area.

This strategy selection produces key guidance to the designers in selecting of sustainable best stormwater management strategies or in finding the best combination of these measures to suit local circumstances. Strategy selection matrix would be useful for land developers as well as authorities, decision makers and policy makers to come up with sustainable land development proposals. Also, the outcomes from this research would aid the development of guidelines and recommendations for best management practices – BMP of infiltration based urban stormwater management.

As the Permeability of soil plays an important role in the whole concept of infiltration based stormwater management, the scope of this research was further extended towards identifying the relationship between the soil permeability and basic soil properties such as particle size distribution, particle density, void ratio, porosity and compaction. The identification of each and every relationship was critically analysed the relationships between basic properties and saturated hydraulic conductivities were investigated. These results were then used to compare the validity of the results by using existing empirical formulas and then to derive a more generalized empirical formula to represent the soil permeability as a function of basic soil properties. The scope of the research was extended to green field developments to mainly explore the role of spatially varying soil permeability of an efficient and sustainable stormwater management approach in green field developments with an extended sand fill. The findings of this study will be very useful for hydrologist, drainage Engineers, land developers, local city councils, authorities and policy and decision makers to reach their design objectives by implementing sustainable land development practices to ensure minimum impacts on urban hydrology.

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Average Annual Maximum Groundwater Levels (AAMGL)

Average Recurrent Interval (ARI)

Best Management Practices (BMP)

District Water Management Strategy (DWMS)

Environmental Protection Agency (EPA)

General Circulation Models (GCMS)

Generalized Likelihood Uncertainty Estimation (GLUE)

Geographic Information System (GIS)

Graphical User Interface (GUI)

Intensity Frequency Duration (IFD)

Light Detection and Ranging (LiDAR)

Low Impact Development (LID)

Local Water Management Strategy (LWMS)

Local Housing Strategy (LHS)

Mean Squared Error (MSE)

Multiple User Corridors (MUC)

One-Dimensional (1D)

ODP Outline Development Plan

Public Open Spaces (POS)

Top Water Levels (TWL)

Urban Stormwater Management System (USMS)

Urban Stormwater Management Systems (USWMSS)

Urban Water Management Plan (UWMP)

Water Sensitive Urban Design (WSUD)

Western Australia Planning Council (WAPC)

XP Stormwater and Wastewater Management Model (XPSWMM)

CHAPTER 1

1 INTRODUCTION

1.1. Background of the study

Urban stormwater is defined as runoff from urban areas, including the major flows during and after the rain, as well as dry-weather flows. There are a number of factors affecting or stimulating the amount of stormwater and the contaminants that are transported by it, such as duration and intensity of rainfall, proportion of impervious surfaces, shape and slope of the land, land use and design and management of stormwater systems.

Even though some areas record annual rainfall of over 1200 mm, Australia is the driest continent. Its climate is extremely changeable - across the continent, as well as from year-to-year. Therefore, it’s very important to manage scarce water resources to protect the environment and the country’s unique ecosystems. Due to the variability of rainfall and runoff that is more extreme than other parts of the world, Australians have made a large investment in stored water capacity to supply urban users. The total stormwater runoff from the urban cities is about equal to the amount of drinking quality water that is supplied at considerable cost each year (Australia, Government, 2001).

As society is continuously developing, the living condition of people has involved meeting their day to day needs. The living units have changed from individuals to small gatherings to the present cities, towns, and suburbs. As these cities and towns have emerged, natural characteristics of the original land and surrounding areas have been altered. In many cases, forest and open spaces have changed to houses and manmade lawns, driveways and roadways, common property access ways and commercial and industrial areas. These vast modifications in land use have given a number of changes directly to the local environment and have had significant consequence on the local ecosystems. Many of these changes have had adverse environmental impacts. As areas under go urbanization, either surface is made less pervious, through impervious cover such as roofing and paving or by disturbance to established soil structures. This has the effect of changing the local water balance by increasing storm flow rates and volumes and decreasing base flow components. As a solution for this, the traditional stormwater management schemes have been introduced which helps to remove runoff from the site immediately to avoid flooding during major rainfall event (Pedini et al. 2005). This system itself has a negative impact on local water balance by affecting the groundwater resources, which tends to lower the groundwater table gradually. The other disadvantages of having conventional stormwater management systems are more cost and utilising such systems can make the ground surfaces less pervious due to the construction of stormwater infrastructures itself. In addition to urban flooding, stormwater runoff, leads to collection of pollutants (MDE, 2000), reduces runoff pollutant channel (Bressy *et al.* 2014), pollutant loads of urban runoff (Ho & Tan 2013) causes erosion (Booth et al., 2002), reduces base flow (Ferguson and Suckling, 1990), degraded receiving water quality (Carle et al., 2005) and causes damage to the aquatic ecosystem (Wang et al., 2001). Many researchers have identified the negative impacts of improper stormwater management as water quality degrades, stream channels erode or sediment deposition and flooding becomes more frequent (Gu & Gu 2014) James, 1965; Hammer, 1972; Pratt and Powell, 1993; Christopher, 2009).

As a result of rapid urbanisation and gradually increasing rainfall intensity, most of the cities have reached their maximum capacity of stormwater handling. The present rainfall trend is getting a huge quantity of water over a shorter period (Westra *et al.* 2014). The flash flood of March 2010 that occurred in Perth, Western Australia is one of the best examples to show the devastation that stormwater can bring. This flash flood events gives the basic idea to stormwater engineers to use higher return period in their stormwater designs and to implement capacity improvement methods for the existing systems, which is costlier than implementing conventional type drainage systems.

Other widely used approaches to manage stormwater are on-site detention and retention basins. Over the past several decades, these systems have been used as structural best management practices (BMPs) that rely on or are supported by stormwater infiltration. The structural detention and retention basins were cost effective urban stormwater management techniques that were widely used, particularly throughout Australia and these facilities have become the most common engineering approach to control the impacts of stormwater runoff (Argue and Pezzaniti, 2003; Yeh and Labadie 1997). These systems are becoming unpopular because of the urban land prices which are increasing day by day unexpectedly. There are extensive literatures on the design, operation, and optimization of individual detention ponds as well as the optimization of systems of detention ponds (Yeh and Labadie 1997; Behera et al. 1999; Harrell and Ranjithan, 2003). The main advantages of these basins are often highly effective means to control peak flows as they act as temporally storage, but they are relatively expensive to construct and to maintain. If the basin is not constructed in a systematic approach to the implementation, it can have some negative impact on the watershed (Ferguson, 1991). Although there are number of studies that have been carried out based on detention and retention basins, this all focus on finding the optimal location and the number for storage- based BMPs in a watershed practice rather than infiltration based BMPs for stormwater management (Mays and Bedient 1982; Zhen et al.2004).

Management of stormwater carries considerable socioeconomic and environmental benefits to the public in various ways all over the world. In countries likes Australia, this includes addressing the water scarcity problems and water reuse as well. Local governments and environmental authorities are mainly responsible for the management of urban stormwater. They can play an important role in maintaining and improving stormwater systems and related resources through their collective and respective actions. Modern hydrologists, environmental engineers and town planners rely on water sensitive urban designs (WSUD) to prevent stormwater management issues and to safeguard urban lives and the urban environment. With the rise of modern human nations, cities are becoming more complicated in their designs and urban lands, buildings and other infrastructure values are increasing rapidly.

Presently there is a higher demand in WSUD for infiltration based approaches to control the storm events by providing infiltration based stormwater management devices (Dodds et al. 2003; Potter 2004). Traditionally, stormwater runoff from several adjacent lots is captured and stored temporarily in basins or sumps from which water infiltrates into the surrounding soil (Jennifer et al, 2008). Due to the increase in housing density in urban cities, the authorities require stormwater runoff from developed lots to be retained /detained within each property. This valuable concept reduces storm runoff to stormwater systems, which are already operating beyond their potential capacity in most urbanized areas. In an urban context, infiltration typically can be done in several ways, such as perforated pipes, trenches, soak pits, leaky wells, swales and also rain gardens or vegetated bio-retention basins and pervious pavements. Typical infiltration based stormwater systems are excavated pits, filled with suitable filter media. The concepts used for the above methods are, use of swales and kerb cuts to direct runoff from impervious surfaces to nearby pervious surfaces. In order to avoid incursion of clay soils in to the filter, some geo-textiles are used (Mikkelsen et al., 1996; Siriwardene et al., 2007; Browne et al., 2008).

In addition to preventing urban flooding, infiltration systems have a major advantage in water quality improvements. Infiltration has been identified as a good solution to minimize adverse impacts on receiving water bodies, especially to minimize the risk for pollution conveyance to receive waters. In the past, infiltration systems have not been designed for removal of pollutants (Mikkelsen et al., 1997). Their primary aim was to reduce the surface runoff volume with a minimum load of pollutant. As result of this, over the past decade, the potential for contamination of groundwater has been identified (Belinda et al., 2006) along with a high groundwater table. The most common stormwater pollutants are nutrients, hydro carbons, heavy metals, bacteria and sediments. Over the past two decades, many studies have been carried out concerning stormwater quality improvements. As a result, different types of devices have been developed, designed and installed to minimize the pollution of surface water as well as the groundwater (Driver and Troutman, 1989; Mullisset al., 1996; Ellis, 2004; Allen et al., 2005). The different processes such as dry detention basin, wet retention ponds, infiltration devices, sand filters, and vegetative practices such as rain garden, bio filters, swales and constructed wetlands can be used depending on the available pollutants in the stormwater and the land use pattern. (Schueler et al. 1992).

Even though the advantage of infiltration systems is that they require lower investments and ongoing maintenance than traditional piped stormwater management systems, the main disadvantage of infiltration systems is failure due to clogging (Galli, 1992; Nozi et al., 1999; Raimbault et al., 1999; Warnaars et al., 1999). The direct effect of clogging of infiltration systems is to reduce the porosity and permeability due to physical, biological and chemical processes. As the clogging process in stormwater infiltration systems can directly affect on permeability and then the volume of surface runoff, studying about its clogging behaviour is as important as studying about capability of pollutant removal. Because there are many factors that have an effect on infiltration process, it is very important to understand a broad infiltration systems to understand how they can be made to be sustainable, environmental friendly stormwater management system in the future. The main factors effecting the performance of infiltration based stormwater management systems are permeability of different soil layers and depth of the groundwater table. Due to a lack of information on local soil properties specifically permeability rates within the soils predominant in the areas, it is difficult to accurately assess stormwater retention/detention requirements without on-site soil testing of the targeting areas. Therefore, it is essential to develop mapping of the soil characteristics pertaining to on-site disposal or retention of stormwater. This would support land development with guidance on the implementation of drainage strategies based on basic underlying parameters.

The aim of this study is to establish a statistically significant broad picture of feasibility of the infiltration based urban stormwater management, taking infiltration rates, groundwater and soil conditions into account. Outcomes of this research would aid the development of guidelines and recommendations to have a best management practice (BPM) of infiltration based urban stormwater management.

1.2. Aim and objectives

As a summary, the main objective of this research is to determine how the infiltration opportunities can be maximized in a residential land development process to manage the total water cycle in a sustainable manner, whilst adhering to the principles of water Sensitive Urban Design (WSUD) principles. Based on this main aim, the objectives of the study can be identified as;

1. Develop the relationships among physical properties of soil types and associated infiltration rates.

2. Investigate the role of spatially varying soil permeability in infiltration based onsite stormwater management and explore sustainable stormwater management approaches in green field and infill land developments.

3. Evaluate infiltration based stormwater management concept as a sustainable approach in urban land development areas.

4. Develop a Decision-support matrix for best stormwater management strategy selection.

5. Develop guidelines and recommendation for sustainable management of stormwater using onsite infiltration in expanding urban and residential land developments.

1.3. Target Audience

This research and its findings mainly target land developers, strategic urban planners, urban designers, engineering consultant, landscape architects, architects, building and construction industry professionals and development assessment staff involved in the formulation and evaluation of WSUD strategies.

- Developers, Strategic Urban Planners, Urban Designers – The research findings and the recommendations of this thesis will assist with the identification and scoping of issues that affect the urban water cycle as well as being able to advice on the general principles and issues that need to be considered when formulating a WSUD. Issues, such as a lack of information in the original application are identified that should be discussed with the local development assessment authority to minimise the time involved in the approval.

- Engineering Consultants, Landscape Architects – While formulating WSUD plans, the recommendations and guidelines will assist with an improved understanding of the issues that need to be addressed to meet the requirements of the local development assessment authority, thereby expediting the approval process.

- Development Assessment Authorities – The recommendations and guidelines developed in this thesis will assist authorities by identifying issues that need to be considered when evaluating a development application. The issues may, in some cases, require the regulator to undertake separate evaluations to establish local criteria and benchmarks depending on the locality and regional. Once these benchmarks are known, they will be available to the proponents of a WSUD project and all relevant issues will be known by all parties so that the subsequent applications should be consistent and address all requirements of the regulators or drainage authorities.

1.4. Significance of the study

The main objective of this study was to develop and provide guidelines for cost effective and simple applicable infiltration based onsite stormwater systems in urban areas.

This research evaluated the feasibility of minimizing the surface runoff component by implementing onsite infiltration based BMPs in urban areas. The other benefits include low stream flow augmentation, water quality enhancement and reduction for meeting the intent and goals of maintaining the predevelopment runoff characteristics.

At the end of this research, it will be able to establish decision making tools and techniques, guidelines and recommendations to facilitate onsite stormwater detention and infiltration procedures and develop suitable drainage strategies targeting a sustainable stormwater management.

The results of this research will assist land developers in their submission of development proposals, as well as local and regional authorities in assessing development applications ensuring a sustainable, stormwater management plan.

Most of the urban and sub-urban cities or parts of cities in Western Australia encountered localised flooding during the storm events mainly due to the capacity constraints of the existing road drainage systems. Several flood prone suburbs were selected for this study to analyse and develop a LWMS for proposed developments. For example, the Central Maddington ODP area was selected as high priority future development area as well as a higher density rezoning area. The outcomes of this whole research have been used to prepare a Local Stormwater Management Strategy (Refer Chapter 09) in order to overcome the existing development constraints, such as the clay nature of the soil and the limited capacity of the existing road drainage system. The LWMS provide suggestions to further develop the ODP area without investing millions of dollars on upgrading the existing infrastructures, including the existing drainage infrastructure.

1.5. Limitation of the study

As the study mainly considered the potential land development areas, the selection of sampling points were limited to cover only the local housing strategy (LHS) areas of City of Gosnells. However, those locations covered most of the soil types, including clayey sites and sandy sites. Getting permission from the property owners to access their land to do field tests was the most difficult task, as this process involved a long procedure to follow up. Initially, permission letters were sent to the property owners based, on the identified sampling locations and responses were received from only about 55% owners. Then the same procedure was followed up twice to get targeted responses. Although the aim was targeted to collect about 200 samples, permission was only by 156 property owners to access their properties for sampling. For this reason, the onsite testing locations were limited to 156 locations which is reasonable number of samples for this study.

The effect of land use changes to the urban water quality has not been analysed in this study. This study only assessed the land use change effect on urban stormwater quantity. Although there are three major components, such as evapotranspiration, infiltration and surface runoff that greatly contribute to the natural water balance, this research focused only on how to maximize the infiltration component in the urban land development process. The groundwater interaction in urban stormwater management systems was considered and its effect assessed with respect to the soil permeability. However, the groundwater data collected was limited and it has been further discussed within the literature review.

1.6. Overview of the thesis

The overall thesis consists nine chapters. Chapter 01 provides the introduction to the overall research. This chapter mainly discusses about the background of the study, aims and objectives, target audience, significance of the study, limitation of the study and the publication associated with the study. The background provides brief discussion about the basis rational of the study. These would be greatly helpful for reader to understand the importance of this research and its findings.

Chapter 02 describes the review of literature prior to and during the research. Literature review is mainly focused on four main research questions; how is the stormwater runoff generated? what are the factors that affect stormwater quantity? how infiltration can affect stormwater quantity? and what are the factors that affect infiltration based stormwater management?

The literature review covers the understanding of the broader effects of land use changes in urban contest, global climatic changes and rapidly changing groundwater environment on stormwater management. Effects of land use change and climate change have been discussed as the main two stressors of urban hydrology. The groundwater effect on urban stormwater management is also considered as one of the main factors due to the existing shallow groundwater condition within the study area. Secondly this chapter is narrowed down to understanding the importance of using infiltration as a technique to manage urban stormwater and to understanding the soil properties that effect the infiltration process. Later part of this chapter discusses how this study relates to the state/territory legislation and Australian stormwater management guidelines which mainly follow the new world's trend of water sensitive urban design (WSUD) as a concept.

Chapter 03 discusses the research methodology including data collection procedures, onsite testings, laboratory testing and measuring the groundwater levels and data analysis techniques. The methods that followed on onsite testing and laboratory testing are totally based on the Australian standards. However, the methodology that is used to measure the groundwater levels is uniquely designed for this study and it is specially designed for measuring the groundwater levels across the existing groundwater bores.

Chapter 04 presents the geotechnical assessments of soil permeability in residential land development process with respect to the stormwater management. it includes the total test result obtained from onsite and laboratory tests. It also, this chapter explains how groundwater level fluctuation effects permeability. Further this chapter concentrate on validation of all the test result focusing on methodical ways of analysing the data in order to achieve the targeted objectives. This include identifying the basic soil properties in different soil types, percentage of existence for both onsite and laboratory test results, categorization of permeability test results based on secondary data, calculating the total average permeability for each soil type, comparison of both onsite and laboratory test results against secondary data, calculation of minimum, maximum and average saturated hydraulic conductivity as a GIS based point representive data set and finally comparison of permeability of soil at different depths.

Depending on the nature of urban development process in Australia, the land development process can be clearly classified into two main different categories as infill and greenfield developments. The Chapter 05 discusses the evaluation of infiltration based stormwater management concept as a sustainable approach in both urban infill and greenfield land development process, whereas the Chapter 06 discusses the identification of some useful relationships among physical properties of soil and the permeability. This is one of the main objectives of the study and also very important findings on best practices of infiltration based stormwater management as a sustainable approach in both greenfield and infill land development process.

The Chapter 07 explains all the stormwater management strategies that are commonly practice around the world and categorizes mainly under six different classes. Each and every strategy has undergone a full review under scale of application and design guidelines.

This chapter also clarifies the Decision-Support Matrix that was developed for selecting a best stormwater management strategy in urban land development as a function of the infiltration capacity of the soil, scale of application and the main objective of having the strategy. The best available stormwater management strategies which have been discussed within the chapter have been analysed further and summarised in a table to provide a user-friendly guidance for designers in selection of best stormwater management strategies.

Chapter 08 addresses practical application of study findings (explained in Chapter 07) on stormwater drainage designs in order to achieve the best outcome of the development. The case study explained in this chapter was conducted in conformity with the Western Australian Planning framework and provides the platform to manage the broader water related issues for the redevelopment of the Central Maddington Outline Development Plan (ODP).

Finally, Chapter 09 summarises the results of the study. Recommendations from the results and recommendations to future studies are given under the final chapter.

1.7. Publications associated with the study

Following publications assists the integrity of the literature review and their results have been used throughout the thesis.

- Kannangara, D. I., and Sarukkalige P. R., 2011, Geotechnical Assessment of Soil Permeability in Land Development Areas, Proceedings of the 2nd International Conference on Environmental Engineering and Applications (ICEEA2011), Shanghai, China, August 2011.

- Kannangara, D. I, Sarukkalige, P. R and Botte, M., 2012, Maximize the Benefits of Water Sensitive Urban Designs in a Local Government Area - Western Australia, International Journal of Environmental Science and Development, 3/1, 27-32

- Kannangara, D. I, Sarukkalige, P. R and Botte, M., 2012, An innovative approach to stormwater management accounting for spatial variability in soil permeability, Proceedings of the 7th International Conference on Water Sensitive Urban Design (WSUD 2012), Melbourne, February 2012.

- Basnayaka A. P., Sarukkalige P. R., Kannangara D. I (2012). Effectiveness of stormwater Best Management Practices in Urban Land Developments. Conference on Water, Climate & Environment, BALWOIS 2012, Ohrid, Macedonia, 28 May – 2 June, 2012.

- Kannangara, D. I, Sarukkalige, P. R and Botte, M., 2012, Geotechnical Investigation of the Relationship Between Physical Properties and Saturated Hydraulic Conductivity by Using the Empirical Formulas, The First Australasia and South-East Asia Conference in Structural Engineering and Construction (ASEA-SEC-1), Perth, Western Australia, December 2012.

- Kannangara, D.I, Sarukkalige, P. R and Botte, M., 2012, Correlation of Soil Permeability and Particle Size Distribution With Respect to Urban Stormwater Management, The First Australasia and South East Asia Conference in Structural Engineering and Construction (ASEA-SEC-1), Perth, Western Australia, December 2012.

- Kannangara, D.I, Thennakoon A. and Botte, M., 2013 A decade of sustainable stormwater management approaches– do we need to go back to basics? The Institute of Public Works Engineering Australasia State Conference (IPWEA), Perth, May 2013. (Best Paper award)

- Kannangara, D.I, Sarukkalige, P. R., Thennakoon A. and Botte, M., 2013 An efficient and sustainable stormwater management approach to Infill Development where existing drainage runs "at capacity" Proceedings of the 8th International Conference on Water Sensitive Urban Design (WSUD 2013), Gold Coast, November 2013.

CHAPTER 2

2 LITERATURE REVIEW

2.1. Introduction

Urban stormwater management and planning has become a challenge due to the continuously changing of physical and natural global environment. Due to this reason, the first part of this chapter has been focused on a broader area of urbanisation, its effect on the natural water balance and the water management.

There are three main factors that directly affect the urban storm water management and its implications; land use changes in urban contest, global climatic changes and rapidly changing groundwater environment. Literature review has been more focused on these three major factors that greatly effect on urban stormwater management. The later part of literature review discussed quantity management of stormwater due to the main factors discussed above. The review is further concentrated on infiltration based stormwater management as a technique, the factors affecting infiltration based stormwater management and the challenges due to partially varying soil permeability of different soil types and the factors that govern soil permeability.

2.2. Effect of urbanisation on the natural water balance and water cycle management

The term urbanization stands for all the process by which large numbers of people become permanently concentrated in relatively small areas, forming cities. As areas undergo urbanization, surfaces are made less pervious, either by increasing impervious cover or by disturbing established soil structure (Holman-Dodds *et al.* 2003). Urbanization is happening everywhere in the world which creates much more and more land use changes in massive scale. The urbanization process in a country runs parallel to economic and cultural development and associated changes to the land use pattern have to be expected with the increasing population and the resource scarcity. Increasing levels of urbanization are caused by either natural growth of the urban population or migration of the rural population towards cities and the motivations include the opportunities and services offered in urban areas especially jobs and education. Urban cities play a major role not only as providers of employment, shelter and services but also as centres of culture, learning and technological development, expose to the rest of the world, industrial centres for the processing of agricultural produce and manufacturing, and places to generate income (UNCHS 2001b).

Most cities around the world are experiencing increased population growth at an accelerated day rate. As a result of this rapid growth of population and migration of people towards the urban cities, authorities have two options with either increase density in their core through infill and vertical development or to incorporate rural and less developed land along the peri-urban fringe, a process known as sprawl (Lily *et al.* 2011). On the other hand, the increase of population in a city also causes increases of demand for services such as transport, health and food.

Over recent decades' broad urbanisation and land use processes have become a progressively prominent but contentious issue in both public and academic discussions (Antrop, 2004). Although worldwide impervious land makes up only 0.43% of the total land area (Elvidge et al., in press), in many European countries >10% land are urbanised and commercial land covers (Nuissl et al., 2008). Impervious cover is one of the most important modifications that affect the urban water balance (Grimm et al., 2008; Elvidge et al., in press). There have been numerous case studies on the spatial-temporal and functional effects of urban growth on ecosystems ((Beltrán *et al.* 2013); Breuste, 1996). These studies demonstrated that urban land consumption affects the environment in terms of biodiversity (e.g. Lofvenhaft et al., 2002), habitat suitability (e.g. Hirzel et al., 2002), water balance and water regulation (e.g. the storm runoff by Whitford et al., 2001, Coldewey et al., 2001; Wessolek,1988; Interlandi and Crockett, 2003; Pauleit et al., 2005; Imhoff et al., 2000).

Urbanization in flood plain areas increases the risk of flooding due to increased peak discharge and volume, and decreased time to peak (Saghafian et al., 2008; Liu et al., 2004; Campana and Tucci, 2001; Nirupama and Simonovic, 2007). An urban watershed, on an average, contributes 90% of the storm rainfall to runoff, whereas the non-urban forested watersheds contribute 25% of the rainfall (Shang and Wilson, 2009). Due to encroachment into flood plain areas, the presence of several structures, and the absence of proper regulations for maintenance, an artificial flood is created

(Mohapatra and Singh, 2003). The impact of man-made changes on the hydrology of developing watersheds can be measured in terms of the ratio flood peak after development to flood peak before development over a range of return periods (Kibler et al., 2007). However, the analysis of urbanization effects on flood frequency seems to be a difficult problem, due to a lack of flood data in urban areas, and also due to the dynamic development process. Land use change is a major force altering the hydrological processes over a range of temporal and spatial scales. On a catchment scale, such impacts on the hydrological processes, in turn, will significantly influence the ecosystem, environment and economy. Therefore, a better under-standing and assessment of land use change impacts on the natural catchment hydrologic processes, is of great importance for the prediction and mitigation of flood hazards, and also for the planning, sustainable development and management of the watershed (Chen et al., 2009).

Water is always in movement, and the natural water cycle, also known as the hydrologic cycle, describes the continuous movement of water on, above, and below the surface of the Earth. The water cycle is a delicate balance among precipitation, evaporation, and all the steps in between. Warmer temperatures increase the rate of evaporation of water into the atmosphere, in effect increasing the atmosphere's capacity to "hold" water (Herath *et al.* 2017). Changes in the amount of rain falling during storms provide evidence that the water cycle is already being affected. Over the past 50 years, the amount of rain falling during the most intense 1 percent of storms increased by almost 20 percent (Anonymous 2011).Warmer winter temperatures cause more precipitation to fall as rain rather than snow. Furthermore, rising temperatures cause snow to begin melting earlier in the year. This alters the timing of stream flow in rivers whose sources are in mountainous areas. Due to these reasons, some part of the world gets increases in runoff, flooding and ultimately rises the sea level (Antin 2009).

There are many extensive researches which have been conducted on the specific impacts of climate change on water cycle. However the research and information on the impacts of climate change on watershed systems use in their early years (Marshall & Randhir 2008). Many researchers have studied the potential effects of climate change on river flows and have been published in the literature. Most studies have been done for Europe, North America and Australia, with a small number of studies for Asia (Bates et al 2008).

Changes in climate regime can influenced the natural processes of a watershed ecosystem (Band et al 1996;(Vogt *et al.* 2016)). It gives some long-term implications on economic and ecological processes (USEPA 2004). The very reason research finding shows that the average global surface temperature has increased by as much as 0.74◦C during the 20th Century (UNEP 2007; IPCC 2007). And also, the average sea level has risen approximately to 15–20 cm during the last century (IPCC 2001b; USEPA 2004). The climate can be changed naturally, with the population growth and fossil fuel burning plus high deforestation rate (FAO 2007) that helps to accelerated the increase of greenhouse gases (carbon dioxide, methane, nitrous oxide, and chlorofluorocarbons) in the atmosphere that trap heat and warm the earth system (USEPA 2004). Due to advances in modelling and understanding of the physical processes of the climate system, most of countries around world are now capable of getting most reliable regional climate change projections (Christensen et al 2007). As explained above, it is clear that climate change has negatively affected on natural water balance and ultimately the stormwater runoff with respect to the quantity and quality.

The recent research outcomes shows that the impact of urbanization on the water balance of a catchment dominated by surfaces water and the groundwater interaction, urbanisation results in particularly large changes in evapotranspiration from the soil profile and shallow water table (Barron *et al.* 2013). Oppositely, the effect of urbanisation on groundwater systems and its influence on the interaction between surface and groundwater is more diverse. Some authors suggest that an increase in groundwater recharge occurs due to the reduction in evapotranspiration (Rose and Peters, 2001; Klocking and Haber-landt, 2002) and leakage from urban water infrastructure (Lerner, 2002; Foster, 1994; Chilton, 1997; Chilton, 1999; Howard, 2002; (Cardoso *et al.* 2012). However, there also exists evidence that impervious surfaces can lead to a reduction in groundwater recharge due to the reduction in permeable areas (Brett et al., 2005; Rose and Peters, 2001; Schoo-nover et al., 2006; Collin and Melloul, 2003). Regardless of the underlying mechanism, the changes in the groundwater recharge rates have follow-on effects on base flow to urban rivers

(Rose and Peters, 2001; Schoonover et al., 2006; Paul and Meyer, 2001). It appears that, in contrast with surface runoff, the effect of urbanisation on shallower groundwater systems is dependent on the geological and hydrogeological setting and the adopted stormwater management practice.

Recharge is the defining factor when examining water balances involving superficial aquifers. It is the amount of water an aquifer receives when losses through drainage and evapotranspiration have been removed. It is this component that offsets the amount withdrawn through abstraction. Recharge is affected by many environmental conditions, and can be intentionally increased through appropriate management techniques (Dillon 2005). Any changes to environmental factors will alter the components of the cycle, and the system will adjust until it is balanced.

Water quality is another significant concern in urbanisation process. The major source of surface water and groundwater contamination in urban areas due to unavailability of proper stormwater management is significant issue in urban environment (Rygaard, Binning & Albrechtsen 2011). Where resources and expertise are lacking, urban water supply systems are constructed with minimal long-term design goals. Regulations concerning pollution and waste management may not be sufficient, and the culmination of these can lead to contamination of urban water resources. This has led to significant health issues in many areas; and increases the considerations when developing water resource management plans. As this research is more concentrated on stormwater quantity management, the effect on water quality due to urbanization would not be discussed in detail within this thesis.

2.2.1. Effect of land use changes on urban stormwater management

There is no doubt that man-made changers have affected significantly on the natural environment, including modification to natural watersheds and hydrologic cycle through land use change. Urban land use changes have caused to increase the runoff, peak flow rates and the runoff volumes at the downstream of catchments. The all man-made urban drainage system and the road ways including all the interconnected impervious surfaces by pass the natural water ways and this cause to decrease the time of concentration. The most of the urbanized cities and their stormwater infrastructure has historically evolved and in oldest growth areas are operating at or beyond capacity. The cost of broad scale conventional upgrades ahead of residential densification has been deemed unviable.

If the stormwater management systems' capacities are inadequate or running at capacity with the increased runoff, issues associated to the urban water can rise. Un-treated urban runoff carries various types of pollutants can cause water quality issues. There are lot of recent studies carried out to identify the impact of urbanization with respect to land use changes on urban stormwater management such as Carlson & Traci Arthur 2000; Holman-Dodds *et al.* 2003; Goonetilleke *et al.* 2005; Pauleit *et al.* 2005. Further studies have been done by Suarez *et al.* 2005; Semadeni-Davies *et al.* 2008a and Semadeni-Davies *et al.* 2008 discussed the effect on stormwater management by both urbanization and climate change. It is mentioned that the land use changes in a watershed can impact on water balance by altering hydrological processes such as infiltration, groundwater recharge, base flow and runoff Bellot *et al.* 2001; Antrop 2004; Lin *et al.* 2007; Haase 2009; Barron *et al.* 2013. With parallel to the urbanization process, it automatically rises the impervious areas such as roads, roofs and paving, construction of manmade drainage infrastructures, compaction of soil, disturbance to the existing soil due to heavy earth moving equipment and modifications to vegetation directly affects its natural stormwater paths and existing stormwater network (Klöcking & Haberlandt 2002; Elliott & Trowsdale 2007). The conventional stormwater management systems including manmade channels, drains, manholes and gutters are costlier and utilising such systems can make ground surfaces less pervious due to the construction of stormwater infrastructures itself. As a result, the runoff which contribute to the drain is much higher than its design (Selvalingam *et al.* 1987). And also the land use changes which involved in urbanization process increase more impervious surfaces by reducing infiltration opportunities of the existing ground surfaces and it help to accelerate the runoff component of a natural water balance (Chen *et al.* 2009). The pattern changes in characteristics of surface runoff hydrographs by increasing stormwater runoff volumes and peak flows (Goonetilleke *et al.* 2005) and (Barbosa *et al.* 2012). This directly affects to exceed the capacity of the existing stormwater drainage systems and the final result would be a flood which ultimately causes damages to the humans and their properties.

The other concern is initial and proportional losses from surface areas which are regularly cited in stormwater management documents and allow a reduction of runoff from the catchment. In particular, it was observed that after a period of dry weather initial wetting of pervious surfaces significantly impacted on the available loss rate, with hydrophobic sandy soils causing a delay in the rainfall runoff infiltrating into the ground surface. This phenomenon of a hydrophobic sandy soils resulted in an increase of the surfaces runoff volume from pervious surfaces during and immediately after a storm event, unless ponding at the surface was able to occur. Where this depression storage was not available, such as on verges that typically grade towards the road pavement, increased stormwater volumes needed to be managed by the drainage network, especially at the beginning of a drainage cycle. (Ogawa *et al.* 1992; Rajaram & Erbach 1999). As a summary, the increased residential densities result in an increase of impervious surface areas. The selection of design runoff coefficients for areas yet to be urbanised must be carefully undertaken to account for hard surface areas beyond house, driveways, footpaths and road pavements. Initial wetting delays of soils can increase the immediate runoff volumes from pervious surfaces.

The recent experience of residential land development process is clearing the entire site by removing all the vegetation including the large trees unless it has been identified initially at the planning stage. As a result, the evapotranspiration is reduced, and leads to stormwater to be retained in the surface for more time. De-forestation is one of the major activities that humans undertake with parallel to rapid urbanisation. The uncontrolled de-forestation of large scale catchments which are ultimately transferred either to agricultural lands or residential developments. The impact of the catchment hydrology due to de-forestation can be both climate change effects and increased runoff generation. The increment of peak runoff from such large catchments by this eventual process of natural catchment land use been transferred to the agricultural land use and to the urban land use is reviewed by many studies in the literature, notably(Andréassian 2004) (Andre´assian 2004); (Best *et al.* 2003) and (Zhang *et al.* 1999). On the other hand, the natural catchment is been converted to a paved infrastructure, this can be conversion of forest to pasture or the afforestation of grassed catchments through the recreational landscaping of public open spaces (POS), play grounds, multiple user corridors (MUC) etc. (Siriwardena *et* *al.* 2006). Siriwardena et al. (2006) identified that the total runoff increments from such large catchment which was subjected to just deforestation as estimated as 40% of the natural catchment runoff. This analysis indicates that the proposed urban development on top of deforestation will increase this 40% value to much higher figure. The recent studies conducted by Lin et al. (2007); Agarwal et al. (2002); Parker et al. (2002); Luijten (2003); Rounsevell et al. (2003); Stewart et al. (2004) and Manson (2005) demonstrated that the land use changes and their effects to urban environment, especially to the urban runoff by using different analytical modelling solutions.

The Infrastructure related to transport such as roads, round-a-bouts, pedestrian crossing, foot paths, tunnels, bridges and buildings is the major land use change in an urban catchment compare to its pre-development natural land use pattern. Due to the land use change, the predevelopment catchment can be obstructed, re-directed or accelerated and significantly alters the way water flows in a watershed. The pervious land use in the natural catchment created significantly smaller volumes of stormwater which runs in to the receiving water body. This has been altered to create more impervious surfaces and the surface roughness is changed from course to smooth by road surfaces. Exampled smooth surfaces are Bitumen, brick paving and concrete used to develop the road networks and foot path. Some corrugated materials and glass are used to cover buildings and their associated paved areas usually having zero infiltration and surface roughness value of about 0.014~0.015 (Chow 1959). This causes stormwater to flow quickly over the hardstand surfaces to become instant runoff through the catchments rather than soaking naturally in to soil or being absorbed by plants.

It is obvious that the runoff increase due to imperviousness can only be managed by providing retention or detention compensated storages within the catchment. However, hydrologists, landscape architectures and town planners now follow more water sensitive urban design concepts in their designs. These concepts would help to reduce the increased impervious land use percentage in urban cities by providing more green spaces with the help of series of stormwater management strategies. The above mentioned green spaces are mainly associated with public open spaces (POS) and some of the stormwater management features such as bio retention basins, flood storage areas, swales and Flood corridors or multiple user corridors (MUC) (SoSJ 2003). In addition to that, the Green roofs and vertical wall concepts are emerging as an increasingly popular Sustainable Urban Drainage Systems (SUDS) technique for urban stormwater management. Indeed, they allow a significant reduction of peak flows and runoff volumes collected by drainage system, with consequent reduction of flooding events (Lamera *et al.* 2014).

Landscape architectures and hydrologist try to maximize the use of landscaping features and bio diversity by increasing green spaces and having variety of plants. However, the urban land use changes even including those landscape feature generate greater impervious area percentage than to the pre-development natural land use. However (Pauleit *et al.* 2005) noted that there is a lack of information on the environmental effects by urban land use change and the dynamics of green-space.

2.2.2. Climate change impacts on urban stormwater management

This part of the literature reviews the anticipated changes to the climate with respect to rainfall intensity, groundwater levels, temperature and sea level rise been collected. Urban stormwater management and planning is really a challenge due to continuous and rapid development of cities around the globe outdating their existing stormwater management systems and by anthropogenic climate changing precipitation patterns (Willems *et al.* 2012; Herath *et al.* 2015).

The greenhouse gas emissions are mainly affecting Climate change that has adverse effects on urban hydrology. The current trend of getting rainfall as shorten recurrent intervals caused flashed foods is heavily affected to the urban stormwater management. (Elliott & Trowsdale 2007) cited that new urban water management approaches have been developed to deliver improved environmental, economic, social and cultural outcomes in last two decades. Stormwater management systems might need to meet the performance expectations under future climate change scenarios. Studies performed by various scientists proved that there is the possibility to analyse the effect of urbanisation on future climate as well as stormwater management system (Semadeni-Davies et al. 2008; Semadeni-Davies et al. 2008a). Although there is a lack of tools and guidelines to ascertain the impact of climate change in hydrology, however, the assessment of the potential impact of climate change on water systems has been considered as an essential part of hydrological research over the last couple of decades (Semadeni-Davies et al. 2008a). Recent studies have discussed the influence of climate change on urban stormwater management quality and quantity (Willems et al. 2012; Gersonius et al. 2012 and Pyke et al. 2011).

Climate change can substantially change the rainfall pattern by increasing the frequency of severe storms (Suarez *et al.* 2005). Based on the result obtained by modelling global climate change, Banaszuk and Kamocki (2008) demonstrated that the most vulnerable areas affected by severe storms will be where winter snowfall and stream flow is largely generated by spring and summer snowmelt. Studies have also suggested that climate change can also change the concept of urban stormwater management systems as it can generate more winter runoff and reduce spring flood pulse (Bergkamp and Orlando 1999).

To investigate the effects of climate change, trends of long-term historical record of rainfall events should be analysed. Various models are devised to ascertain the future scenarios namely atmosphere–ocean circulation models, General Circulation Models (GCMs), Regional Climate Models (RCMs) etc. However, statistical extrapolation based on historical observations need to be transferred in the urban drainage inputs of these models (Willems *et al.* 2012). But, the question is how to assess the urban stormwater management systems considering the climate change under regional scale. One of the ways is to downscale the results from global circulation models or regional climate models to urban catchment scales to analyse the urban catchments (Willems *et al.* 2012) and (Schilling 1991).

2.2.3. Effect of groundwater on urban stormwater drainage

Groundwater is constantly flowing from areas of high pressure to low pressure, or from higher groundwater levels to lower. Once again, the composition of the soil will affect how quickly groundwater flows are. Sandy soils, such as those experienced in the Perth region will exhibit faster flows (Salama, Silberstein & Pollock 2005).

Urban drainage systems comprising underground drains, manmade channels, manholes and gutters can generate more runoff rate than predevelopment runoff rate and can also decrease the time of concentration (Selvalingam et al. 1987). The result is an intense peak flow in the runoff hydrographs which the engineers are trying to reduce by implementing devices attached to the drainage systems such as weirs, treatment spots like raingardens and bio pockets, lot wise storage areas such as rain water tanks, infiltration storage areas like soakage pits, water retaining and detaining structures, subsurface storage areas and slotted pipe systems like French drains etc. In recent studies, the effects of urbanization on the urban drainage and urban flooding have been correlated in terms of drainage network structure drainage network efficiency, drainage pathway distribution and model resolution (Fewtrell et al. 2010).

Urban catchments situated within the river estuaries, nearby coastal areas and low elevation urban catchments with shallow groundwater table can have the effect from rising groundwater level especially in winter and rainy seasons. Elevated shallow groundwater table can submerge the underground stormwater and sewer drainage. The result can be a localised flooding due to decreased capacities under submerged condition. Road drainage network is draining the groundwater when the groundwater level reaches to the level of the drainage. Soil layer near the surface usually absorbs the initial rainfall and can be saturated by the shallow groundwater effect and can cause increased urban runoff.

The groundwater can be leaked to the drainage from the defected water tightened joints and the unsealed bottoms of the manholes (Berthier et al. 2004). Likewise, the stormwater infiltration through un-sealed manholes and drainage joints can cause rising groundwater tables in urban areas (Göbel et al. 2004). The groundwater table is always dynamic and characteristics with the seasonal variations and quick response to the heavy rains. Groundwater table rises to the natural surface level and stops the infiltration and occupies the stormwater drainage network leads. As a Consequent, most of the rainfall flows as surface runoff. In other hand, groundwater recharge in urban areas is dramatically reduced by the accelerated base flow through the stormwater drainage and less infiltration and accelerated surface runoff by the urban impervious surfaces (Wheater & Evans 2009). There is also the potentiality of groundwater contamination associated with stormwater infiltration (Pitt et al. 1999). Urban stormwater runoff flows along the urban surfaces absorbing more pollutants and infiltrate through a thin soil layer. This means inadequate treatment measures and can deteriorate the groundwater quality. Therefore, groundwater treatment should be one of the major parameters in such urban catchments.

Urban catchments which are situated in a shallow groundwater environment tend to faced the situation where their underground drainage is submerged. Effect of groundwater can cause to inundate the urban areas by reducing infiltration and seeping in to the stormwater drainage occupying the stormwater drainage.

There are numerous issues on managing urban stormwater with the effects of combined anthropogenic stresses upon the urban hydrology. Urbanization and land use change affected surface runoff, variation of weather patterns, intensified storm events and increased demand have proved the necessity of implementing sustainable stormwater management strategies through best management practices (BMPs) based on water sensitive urban designs (WSUD) in urban cities. There for the groundwater effect on stormwater management in an urban development environment is critical and should follow a high level of drainage assessment before the subdivision process starts.

2.3. Infiltration based stormwater management as a technique

Literature provides an interesting accounting of the historical context of stormwater drainage design in which they state that evidence of drainage design goes back many centuries, perhaps even 5000 years, however much of this infrastructure has since been abandoned (Chocat, Krebs et al. 2001). Since then, the concept of infiltration based stormwater management as a technique plays and important role in design of stormwater management infrastructures and it has now become the most attractive feature in water sensitive urban designs.

This is where the retention and detention storages come in to the picture and place an important role in stormwater management system. End-of-line flood controlling structures such as retention and detention basins are still popular in stormwater management. Scholz and Sadowski (2009) cited that aesthetically pleasing retention basins have been predominantly used for flood protection, adhering to sustainable drainage and best management practices. Stormwater control structures (sometimes called Best Management Practices or BMPs) like dry extended detention ponds or wet retention ponds have been installed, mostly in new developments, to intercept stormwater on its way to surface waters (EPA 2006).

A common practice of WSUD in Australia is to use the road network as the conveyor of excess runoff of ARI events greater than 5 years (major rainfall events). The excess runoff to the drainage system is controlled and/or attenuated fully within the catchment or at the end of the catchment (or the end of the pipe system) according to the local authority's guidelines (WAPC 2008). Usually the 100-year ARI critical duration event is used to design the retention or detention basins. Control peak flow measures can be varied, but common practise is to match the pre-development and post-development 100-year peak flows. Similar pre-development conditions to the post-development peak flow are achieved by using storage and controlling structures such as weirs. Providing treatment units to match major rainfall events is advised by local authorities (WAPC 2008). To match the pre-and post-development situations, flood retention basins are used commonly. They can store the excess volume of urban runoff generated due to the post-development land use change and limit the outflow from the catchment.

The designing of retention and detention basins should be incorporated with many aspects such as the infiltration capacity of design basins, possible clogging, outflow controls such as weirs and maximum water retention time with care for public health (i.e. mosquito breeding issues). The traditional practice of designing retention basins mostly accounted for the peak flow rates of the catchments being calculated by the rational method and then the infiltration rates being calculated by using equations such as a modified Darcy's Law. However, some studies in the recent past provide some modelling methods for designing infiltration basins by considering complex urban catchment characteristics, which may not be represented by the usual direct rational method calculations. As an example of such a practice, Scholz and Sadowski (2009) have recommended a rapid conceptual classification model for Sustainable Flood Retention Basins (SFRB) used to control runoff in a temperate climate.

However, there are some problems associated with end-of-line large-scale retention and detention basins. Artificial recharge of urban aquifers with stormwater has been used extensively in urban areas to dispose of stormwater and compensate for reduced groundwater recharge (Hill et al. 1998; SoSJ 2003). As a result, considerable amounts of stormwater sediment contaminated with heavy metals and organic compounds can accumulate over time in the upper layers of infiltration beds and can be a threat to surface and groundwater quality (Hill et al. 1998). Therefore, (Lassabatere et al. 2010) underlined the need for efficient monitoring of infiltration basin sedimentation and its impact on water infiltration capacity.

Source control, introduced during the 1980s, is a technique aimed at temporary storage in urban lots for flow reduction and when reduction of volumes is required (Augusto Pompêo 1999). Temporary storage based on infiltration soak wells and storage that directly attenuates water from roofs and paved surfaces, such as rainwater tanks, is one popular source control option for modern urban drainage planners (Coombes et al. 2000). To use the soak wells efficiently, the soil should be high permeable and the groundwater level should not be encountered within the depth of these soak wells. The mulches and filling soil on urban lots provide a good infiltration media and extra height to the surface above the groundwater table. Sometimes the infiltration of filled soil is better than the pre-development soil infiltration, especially in areas where more clay mixed soils can be found. However, this source control technique should be addressed at an individual lot scale and individual attitudes will highly influence the use and maintenance of the system (Augusto Pompêo 1999). Also, the usage of slotted pipes as sub-storage units, which attenuate and infiltrate the surface runoff to the sub–surface, is another version of combined storage and infiltration systems.

The practice of Bio retention systems is another kind of strategies that use infiltration as basic technique to treat the polluted runoff and attenuating method (Kazemi et al. 2009b). Bio-retention basins, which are a type of vegetated WSUD system, can be used to promote biodiversity by designing and managing them with different plant varieties. A bio-retention basin, also called a rain garden by landscape architects, naturalizes stormwater recharge and has other ecological attributes (WAPC 2007). The (WAPC 2007) again cited that the ecological attributes of the bio-retention basin as its ability to effect nutrient cycling, air and water pollutant abatement, carbon, habitat augmentation and connectivity, street-side beautification, reduction of building heating and cooling costs and urban heat island mitigation through direct shading and indirect evaporative cooling. Several recent studies on bio-retention basins in Australia have been carried out (Kazemi et al. 2009a, 2011; (Taylor & Fletcher 2004); (Trinh & Chui 2013)). The importance of the bio-retention basins is that they can help remove pollutants from runoff and in the meantime, support the concept of a liveable urban environment by contributing to sustainability in landscaping. Water within the bio-retention basin infiltrates through a layered organic–mineral soil (WAPC 2007). They can be used as on-line treatment units in urban stormwater management systems which provide extra volume capacity to deal with runoff and slow down the downstream runoff flow rate by providing high roughness values in the flow path. Bio-retention systems can be easily adapted to landscaping designs and usually can be placed alongside streets, car parks and traffic islands (Kazemi et al. 2009b). They are being used commonly in Australian urban areas as a WSUD system component to treat and attenuate 1-year ARI event's runoff. Stormwater trenches and grassed swales are similar versions used commonly, but mainly convey the runoff while treating rather than attenuating.

The use of permeable pavement as a sustainable infrastructure material (Kuang *et al.* 2011; Sansalone *et al.* 2012) to infiltrate the road runoff is another infiltration based solution to source control. The permeability of soil is important to achieve efficiency in such an infiltration system. Also, the type of source, which the type and amount of waste and pollutant load can vary according to, and factors such as gradient of the pavement and roads can be the key parameters in deciding the suitability of permeable pavements to a particular urban catchment because of the clogging factor, which reduces the efficiency of such a system. Again, there can be adverse effects from the use of permeable membranes, as in the case study done based on the new BBC centre at Pacific Quay, Glasgow, associated with extensive use of porous paving. A permeable membrane, letting water pass through the porous media without natural infiltrating through the subsoil, allowed contaminants to leach into the River Clyde (Jones & Macdonald 2007).

However, stormwater infiltration facilities (strips, porous pavements, basins, etc.) that collect pollutants accumulated on carriageways, have to be integrated in risk assessments on water resources in urban zones and should be maintained to reduce the risk (Hill et al. 1998). Also, there is the potential to raise the groundwater table by stormwater infiltration methods, especially large bio-retention basins, and adversely impact sub-surface infrastructure, undermining the benefits of naturalizing the urban water cycle (WAPC 2007).

2.4. Factors affecting infiltration

The concept of infiltration based stormwater management is vital and mostly applicable for reducing runoff at lot scale. Any development increases impervious runoff against the pervious areas and can generate significantly greater runoff compared to the pre-development condition. Due to this reason, it is required to modify the properties which govern the infiltration rate of the receiving pervious areas to maintain the water balance. On the other hand, the site compaction and the movement of heavy construction vehicles tend to decreases infiltration capacities compared to the pre-development condition. So, it is very important to understand the clear picture of ultimate capacity of infiltration rates at the post development stage. In reality, examination of the complexity of spatially varying soil permeability is more difficult as explained by (Benson *et al.* 1997).

There are many factors that govern the rate of soil permeability such as physical, chemical biological and human-imposed process. This study paid special attention on identifying the factors that mostly influence the infiltration capacities, to analysis how those factors influence and how human intervention alters infiltration capacities. For easy explanation, the factors that influence infiltration rates can be mainly categorized in to three groups. They have been separated by considering the natural environment and the human interactions and named as Ecosystem, Human and Characterizing factors.

2.4.1. Environmental Factors

Even in the past, about 75 years ago many researches have been conducted to identify the relationships between infiltration rates and the factors of the natural system. As explained by Horton 1941, the below factors were important in estimating the local infiltration rates: soil type and soil profile, biologic and macrostructure within the soil, vegetal cover. Since then many numbers of research have been conducted to interpret the infiltration rates with respect to the various ecosystem factors.

2.4.1.1 Soil Properties

This is the most influencing factor on infiltration rates and many researches have been conducted to identify the relationship between the physical soil properties and respective infiltration rates. There are many important soil properties such as soil composition, texture, structure, pore spaces, bulk density, horizon development and moisture state and these soil properties are correlated to each other.

Due to this reason, it is important to study the basics of soil formation that gives much more border area to deal with. Soils are mainly comprised of both minerals and organic matters. As a result of the process of mechanical breakdown, the soil parent material and the secondary materials further subdivided in to primary minerals which are normally found in clays. These finer matters called clay mostly undergone a chemical alteration (Hillel 1998) that greatly influence the infiltration rates. Further it is identified that the presence of soil organic matter is disproportionately accountable for increases in infiltration (Boyle *et al.* 1989b). However this relationship for hydrophobic soils were exceptional (Blackburn 1975b).

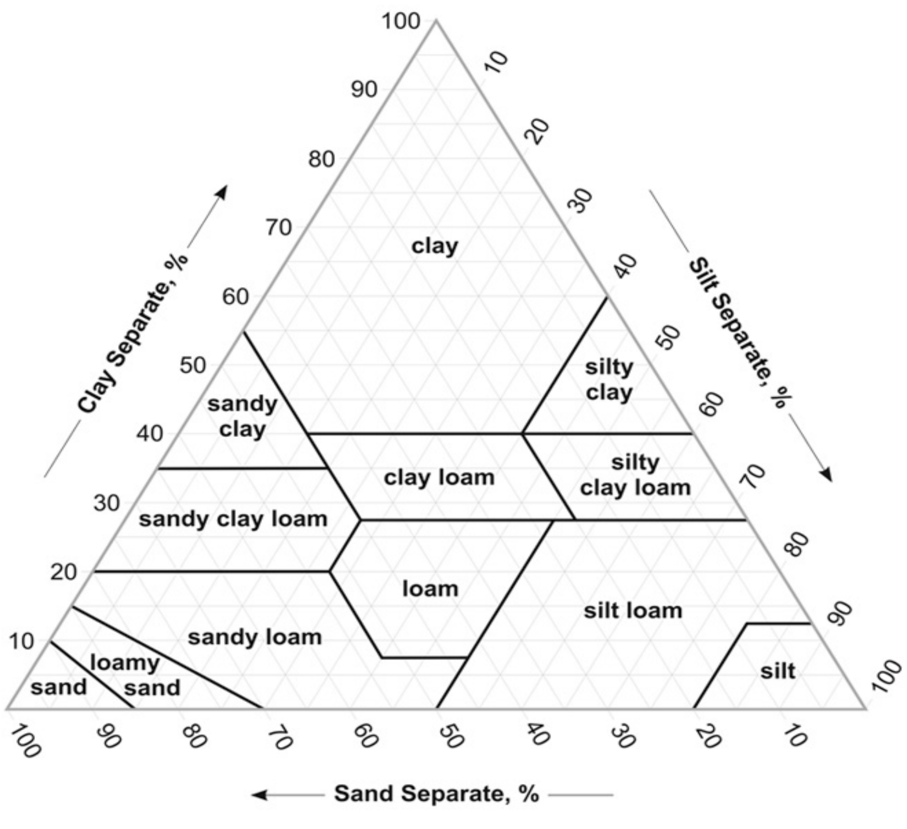


Figure 2:1 - USDA soil textural triangles

The soil texture is defined by proportions of clay, silt and sand sized particle of a mineral portion of soil. There are few soil classification systems available depending on the use. The most common and the core criteria for differentiating soil is United States Department of Agriculture scheme (USDA). USDA classification defines sand as particles with diameter 50 µm and 200 µm, silt as 2 µm to 50 µm and clay as < 2 µm (Hillel 1998). The textural classification is determined by the proportions of these three percentages based on the textural triangle given in Figure 2:1.

For engineers, a standard method of identifying and classifying soils regarding their engineering characteristics rather than agricultural or geological or other characteristics is needed. The borehole logs of soil profile give an adequate description and soil classifications and can be used in providing preliminary estimates to determine the extent of additional field investigation needed for the final design, planning the next stage of testing or request of finer testings. For final design of structures including stormwater management infrastructures, visual soil identification or classification is not adequate and it may have to be supplemented by laboratory tests to determine the performance characteristics of the soil, such as permeability, shearing strength and ability of compaction under given site conditions. The grain size distribution of a soil sample is important in describing the above mention factors and in the history, much work was concentrated on grain size relationships as given by the U.S. Bureau of Public Roads classification system (Rose, 1924) however this was found insufficient for engineering use.

Later in 1952, researchers introduced a new system called Unifield Soil Clasification System (USCS) (Casagrande 1947) which is current and most common engineering classification system for soils around the world. It is more extensive and periodically updated by the American Society for Testing Materials via their two standards ASTM-D2457 and ASTM-D2488.

The soil texture contributes to soil permeability properties (Connolly 1998) and generally, the coarser the texture, the higher the infiltration rate (Blackburn 1975a). The soil aggregates develop as a result of complex interaction of chemical, physical and biological processes within the soil structure (Jackson 2004; Angers & Caron

1998). The hydraulic conductivity has a direct relationship to the soil structure, however, it is not easily determine through analysing the structural details(Cresswell & Paydar 2000). The determination of a soil structure or the particle size distribution gives an indication of the available pores space between the particles and the infiltration of water through the soil structure depends on properties and interconnectedness of these pore spaces (Connolly 1998). The cause of having low infiltration rates most commonly caused by small pore size as velocity of water movement is inversely related to the cross-sectional area and the large pore spaces helps for a considerable high rate of infiltration rates (Kemper 1993).

The vertical variation in soil properties occur as a result of the complex processes operating from the surfaces downward. The soil profile is composed of strata which tend to parallel the soil surface. The surface horizons which is dominated by organic material and the upper most mineral horizon have a strong influence on soil behaviour. If the surface horizon thickness is greater, the ability to infiltrate of water increases (Blackburn 1975b). The vertical variation of soil permeability will be further discussed with field analysed data in the Chapter 4.

The bulk density is related to both pore spaces volume and organic content of soil and it is defined as the ratio of the mass of the soil solids to the total soil volume. The infiltration rates tend to decrease with increasing bulk density (Blackburn 1975b). In many cases, the variability of infiltration rates is well explained by variation in bulk density (Al-Omran and El-Bassir 1993).

The soil moisture content is another factor that greatly affect to the soil permeability. Due to this reason, there are two types of soil permeability values that are to be considered in the design of infrastructures including stormwater management measures. They are saturated and unsaturated permeability. The role of antecedent moisture state on runoff generation has been well established (Blackburn 1975b; Soil conservation service 1986). The availability of silt and clay minerals tend to shrink and swell with changing moisture state (Hillel 1998) which can lead to significant changes in porosity. The expanding clays due to the moisture content causes closing of pores and subsequent cracking as the clays drying can lead to increase of pores that make changes to infiltration rate (Lin 1995).

A regression equation for infiltration parameters had been developed in earlier days by (van Genuchten 1980) based on the textural information and (Al-Omran and El-Bassir 1993) used a state-space approach to interpolate infiltration rates with respect to the available clay content. In common practice, the permeability value of a soil sample is usually obtained by constant head and falling head permeability test and utilized in stormwater drainage design, waste water management systems, ground settlement issue, slope stability calculation, erosion and structural designs. In this respect, series of empirical equations have been developed and utilized to predict these parameters. However, these equations cannot be applied to each and every situation as they have their limitations and uncertainties. This will be further studied and discussed with the detailed analysis data in the final Chapter and finally a more generalized empirical formula will be developed specially for analysing of infiltration based stormwater management technique.

Although constant head, falling head and some other onsite permeability tests (Guelph Permeameter) don't take much time to perform (if the sample contain less silt and clay), the relationship between permeability parameter and a number of grain size distribution parameters have been investigated by several researchers (Freeze and Cherry, 1979; (Seelheim 1880 ;Hazen 1892; Slichter 1898; Carrier III 2003; Juarez-Badillo *et al.* 1991; Carrier 2003). The most of the empirical equations presented by a number of researchers are given in Table 2:1. All the advantages, disadvantages and limitations of these equations are also given in separate column. These formulas are capable of estimating the permeability values up to certain accuracy and those will be further analysed in this study to obtain an alternative and more generalized way to interpret the soil permeability.

In this study, using the database obtain by about 150 onsite and 89 laboratory permeability tests, which includes particle size distribution, dry density and moisture content, some of the existing empirical formulas will be critically analysed.

Table 2:1 – Empirical equations manifested for permeability prediction of soil

Researcher/ Organization	**Equation**	**Limitation, Advantages/ Disadvantages**
Hazen (1892)	$k = C_H d_{10}^2$	Effective diameter changes between 0.1 and 30mm (Hazen 1892; Carrier III 2003
Kenney (1984)	$k = (0.05\sim1) d_{10}^2$	D=0.074-25.4mm and C_u =1.04-12
Breyer –(Kresic 1998)	k = $6\times10^{-2}\times\frac{g}{v}\times log\left(\frac{500}{C_u}\right)\times d_{10}^2$	$C_u = 1\sim20, d_{10}$ =0.06 $\sim0.6mm$
Slichter (1898)	k =$\frac{g}{v}\times n^{3.287}\times d_{10}^2$	Best suited for soils with d_{10}=0.01$\sim5mm$ ($Vukovic$ & $Soro$, 1992)
Chapuis (2004)	k = $1.5\times d_{10}^2\times\frac{e^3}{1+e}\times\frac{1+e_{max}}{e_{max}^3}$	N/A
NAVFAC (Chapuis 1989)	k = $10^{1.291e-0.6435}\times d_{10}^{10^{0.5504-0.2937e}}$	e = 0.3$\sim$0.7; d_{10}=0.10 $\sim2.0mm$; C_u= $2\sim12; and \frac{d_{10}}{d_5} > 1.4$
Terzaghi-(Odong 2007)	k = $0.0084\times\frac{g}{v}\times\left[\frac{n-0.13}{(1-n)^{1/3}}\right]^2\times d_{10}^2$	The selected average value of 0.0084 is actually a classification coefficient typically ranging between 0.0061and 0.00107
USBR-(Vukovic and Soro 1992)	k = $0.048\times\frac{g}{v}\times d_{20}^{0.3}\times d_{10}^2$	Gives the best results when C_u is lower than 5 (Cheng and Chen 2007)

Alyamani and Sen(1993)	k = 1.5046 $\times (I_0 + 0.025 \times (d_{50} - d_{10}))^2$	This method is more accurate for well-graded sample (Odong 2007)
Kozeny-Carman(1956)	k = 0.083$\times \frac{g}{v} \times \left[\frac{n^3}{1-n^2}\right] \times d_{10}^2$	$d_{10} < 3mm$, for granular soils, the inertia term is not taken into account (Carrier III 2003)

2.4.1.2 Topography

One of the most important factors that greatly influence soil permeability is topography which tells about the sequence of soil profile down a slope. If other factors that greatly affect soil permeability keep constant, still difference to the permeability can be raised as a result of varying drainage, erosion, sedimentation and environmental behaviour along the soil profile down the slope. These help to make changes to the soil texture, soil profile, soil moisture and the amount of organic matter and ultimately influence the soil permeability (Birkeland *et al.* 2003) Accumulation of organic matter results in thicker A horizons as well as the development of an AB horizon and a more gradual transition from surface to subsoil (Williamson *et al.* 2004).

The other topographic factor that supports the infiltration is micro-topography which is characterised by small depression creates locally pond water. This allows greater opportunity for infiltration. It is observed that the local thickening of the A_h and B horizons under small topographic depressions in a forest podzol (Price 1994). In place, the A_h horizon had increased from a typical thickness of 20-50 mm to more than 300 mm. Furthermore, in soil sampling exercises where a time sequence of cores is taken at different locations in order to characterize temporal change in some variable, the structures described introduce a large element of uncertainty, in that the difference between two cores is a combination of temporal and spatial change in unknown relative proportions.

2.4.1.3 The presence or absence of vegetation

There are well fitted relationships between infiltration rates and the presence of vegetation available in the catchments. The changes in infiltration rates have been associated to the changes in soil properties resulting from the interaction between vegetation and soil (Pearse & Woolley 1936).

The root system is mainly responsible for increasing the infiltration rates as well as numbers of changes to the soil structure. In the past, some of the researchers have identified that deeper penetrations of water can be achieved at near to the roots (Pearse & Woolley 1936). Also, deep penetration of roots creates significant compressive and shear stresses. These stresses help to creates more and more pore spaces which lead to increase the capacity of the soil permeability. On the other hand, root systems directly interact with soil moisture content for drawing the water for transpiration (Angers & Caron 1998; Amézquita *et al.* 2004).

The above ground biomass layer also contributes to the infiltration capacity of soil. The infiltration capacity is proportional to the quantity of living plants and the biomass which accompanying a particular drainage catchment (Tromble *et al.* 1974). The surface litter also absorbs rainwater impact and reduces the erosion and compaction due to traffic. This also helps to reduce the evaporation to modify the soil moisture content (Angers & Caron 1998). The relationship between soil surface roughness and hydrologic variables on natural and reclaimed range land aslo been studied (Sanchez & Wood 1987).

There are some differences in soil physical properties that can be explained by the biomass, composition and distribution of soil fauna (Gijsman et al. 1996). Plant microenvironments provide improved habitat for burrowing fauna (Dunkerley 2000). In addition to this, grass root release material that favor microbial activity, that helps improve soil structure (Boyle *et al.* 1989a). In general, infiltration rates increase with the plants and more advanced on the successional scale and the state of succession within the community (Branson et al. 1981). The relationship between infiltration rates under different type of vegetation can be complex. Wood and Blackburn (1981) found infiltration undershrubs to be significantly higher than infiltration into grasses; however, Wainwright et al. (2000) found the reverse.

There are some identified differences in properties between vegetative covers, predicting infiltration properties are not as easy as delimiting boundaries between species or ecosystems. A number of studies of the mulga groves in Australia (Dunkerley 2000) have provided insight into vegetation mosaics. These ecosystems are characterized by clearly delineated grove strips alternating with intergrove areas. While infiltration rates are highest near the mulga stems and lowest in the intergrove areas, there is no clear boundary between two regions.

2.4.2. Human's intervention on infiltration

In this section, the discussion is only focus on the human activities that alter a natural environment. There are some factors that significantly alter infiltration rate due to human intervention such as urbanization, agricultural activities and soil conditioning. Numerous field experiments have revealed that hydrological processes and parameters can show considerable spatial variability concerning soil parameters (Warrick and Nielsen 1980). Compiled the results of different field studies and found coefficients of variation of 90-190% and 170-400% for saturated and unsaturated hydraulic conductivity, respectively. Because of the complexity of spatial patterns of soil, topography, meteorological boundary conditions, and vegetation, the soil moisture within a catchment is expected to be highly variable in space (e.g., Lehmann, 1995).

2.4.2.1 Urbanization

As a result of urbanization processes, ground surfaces converted in to more impervious areas. Most of the time, developers replace the existing permeable and organic-rich top soil layers with an imported sand fill subject to standard compaction. On the other hand, the heavy machineries used on sites create more impervious areas. This process further result in increasing of impervious percentages. Finally, even vegetated spaces in urban areas can generate significant runoff compared to undisturbed area (Anonymous 1995; Schueler 2000). As areas under-go urbanization, it increases surface runoff volumes. So, there is no doubt that humans have caused significant impacts on the natural environment, including alterations to watersheds and the hydrologic cycle through the urbanization.

Alteration of the land surface for various uses including light and heavy industry, urbanization and suburban developments has changed the water pathways and induced changes to natural processes (Booth & Jackson 1997).

2.4.2.2 Soil Amendments

The soil amendments and conditioners are used to improve the infiltration rates and reduce erosion. The most common soil conditioners are a wide range of organic soil amendments, composts, mulches and municipal solid waste. Numbers of studies have been conducted on identifying the effects of soil amendments on infiltration rate and the results have clearly showed improvements in infiltration rates with manure(Paker & Jenny 1945; Mbagwu 1992; Rao et al. 1998a, b) sewage sludge (Abu-Sharar 1996; Neilsen et al. 2003).

The infiltration rates can be improved with a help of numbers of processes through organic amendments. As stated by (Boyle *et al.* 1989a), the organic-matter can influence soil aggregation and its infiltration rate by improving water holding capacity. The increasing of organic carbon percentage can improve the structural stability (Lax *et al.* 1994).

Furthermore, there are some chemical amendments that can be used to improve the infiltration rates. In order to prevent surface sealing, the organic polymers such as polyacrylamide have been used (Levy & Agassi 1995). It was given that a poorly crystalline iron oxide (Ferrihydrite) on acid soils helps to increase infiltration rates. Soil with high pH (>7) shows decreased runoff with ferrihydrite use (Rhoton *et al.* 2003).

Chollak *et al.* 1998 explained the amendments used in urban residential fabric and its effect on stormwater management. The use of compost into soil in new development sites before to setting up of turfgrass or landscapes reduced the use of fertilizer, pesticides and less irrigation Further it was observed that replacing turf-grass areas with mulched leaves has increased invertebrate populations and improve soil quality plus infiltration capacity (Acosta-Martinez *et al.* 1999; Jordan 2004).

2.5. Water Sensitive Urban Design (WSUD)

WSUD is the integrated design of the urban water cycle, incorporating water supply, wastewater, stormwater and groundwater management, urban design and environmental protection (Bach *et al.* 2015). It represents a fundamental shift in the way water and related environmental resources and water infrastructure are considered in the planning and design of cities and towns, at all scales and densities. WSUD aims to see all streams of water being managed as a resource, as they have quantitative and qualitative impacts on land, water and biodiversity, and the community's aesthetic and recreational enjoyment of waterways. This applies at all levels of urban water governance, i.e. community, institutional and government which gives three diagrams below to illustrates how the water-cycle works in natural and urban areas. Figure 2:2 highlights the potential benefits of Water Sensitive Urban Design in achieving a more natural hydrologic regime.

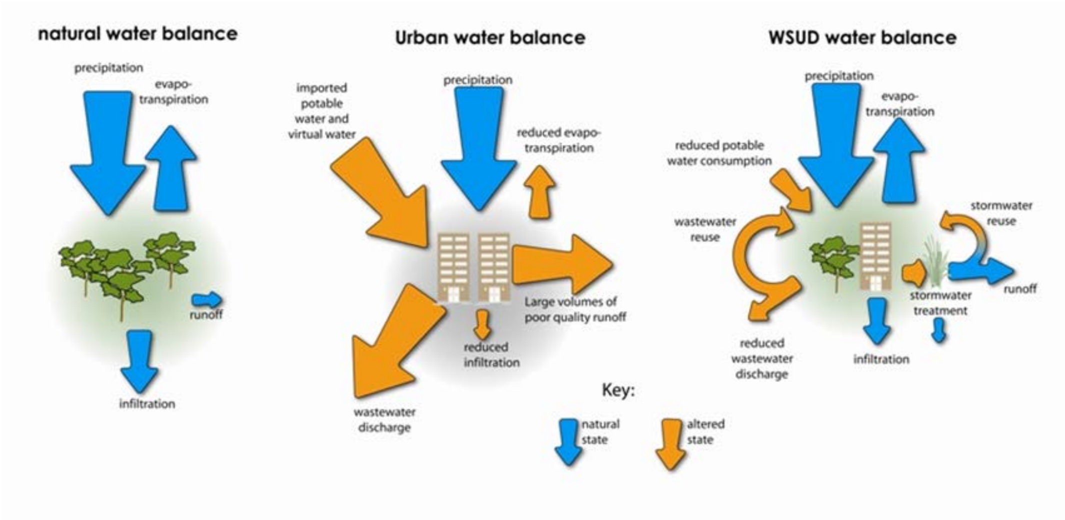


Figure 2:2 - The concept of Water Sensitive Urban Design

(Source: Hoban & Wong, 2006)

WSUD is based on the principle that the process of urban development and (importantly) redevelopment needs to address adequately the sustainability of the water environment. A planning and design approach is adopted in WSUD that integrates the following potential opportunities into the built form of cities and towns:

- The use of water efficient appliances and rainwater, stormwater, wastewater groundwater and greywater reuse as alternative sources of water to conserve potable supplies

- Detention, rather than rapid conveyance, of stormwater
- Reuse, storage and infiltration of stormwater, instead of drainage system augmentation
- Use of vegetation for stormwater filtering purposes
- Water-efficient landscaping to reduce potable water consumption
- Protection of water-related environmental, recreational and cultural values by minimising the ecological footprint of a project associated with providing supply, wastewater and stormwater services
- Localised wastewater treatment and reuse systems to reduce potable water consumption and minimise environmentally harmful wastewater discharges
- Provision of stormwater or other recycled urban waters (in all cases subject to appropriate controls) to provide environmental water requirements for modified watercourses
- Flexible institutional arrangements to cope with increased uncertainty and variability in climate; (Brown et al (2007))
- A focus on longer term planning
- Ongoing monitoring, evaluation and review

The overall objectives of WSUD include:

- Reducing potable water demand through demand and supply side water management, incorporating the use of water efficient appliances and fittings as well as a fit-for-purpose approach to the use of potential alternative sources of water
- Minimising wastewater generation and treatment of wastewater to a standard suitable for effluent reuse and/or release to receiving waters

- Treating stormwater to meet water quality objectives for reuse and/or discharge
- Restoring or preserving the natural hydrological regime of catchments
- Improving waterway health by the management of the previous two objectives
- Improving aesthetics and the connection with water for the residents of developments where it is applied and
- Promoting a significant degree of water related self-sufficiency within a development by optimizing the use of water sources from within the development to minimise potable water inflows and water outflows from a development, both stormwater and wastewater

The most innovative WSUD approaches also incorporate the design of localised water storage, treatment and reuse technologies. Such approaches often referred to as distributed systems, can involve the application of these alternative technologies at lot, neighbourhood or district residential scales or for commercial/industrial/high rise developments.

2.6. Australian stormwater management guidelines

Around the world, principles and guidelines are developed for the development and implementation of WSUD through BMPs to achieve sustainable levels of environmental enhancement in urban flood ways and corridors (Ellis 1995); (International Conference on Urban Drainage 2006). However (Benzerra *et al.* 2012) noted that the task is difficult because of the multi-dimensional requirements of a sustainable development approach (economy, society and environment), as well as the lack of structured methodology and information at various levels of the hierarchy. It is now clear that a new approach to stormwater management is needed - an approach that addresses issues of stormwater quality and aquatic ecosystem health, as well as stormwater quantity. Researchers need an approach that recognises the environmental impacts of urbanisation, the linkages between land and water management, and the importance of community values and involvement. Urban stormwater management and planning should include the planning of the urban grid and its expansion, the zoning of activities, the road and transport network, landscape aspects and other issues (Augusto Pompêo 1999; Tarlock & Deborah 2016). Also (Lin *et al.* 2007)) cited that the development of an integrated approach to assess land use changes, land use patterns and their effects on hydrological processes at the watershed level is crucial to land use and water resource planning and management.

Hydrologists, stormwater managers, town-planners and architects are expected to evaluate the possibilities and the potentials of stormwater management in to their development proposals. This is to integrate the urban water cycle into the town planning during the initial phase of town planning process (Icke *et al.* 1999). Urban stormwater presents a management challenge in terms of quantity (flood and drainage management, stormwater reuse), quality (litter, nutrients, chemicals, sediments) and aquatic ecosystem health (aquatic habitats, riparian vegetation, stream stability and environmental flows). Under the national, state and local level, the Australian governments have established numbers of environmental protection agencies which have developed policies and guidelines to manage urban stormwater in new land development sites and sub-division processes, urging plans and strategies for stormwater management in quality and quantity, based on best management practices (BMPs) prior to land development processes.

All local government, States and Territory Agencies are encouraged to consider the adoption of the WSUD principles and techniques presented in storm water management manual for western Australia. However, these guidelines are not mandatory and have no formal legal status. The adoption of national guidelines provides a shared national objective, while allowing flexibility of response to different circumstances at regional and local levels. Application of these guidelines may vary between States/Territories, depending on local water management and other arrangements.

In Western Australia, the Department of Water has developed Better Urban Water Management (BUWM) guidelines which intended to assist regional, district and local land use planning, as well as subdivision and development phases of the planning process to sustain BMPs in stormwater management (WAPC 2008). These guidelines are based on State Planning Policy 2.9 (WAPC 2006), which is a requirement of the State Water Strategy for Western Australia (GoWA 2003). Figure 2:3 shows the structure of implementation of the planning policy during a development process. The WA planning system is a hierarchical process which generally requires consideration of issues at decreasing scales before planning decisions are made. The following scales of planning are recognised.

- State
- Regional and sub-regional
- District
- Local
- Subdivision application, clearance of conditions and construction
- Development of lot

The preparation of a state and regional water management strategy (SWMS and RWMS), which includes the broader catchment description, local water issues, a plan and methodology of regional scale water resource management, is done by the Department of Water (DoW), under the Government of Western Australia. During these two stages DoW should consult all the other agencies that also located within the study area such as local authorities and environmental planning agencies; for example, the Swan River Trust and the Department of Environment and Conservation. These strategies are general drainage structure plans or will say a drainage concept for a broader region.

District water management strategy (DWMS) preparation is a process of scaling down the RWMS and including more strategic components that are unique to that district in detail. Again, the preparation of DWMS is the responsibility of the state government. It is generally a detailed structure or gives more information to:

- ✓ Provide a broad level stormwater management framework to support future development.
- ✓ Incorporate appropriate best management practices into the drainage systems that address the environmental and stormwater management issues identified.

- ✓ Minimise development construction costs, which will result in reduced land costs for future home owners.

- ✓ Minimise ongoing operation and maintenance costs to land owners.

- ✓ Develop a water conservation strategy for the area that will accommodate existing groundwater allocation constraints for the area.

Such DWMS strategies are already in place for most of the districts in Western Australia and they greatly support the developers when they going to prepare the LWMS and UWMP supporting to their development projects.

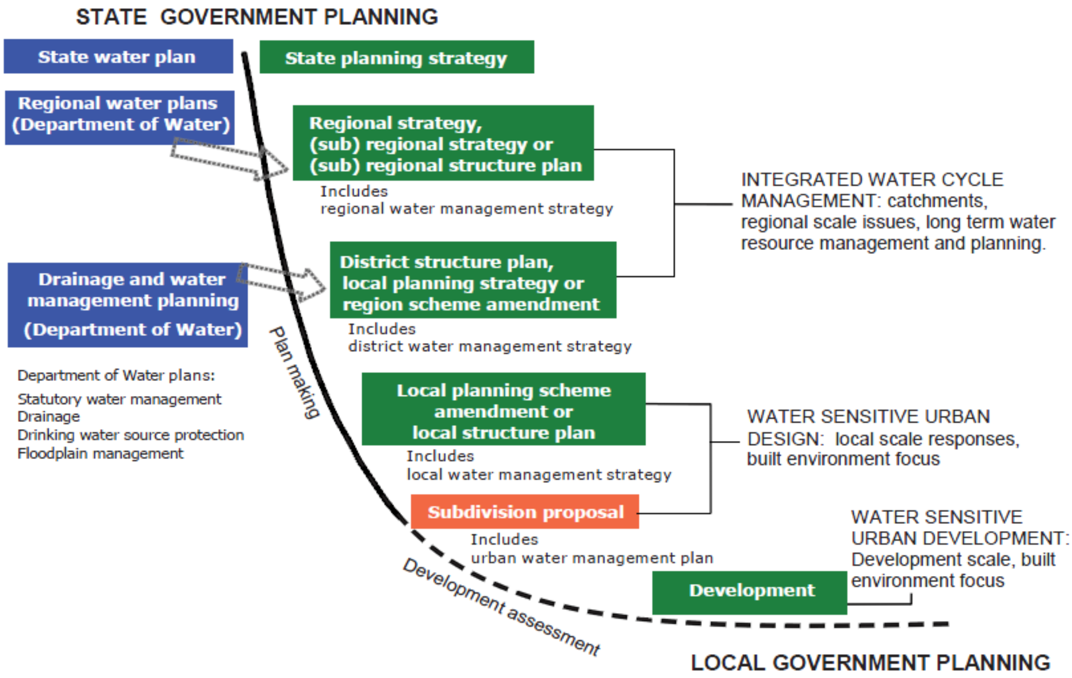


Figure 2:3 – Western Australian Planning processes related to stormwater management (DoW 2008b).

(DoW 2008a) provides guidance on urban water management issues to be addressed at the stage of local planning the land development process, while supporting the rezoning of local schemes and/or local structure planning. The documents also guide the preparation of supporting documentation of LWMS to the approval of urban structure and landscape for new residential, rural-residential, commercial or industrial development (including redevelopment) areas. In the next stage, after the approval of LWMS supporting initial identification of the zoning (or re-zoning), preliminary structural plans and landscape architectural work, (DoW 2008b) provides guidance on the urban water management issues that need to be addressed at the subdivision stage of a development and explains the integrity of a UWMP. It is expected that a proper structural plan and landscape architectural plans for the development site will be made at this stage.

Urban surface water modelling assessment by using approved software (e.g. XPSWMM) should be carried out prior to addressing the stormwater management section in a LWMS or UWMP. The following tasks should be addressed during the modelling process (WAPC 2008).

- Floodplain and wetland modelling to determine minimum building levels, catchment breaks for development and receiving water levels.

- Flow monitoring of existing surface water streams to establish current requirements.

- Identify how to manage post-development flows to meet catchment target flows.

- Drainage modelling to determine the detailed land requirements and flood ways needed to cope with major and minor storms (1 in 1 year, 1 in 5/10 year and 1 in 100 year), based on the receiving environment's requirements and/or design criteria provided in an endorsed water management strategy or plan.

- Establish acceptability of location of surface water flow paths (streams) and floodwater storage areas (floodplains) in consultation with the drainage service provider.

- Identify and address potential impacts on surface water-dependent ecosystems that are to be protected. Demonstrate that any potential impacts on flow will not have a significant environmental impact. Where any changes to the hydrological regime are proposed, this should be demonstrated to be consistent with the guidelines for ecological water requirements for urban development's currently being developed by Department of Water.

The document also highlights the modelling components to be carried out with the LWMS and UWMPs as:

- Demonstrating how post-development flows will meet catchment criteria.

- Modelling of up to 1 in 1-year ARI event to determine capability for retention/detention and water quality treatment, where/if required.

- Modelling of "minor" and "major" stormwater systems to identify and size flow paths (via pipes or overland flow) and required flood detention volumes.

- Refinement of 1 in 100-year floodway if required.

2.7. Summary of literature review

There is no doubt that human's activities have caused significant influence on the natural environment. The word "urbanization" itself has a great impact on hydrological cycle. Urbanization changes the catchment land use pattern, climate and the groundwater levels which would ultimately result in creating more runoff than the pre-development condition. The importance of re-establishing stormwater runoff to its pre-development or even pre-settlement status has gained interest as evidenced by increased discussions among academic's researchers, professionals and government agencies.

The runoff generated due to urbanization creates more runoff than pre-development in quantity and also in quality due to highly polluted runoff. In order to prevent from disasters such as urban flooding when urban stormwater management systems face adverse impact due land use change, groundwater rise and climatic effects, analysis of urban hydrology and stormwater management systems are vitally important.

Urbanization generates more impervious land use patterns than the natural pervious land use where the opportunities for infiltration of stormwater at source is very limited. Then the stormwater runoff should be routed across pervious surfaces thus reducing impacts to receiving streams. An important point made by researchers is the characteristic of soil texture and it's physical and chemical properties are limiting factors when trying to increase infiltration capacities of the soil. There are three main factors that govern the infiltration namely, Environmental, human's intervention and characterizing variability. The studying on these factors and identifying the relationship between the factors would be greatly helpful on implementation of best stormwater management strategies on new developments. This study also focused on calculating the soil permeability of different soils types and identifying the relationship between factors that govern the soil permeability.

As some of the pre-existing site constraints are stand against, the generalization of research finding over the other states or all over the other countries around the world would not be straight forward. The proposed strategies used for one project by different authority in different place cannot be extrapolated to another project in a totally different authority and a totally different place even in different drainage experts advises. As explained above, the selection of best stormwater management strategy can vary depending on the climate, capacity of the existing urban stormwater management system, level of urbanization, available technology and economic viability.

These guidelines provide more economical and less environmentally damaging, ways of managing urban water, wastewater and stormwater solutions. Modern infrastructure projects and subdivisional works are totally based on these guidelines to prevent potential disasters and promote stormwater reuse. These guidelines provide both structural and non-structural measures for managing stormwater runoff.

CHAPTER 3

3 METHODOLOGY

3.1. Introduction

There were series of tasks that have been carried out during this research study, including literature review, identifying the test methods, calibration and verification of data, finding suitable methods to analysis the data, finding the groundwater effect on soil permeability, develop stormwater management strategies based on the soil infiltration of the sites, etc. The overall research methodology used for the study includes as follow:

1. Detailed literature reviews to understand the urban hydrology, the effect of land use change, climate change and groundwater level on urban stormwater management, an identifying infiltration based urban stormwater management as a best management technique, identifying the properties that effect to infiltration based stormwater management, WSUD and stormwater BMPs.

2. Study and understand the existing best management practices of urban stormwater management and find out the data availability and the gaps between data available and the design requirements of infiltration based stormwater management strategies.

3. Collect all reference documents which help to identify the best sampling locations. (Geology, geography, and topography data).

4. Study and understand the local governments' stormwater management policies and guidelines (including limitations to stormwater peak flows and regulations in using BMPs).

5. Study and further understanding of Australian standards for the selected laboratory and onsite testings.

6. Contact property owners by sending letters and get the permission to access their properties for onsite testings.

7. Carry out field testing and data collection campaign (locate the coordinates of each and every testing location by using GPS instrument) including permeability tests and prepare an undisturbed soil sample for laboratory testing.

8. Conduct the laboratory permeability test (falling head permeability test) for the undisturbed soil samples which have been collected at site. Then the samples were oven dried and separated for smaller samples based on the particle size distribution as followed by each test standards.

9. The soil samples were subjected to the following laboratory tests to determine basic soil parameters such as soil texture, soil classification and soil permeability.

    1. Sieve analysis (particle size distribution)
    2. Saturated density of soil
    3. Particle density and water absorption of fine aggregate
    4. Dry density/ moisture content relation-modified compaction
    5. Void ratio / Porosity

10. Develop the relationship between soil types and associated infiltration rate.

11. Identify the suitable areas for infiltration based onsite stormwater management and explore further developments.

12. Evaluate the infiltration based stormwater management concept as a sustainable approach in urban land development areas.

13. Identified the relationship between the particle size distribution and soil permeability.

14. Develop guidelines and recommendation for sustainable management of stormwater using onsite infiltration in expanding urban and residential land developments.

15. Investigated the relationship between physical properties and saturated hydraulic conductivities by using empirical formulas

16. Derive an empirical formula to represent the soil permeability as a function of basic soil properties.

17. Develop a Decision-support matrix for best stormwater management strategy selection.

18. Investigate the role of spatially varying soil permeability of an efficient and sustainable stormwater management approach in both infill and green field developments with some extended sand fill land developments.

3.2. Study Area – City of Gosnells

The City of Gosnells is a growing residential area, located in Perth's south-eastern suburbs, about 17 kilometres from the Perth CBD. The City encompasses substantial rural areas in the east and south and some commercial and industrial areas, particularly along Albany Highway. The majority of the population live in suburbs west of Albany Highway.

Significant development did not occur in the City of Gosnells until the post-war years. By the early 1950s the post war migration population boom was impacting on Perth. The population grew from 7,400 in 1954 to about 11,000 in 1966, and then to 21,000 in 1970. From the 1950s to the 1980s rapid growth took place along Albany Highway, the Canning River and Southern River (the suburbs of Beckenham, Gosnells, Kenwick, Langford, Maddington and Thornlie). The suburb Huntingdale was developed in the 1970s. As shown in Table 3:1 the population of the City continued to increase from the early 1990s, rising from 69,500 in 1991 to over 90,000 in 2006. Much of this growth has been from new residential development in the suburbs of Canning Vale and more recently, Southern River.

Table 3:1 – Population growth

Year	1911	1921	1933	1947	1954	1961	1971	1986	1996	2009	2011	2016
Population	737	1,936	3,016	4,405	7,366	7,524	22,040	60,610	73,421	90, 249	104,966	125051

Source: Australian Bureau of Statistics, Census of Population and Housing 2016

According to Table 3:1 the City of Gosnells comprises significant diversity in terms of residential and economic role and function. Progressive residential development of the City over many decades has resulted in the development of land and a broad range of land uses, where areas have developed different roles within the housing market. Older established suburbs, such as Maddington, Beckenham, Kenwick and Gosnells (Central), which are expected to undergo a degree of redevelopment, are likely to attract a large number of people in their late teens and early twenties, which is a reflection on the increasing amount of diverse housing and rental accommodation and being close to services. In contrast, small areas of Thornlie (Central), Thornlie (East) and Gosnells (Balance) have limited development opportunities and consequently are losing a large number of younger households and established families who are seeking new housing opportunities elsewhere. Development areas in Canning Vale and Southern River and in the longer term, Martin (West) provide a broader range of housing choices for first home buyers through to upgrade markets. Finally, the predominantly rural area of Martin (East)-Orange Grove attracts established and mature families. This variety of functions and roles of the small areas in Gosnells means that population outcomes differ significantly across the City. Table 3:2 is given below.

Table 3:2 – Suburbs in City of Gosnells

Suburb	Population (2011 census data)	Area (Sq. Km)	Population Density (people/km^2)
Beckenham	6,531	5.88	1,110
Canning Vale *	20,172	9.97	2,023
Gosnells	18,878	14.82	1,274
Huntingdale	8,359	4.8	1,741
Thornlie	22,592	11.56	1,954
Maddington	9,829	10.83	908
Kenwick	5,402	9.81	551
Martin	1,119	28.46	39
Orange Grove	679	13.79	49
Southern River	5,895	14.04	420
Langford	5,477	3.29	1,665

Note: - * represent two city councils
Source: Australian Bureau of Statistics, Census of Population and Housing 2016

To cater for population growth and changes into the future, the city has implemented a strategy by identifying areas that could accommodate denser forms of residential development in order to meet the future housing needs within the City in a sustainable manner. This strategy is called as local housing strategy (LHS) and this was adopted by the Gosnells Council in December 2003 and approved by the Western Australian Planning Commission (WAPC) in October 2005.

3.3. Collection of secondary data

As the initial part of the study, an extensive literature review was conducted to understand the research gap and collect the required secondary data and information. As given below Table 3:3, all the secondary data required for this study has been collected from relevant government organizations such as Department of Agricultural WA, Department of Water WA, Bureau of Meteorology WA, Water Corporation WA and City of Gosnells.

Table 3:3 – Collected secondary data and the source

Data	**Source**
Perth groundwater	Atlas of Australia
Soil maps (Sheet 05 hard copy)	Atlas of Australian
1: 250 000 geological series map images (soft copy)	Atlas of Australia
Soil group of western Australia	Department of Agriculture
GIS Maps of developing areas (soft copy)	City of Gosnells
Topography maps (contour maps, soft copy)	Landgate Australia
Land use maps (soft copy)	City of Gosnells
Past permeability data	Department of Agriculture
Rain fall data	Bureau of Meteorology
Catchment area boundaries (soft copy)	City of Gosnells
River basin maps (soft copy)	Department of Water
Details drawings of present stormwater management system (soft copy, hard copy)	City of Gosnells
Past groundwater level data and the location map of existing bores	City of Gosnells

3.4. Selection Criteria of field testing sites/sampling points

To evaluate the general condition of the study area, widely distributed field sampling is highly important as hydro-geological properties are highly heterogeneous over the study areas. There are a lot of factors should be considered in selecting the appropriate field testing sites to represent the general hydro-geological characteristics of the study area. Based on the high priority, this study considered the following key factors in selecting the field test location and sampling points.

1. City of Gosnells proposed Local Housing Precincts (64 area)
2. Soil distribution of Western Australia
3. At least one sampling point from one housing sub precincts
4. Accessibility
5. Ground elevation

3.4.1. City of Gosnells Local Housing Precincts

The local housing strategy (LHS) was adopted by the Gosnells Council in December 2003 and approved by the Western Australian Planning Commission (WAPC) in October 2005. The main aim of a LHS is to meet future housing needs within the City in a sustainable way. Population growth and changes are catered for by identifying areas that could accommodate denser forms of residential development.

Town Planning Scheme six (TPS 6) is a key planning tool used to guide the use and development of land. All land zoned under TPS 6 as Residential is allocated a residential density code. Approximately 3,500 properties throughout the City have been identified in the LHS for an increased residential density code, based on their proximity to commercial centres, public transport nodes or community facilities. Areas identified for increased density coding are shown in the Figure 3:1.

Development of all properties in accordance with the identified increased density coding in the LHS would yield approximately 11,000 additional dwelling, which would make a significant contribution to housing supply and a resulting increase in patronage of local businesses and services.

Schedule of Proposals

Proposal Number	Local Housing Strategy Sub-Precinct	Proposed Residential Coding
1	Central Beckenham A	R20/R60
2	Central Beckenham B	R20/R60
3	Central Beckenham C	R20/R60
4	Central Beckenham D	R20/R25
5	Central Beckenham E	R20/R25
6	Central Beckenham F	R20/R25
7	Central Beckenham G	R20/R25
8	Central Beckenham H	R20/R25
9	Outer Beckenham A	R20/R25
10	Outer Beckenham B	R20/R25
11	Outer Beckenham C	R20/R35
12	Outer Beckenham D	R20/R25
13	Outer Beckenham E	R20/R30
14	Outer Beckenham F	R20/R30
15	Langford A	R20/R30
16	Langford B	R20/R30
17	Langford D	R20/R30
18	Kenwick A	R20/R60
19	Kenwick B	R20/R60
20	Kenwick C	R20/R60
21	Kenwick D	R20/R60
22	Kenwick E	R20/R30
23	Kenwick F	R20/R30
24	Kenwick G	R20/R30
25	Kenwick H	R20/R30
26	Kenwick I	R20/R30
27	Central Maddington A	R20/R30
28	Central Maddington B	R20/R30
29	Central Maddington C	R20/R30
30	Central Maddington D	R20/R30
31	Thornlie East A	R20/R40
32	Thornlie East B	R20/R40 & R20/R60
33	Thornlie East C	R20/R30
34	Thornlie East D	R20/R30
35	Thornlie East E	R20/R30
36	Thornlie East F	R20/R30
37	Thornlie West A	R20/R30
38	Thornlie West B	R20/R40
39	Thornlie West C	R20/R30
40	South Thornlie A	R20/R40
41	North Gosnells A	R20/R30
42	North Gosnells B	R20/R30
43	North Gosnells C	R20/R30
44	North Gosnells D	R20/R30
45	North Gosnells E	R20/R60
46	North Gosnells F	R20/R40
47	North Gosnells G	R20/R40
48	North Gosnells H	R20/R40
49	North Gosnells I	R20/R30
50	North Gosnells J	R20/R30
51	South Gosnells A	R20/R35
52	South Gosnells B	R20/R35
53	North Huntingdale A	R20/R35
54	North Huntingdale B	R20/R35
55	Central Maddington F	R20/30
56	Thornlie East G	R20/30
57	North Gosnells K	R20/30
58	North Gosnells L	R20/30
59	North Gosnells M	R20/30
60	North Gosnells N	R20/30
61	North Gosnells O	R20/30
62	South Gosnells C	R20/30
63	South Gosnells D	R20/30
64	Thornlie West E	R20/60

Figure 3:1 - Identified Density Coding (Source – City of Gosnells)

Currently, there are 64 housing precincts located in the City of Gosnells, where the City has identified that stormwater management is a challenge. Figure 3:2 shows these housing precincts which are empty lots or parks, while some of the precincts are existing residential houses. Hence, identifying stormwater drainage problems before any damage can be caused by major storms or floods on existing residential housing lots is critical and justifies the necessity for this project. Our job as civil engineers, disciplined in water engineering, is to provide the City expert and professional advice on infiltration based stormwater management solutions, depending on the soil infiltration characteristics.

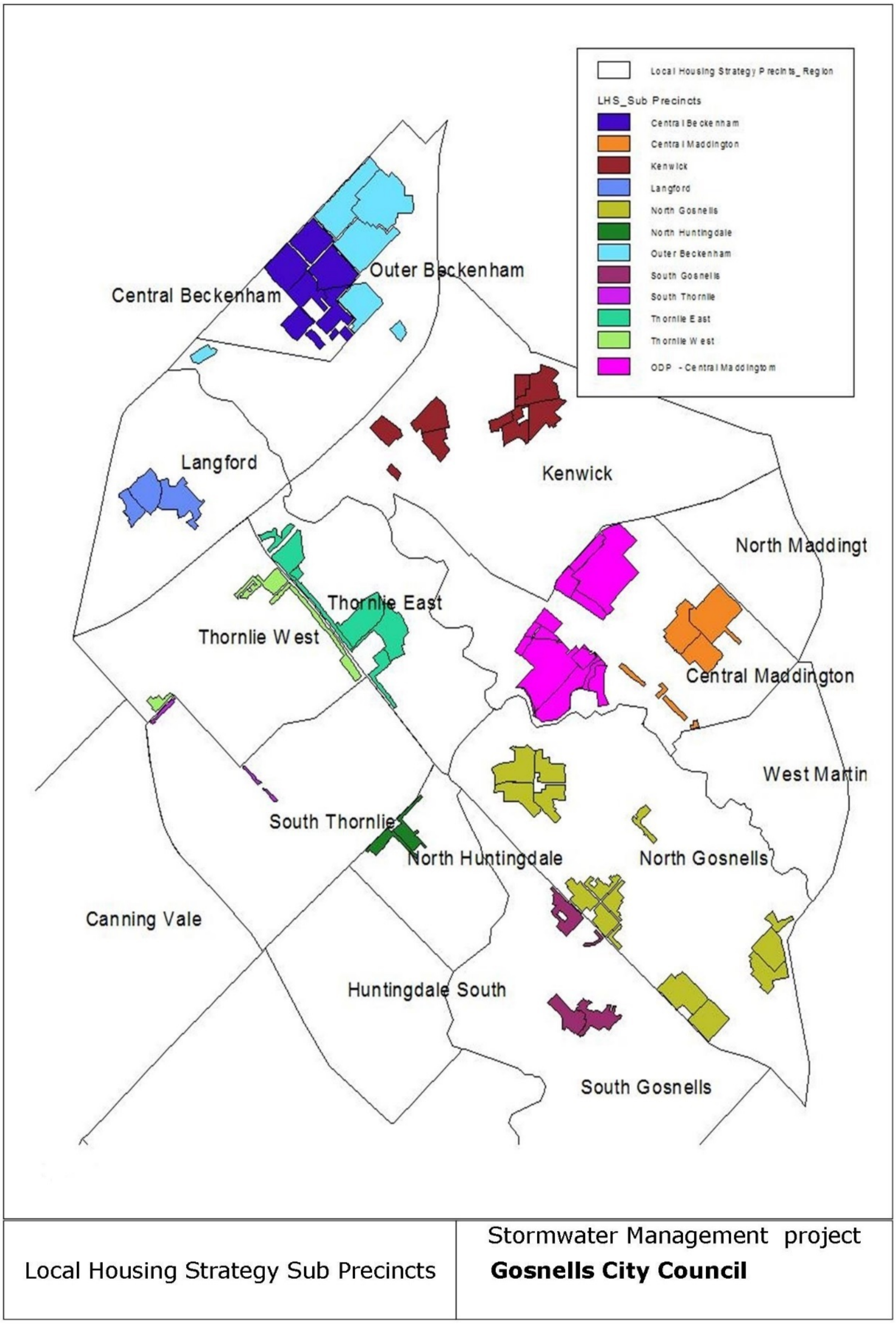


Figure 3:2 - Local Housing Strategy Sub Precincts

3.4.2. Soil distribution of Western Australia

The Department of Agriculture WA has produced a handbook entitled "Soil Groups of Western Australia, a simple guide to the main soil of Western Australia" which suggests to describe a soil, it is best conducted on an exposed profile such as a pit or a road cutting, but alternatively using a soil auger or coring device. In the field, the soil profile is divided into layers, based on one or more of the properties or characteristics. The properties, depths and arrangement of the layers are used to assign the soil to a soil supergroup or soil group. A soil supergroup is made out of several soil groups. There are 13 soil supergroups and each can be defined by three criteria, texture or permeability profile, coarse fragments (presence and nature) and water regime. For the texture or permeability criterion, it is important to estimate how quickly the texture or permeability changes occur between layers down the profile (over indicates a rapid change whereas grading which indicates a gradual change)(Schoknecht 2002). Have another tier of secondary criteria based on colour, calcareous layer, depths of profile, pH (alkalinity) and structure, about sixty soil groups have been found as a combination of one or more soil types in Western Australia.

Out of this sixty soil groups, City of Gosnells covers 25 soil types and the soil map is attached in Figure 3:3. As this study is limited in to 64 housing precincts, the study area is covered only 8 types of soil supergroups and 9 types of soil groups as given in below. These soil groups were named as A, B, C, D, E, F, G, H and I for the purpose of easy in referencing instead of corresponding name and map unit locations throughout this report. Details are provided in (Table 3:4, Table 3:5, Figure 3:3)

Table 3:4 – Soil Super Groups in LHS

Soil Super Group	**Notation Used**
Wet or waterlogged soils	100
Rocky or Stony soils	200
Sandy duplexes	400
Shallow sands	420
Deep sands	440
Sandy earth	460
Loamy duplexes	500
Loamy earth	540

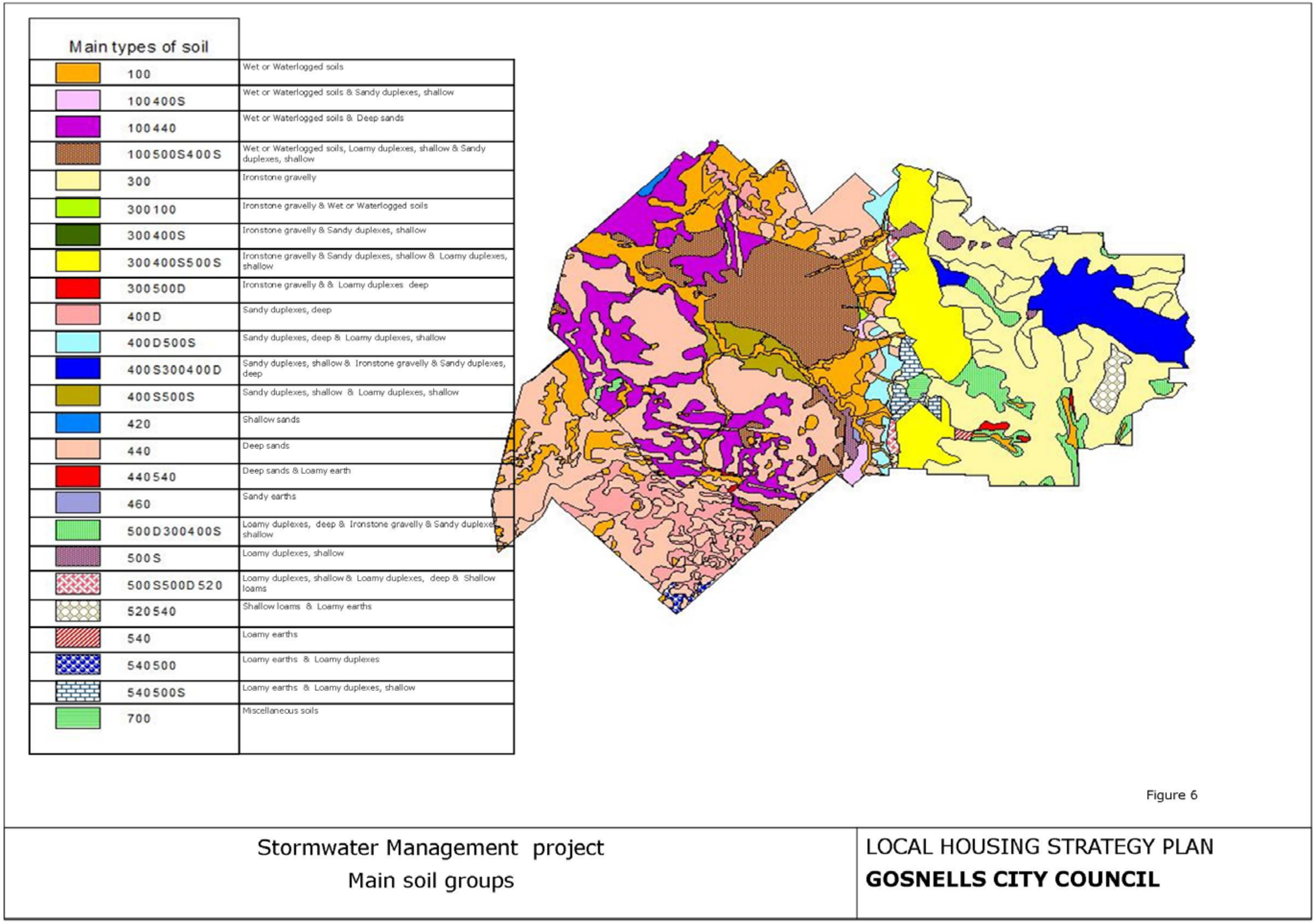


Figure 3:3 – Main soil Groups

Table 3:5 – Soil Groups in LHS

Referenced Notations	Composition of soil Supergroups							
	SGRPS1	**%**	**SGRPS2**	**%**	**SGRPS3**	**%**	**SGRPS4**	**%**
A	420	80	440	15	200	5		
B	440	100						
C	100	70	460	30				
D	100	30	500S	28	400S	27	400D	15
E	400S	30	500S	30	100	20	400D	20
F	500S	55	400S	25	400D	20		
G	100	40	440	34	400S	16	500S	5
H	100	52	440	25	540	23		
I	100	100						

Note - S – Shallow, D – Deep, SGRPS1 – Supergroups 1

3.5. Field test/Sampling locations

After carefully considering above key points in selecting of sampling points, initially 132 testing locations were selected covering all the 64 Local Housing Precincts.

Some soil types did cover very small numbers of samples (For an example, the samples 2, 3 and 1 have been identified for representing soil types A, C, F and I). As a result, it was proposed to conduct few additional samples within those areas and the approval was given by the City Council to carry out 14 numbers of additional samples in selected areas. Finally, 146 locations were selected as total sampling locations for onsite testing (Table 3:6).

Further, based on the suburb, the details of the selected sampling locations and the soil type have been given in Appendix A. Depending on the importance of the collected soil sample such that more sample from the large areas covered soils types, 89 sampling locations were selected to measure the permeability at 1.5 m levels in the laboratory (Table 3:7).

Table 3:6 – Sampling locations selected for onsite testing

Soil Type	No of sampling locations identified	Additional locations selected	Total
A	2	4	6
B	48		48
C	3	3	6
D	23		23
E	5	1	6
F	1	2	3
G	43		43
H	6	1	7
I	1	3	4
Total	132	14	146

Table 3:7 – Sampling locations selected for laboratory testing

Soil Type	No of sampling locations identified	Additional locations selected	Total Samples
A	2	4	6
B	24		24
C	3	3	6
D	13		13
E	5	1	6
F	1	2	3
G	20		20
H	6	1	7
I	1	3	4
Total	75	14	89

The permission has been taken from the property owners to carry out the testing in their lands by sending letters to each individual. Based on their feedback, the final work program has been prepared for testing. A housing precinct may have several different soil types with each soil type containing different amounts or percentages of a type of soil supergroups (Table 3:5). Therefore, as each soil type must be tested on, a housing precinct can sometimes have more than one soil test performed on it. Each soil test at each housing precinct has been provided with a number and where numbers are split by letters such as 4a or 4b, more than one soil tests has been performed on the same housing precinct for different soil types. The additional sampling points selected at later stage have been noted as A1, A2 based on their soil types. The details about the selected sampling points for each and every suburb have been provided in Appendix A. (see Figure A-1 to A-12)

3.6. Onsite testing of soil permeability

In this research, on-site investigation has been conducted to discover the levels of soil infiltration capacities (permeability), the basic soil profiles of top layers up to 1.5m deep. Also, visual inspection of soil profile is observed to re-confirm the soil type and understand the physical characterises of the soil profile. Some locations are selected to take the samples for laboratory testing of soil permeability.

The Guelph Permeameter kit was used as an on-site investigation tool to investigate field saturated hydraulic conductivity and 149 onsite permeability tests have been conducted at 1 m depth. A one man can operate, 100 mm diameter auger coupled with motor driven post hole digger was used to dig the hole up to the required depth of 1.5m and 89 undisturbed soil samples (70mm diameter, 152 mm height) have been collected by using the core sampler. The GPS coordinate will be recorded at each sampling points for the future mapping requirements. The collected soil samples were subjected to the following laboratory tests to determine soil texture, soil classification and soil permeability.

3.6.1. Guelph Permeameter

The Guelph Permeameter is an easy to use instrument to quickly and accurately measure in-situ hydraulic conductivity above the ground water in vertical wells (Reynolds & Elrick 1986). The application of a constant head through the use of a Mariotte siphon reservoir is in a vertical well result in a constant wetted surface area in the well. This elegant way of establishing the flow boundary condition facilitates collection of data on flow rate as a function of constant applied head. The Guelph Permeameter is capable of accurate evaluation of soil hydraulic conductivity, soil sorptivity and matrix flux potential can be made in all types of soils. The equipment can be transported, assembled, and operated easily by one person. Measurements can be made in 1/2 to 2 hours, depending on soil type, and require only about 2.5 liters of water (Rienzner & Gandolfi 2013).

The Guelph Permeameter is a breakthrough in the science of soil permeability allowing for multiple depths, multiple head heights all in the same bore hole (Figure 3:4). Measurements are based on both vertical (gravity) and lateral (capillary) flow from a point source of known head height forming saturated flow patterns as would be the case in nature (Corp 2008).

It is an easy to use instrument for quickly and accurately measuring in-situ hydraulic conductivity, generally less than 20 minutes where it used to take multiple hours in the past. These quick measurements, at various depths will provide efficiency of irrigation and drainage, optimizing the availability of water for plants, improving the yield of crops and minimizing erosion.

The stand included with the unit allows for easy setup and take down in a matter of minutes. The valve at the base of the reservoirs allows you to choose an inner (for very low flow soils) and larger outer reservoir capacity (for moderate and high flow soils) (CORP. 2010).

There are two methods called direct method and the indirect method to determine the field saturated conductivity (permeability) (Kfs) of the soil. The direct method which is the equation provided with the manual was used to calculate the Kfs. The detailed information regarding the method of calculations has been discussed later in this chapter.

Figure 3:4 – Guelph Permeability Kit

These are the steps used to perform the Guelph Permeameter test:

a) With an auger, choose a location and drill to the required depth. In this study, it was used depths of one meter. After drilling with the soil auger, use a bottled end piece called a sizing auger to retain a certain bore hole size all the way through the bore hole. Usually the hole is 5cm in diameter. Use the soil auger to excavate until most of the hand auger is underground, this should provide an excavate borehole of around 1m (Figure 3:5).

Figure 3:5 – Initial drilling of the hole for permeability testing using hand auger

With the help of a GPS (Global Positioning Satellite) device, record the longitude and latitude of the bore hole. Remove the stands from the Permeameter, and place the Permeameter in the bore hole. Make sure the cap seals the borehole on the ground surface, as this cap helps to collect any fallen water from the pouring stage (Figure 3:6).

Figure 3:6 – Installation of the Guelph Permeability Test Kit

b) Make sure the valve is closed before filling the reservoirs with water. This will ensure that no water enters the bore hole while the pouring stage has started. The well head scale at the top must also be closed.

c) Fill the outer and inner reservoirs with water. This can be done by removing the cap above the reservoir and pouring water through a funnel (Figure 3:7).

Figure 3:7 - Filling the outer and inner reservoirs

d) Make sure the dial is set so that either the inner reservoir or both reservoirs are used. With the gauge set to 6 o'clock, only the inner reservoir is being used. With the gauge set to 12 o'clock, both reservoirs can be used. As the inner reservoir is obviously smaller in diameter and can hold less capacity of water, the inner reservoir is used for soil locations with low permeability levels like clay. Set the gauge as required.

e) Slowly, release and lift the well head scale to the required head at the bottom of the Permeameter kit. This will determine the size of the opening, with which water will be released into the soil. The greater the head, the greater the volume of water to be released from the reservoir into the soil. In this investigation, initial falling head used was 5cm. (note: a head of 10cm is used further in the investigation)

f) Start timing as soon as the water drops to a unit of measurement comfortable to make calculations and collect as data. Write this whole number on recording sheet and the time interval being used to record results.

g) Selecting a time interval between results help us to collect accurate data. If water seems to be running quite quickly after time has started choose a 30 second time interval. If water is running slowly, choose a one minute time interval, or a time interval of a few minutes (i.e. 3minutes). Record this time interval on sheet. Judging what time intervals are needed such as 30seconds or 1minute, comes from experience. Start at 30seconds if unsure.

h) Continue to record, the water level until the difference of three set of results is the same. At this point, you may stop recording the water level and can end the investigation for that specific level of head. (I.e. if water level drops from 2cm to 5 cm to 8cm, every one minute, the difference between each reading is 3cm, hence the difference between the three set of results is the same, investigation can stop).

i) Repeat process in same borehole for a greater falling head. In this investigation, 10cm falling head was used to repeat the process.

The following flowchart well explains the basic testing procedure of the measuring soil permeability using the Guelph Permeameter

FLOW CHART OF PROCEDURE FOR STANDARDIZED METHOD OF MEASUREMENT USING THE GUELPH PERMEAMETER

SITE EVALUATION

↓

WELL HOLE PREPARATION

↓

ASSEMBLE PERMEAMETER

↓

FILL RESERVOIRS

↓

PLACE PERMEAMETER

↓

SELECT RESERVOIR

↙ ↘

RESERVOIR COMBINATION (FAST BUBBLING)	INNER RESERVOIR (SLOW BUBBLING)
SET H_1 = 5 cm DETERMINE $\overline{R_1}$	SET H_1 = 5 cm DETERMINE $\overline{R_1}$
↓	↓
SET H_2 = 10 cm DETERMINE $\overline{R_2}$	SET H_2 = 10 cm DETERMINE $\overline{R_2}$
↓	↓
CALCULATE $K_{fs} = (0.0041)(X)(\overline{R_2}) - (0.0054)(X)(\overline{R_1})$ $\phi_m = (0.0572)(X)(\overline{R_1}) - (0.0237)(X)(\overline{R_2})$	CALCULATE $K_{fs} = (0.0041)(Y)(\overline{R_2}) - (0.0054)(Y)(\overline{R_1})$ $\phi_m = (0.0572)(Y)(\overline{R_1}) - (0.0237)(Y)(\overline{R_2})$

Glossary

$\overline{R_1}, \overline{R_2}$	Steady State rate of fall corresponding to H1 and H2, respectively, and converted to cm/sec
K_{fs}	Field-saturated hydraulic conductivity (entrapped air present), in cm/sec.
ϕ_m	Metric flux potential in cm^2/sec

3.6.2. Water transmission theory and parameters (Guelph Permeameter)

As per the Guelph Permeameter theory, there are two methods called direct method and the indirect method to determine the field saturated hydraulic conductivity (permeability) (K_{fs}) of the soil. The direct method which is the equation provided with Guelph Permeameter manual was used to calculate the K_{fs}. The derivation of the K_{fs} is given below.

The transmission of water through unsaturated soil can be described by Darcy's law:

$$q = -k(\emptyset)\frac{\Delta H}{\Delta z} = -k(\cup)\frac{\partial H}{\partial z} \quad \ldots\ldots\ldots \quad (3:1)$$

Where

$$H = \Psi + z \quad \ldots\ldots\ldots \quad (3:2)$$

and $q[L^3L^{-2}T^{-1}]$ is the volume flux density of water (volume of water passing per unit time through a unit cross-sectional area of porous medium perpendicular to the direction of flow), $\delta H/\delta z$ $[LT^{-1}]$ is the hydraulic head gradient, $K(\theta)$ $[LT^{-1}]$ is the hydraulic conductivity (K) ver-sus volumetric water content (θ) relationship, $K(\Psi)$ $[LT^{-1}]$ is the hydraulic conductivity versus pore water pressure head relationship, H[L] is hydraulic head, Ψ [L] is pore water pressure head, and z [L] is elevation or gravitational head (positive upward).

When the porous medium is saturated,

$$K(\theta) = K(\Psi) = \text{constant} = Ks \quad \ldots\ldots\ldots \quad (3:3)$$

where K_s [LT^{-1}] is known as the saturated hydraulic conductivity. The K_s parameter is highly sensitive to porous medium texture and structure, and as a consequence, its value ranges from as high as 10^{-2} - 10^{-4} m s^{-1} in coarse-textured and/or highly structured or cracked soils, to as low as 10^{-8} - 10^{-10} m s^{-1} in compacted, structure less clay soils and landfill liners. When hydraulic conductivity is measured via ponded infiltration into initially unsaturated soil, it is often referred to as the "field-saturated" hydraulic conductivity, K_{fs}, as some amount of air is usually entrapped in the soil by the infiltrating water. This can result in $K_{fs} \leq K_s$, but it is often argued that K_{fs} is more appropriate than K_s because most natural and man-made infiltration processes result in entrapment of air in the soil.

Ponded infiltration ($\Psi \geq 0$) into initially unsaturated soil is affected not only by K_{fs}, but also by one of several parameters that derive from the $K(\Psi)$ relationship. To illustrate this, we can conveniently use the empirical $K(\Psi)$ function of Gardner (1958):

$$K(\Psi) = K_{fs} \exp[\alpha(\Psi-\Psi e)] ; 0 < \alpha < + ; \Psi < \Psi_e \leq 0 \qquad \text{……….. (3:4)}$$

$$K(\Psi) = K_{fs} ; \Psi \geq \Psi_e \qquad \text{………. (3:5)}$$

Where α [L^{-1}] is a slope parameter that depends primarily on soil texture and structure, and Ψ_e [L] is the air-entry or water-entry pressure head, depending on whether the soil is draining or wetting, respectively. Integrating equation (3:4) between $\Psi = \Psi_i$ and $\Psi = \Psi_e$ produces,

$$\emptyset_m = \int_{\Psi_i}^{\Psi_e} K(\Psi) d\Psi = \frac{K_S - K_i}{\alpha} \approx \frac{K_S}{\alpha^*} \qquad \text{……. (3:6)}$$

where Φ_m [$L^2 T^{-1}$] is the matric flux potential, Ψ_i L] is the initial or back-ground pore water pressure head in the unsaturated porous medium, and K_i [LT^{-1}] is the initial or background hydraulic conductivity corresponding to Ψ_i. The Φ_m parameter is an indicator of the capillary pull or "capillarity" exerted by the unsaturated porous medium on the water during an infiltration or drainage process. Under saturated conditions, $\varphi_m = 0$ because $K_i = K_s$ in equation (3:6).

In most natural unsaturated soils, we can assume that:

$$\alpha \approx \alpha^* \equiv \frac{K_{fs}}{\emptyset_m} = -\frac{1}{\Psi_f} =\downarrow \frac{1}{\Psi_f} \qquad \ldots\ldots \qquad (3:7)$$

where the macroscopic capillary length parameter, α* [L^{-1}], represents the ratio of gravity to capillarity forces during infiltration or drainage and Ψ_f [L] (negative in value) represents the effective wetting front pressure head of the Green-Ampt infiltration model (Green and Ampt, 1911). Large α* values indicate dominance of gravity over capillarity, which occurs primarily in coarse textured and/or highly structured porous media. Small α* on the other hand, indicate dominance of capillarity over gravity, which occurs primarily in fine textured and/or unstructured porous media. Although, K_{fs} and φ_m can individually range over many orders of magnitude in a porous medium, α* generally varies from about 0.01 cm^{-1} to 0.5 cm^{-1}. The reduced variability of α*, along with its connection to porous medium texture and structure, make it a useful parameter in simplified single-head analyses for estimation of K_{fs} and φ_m in unsaturated porous media (dis-cussed further below, and in Reynolds et al., 2002).

Sorptivity (S) is a measure of the ability of an unsaturated porous medium to absorb or store water as a result of capillarity. The S and φ_m parameters for one-dimensional flow under a constant head H are related by (White and Sully, 1987):

$$S_{H=\left\{\frac{(\Delta\theta)\emptyset m}{b} + 2(\Delta\theta)K_{fs}H\right\}}{}^{1/2} \qquad \ldots\ldots \qquad (3:8)$$

where Δθ = (θ_{fs} - θ_i), θ_{fs} (L^3 L^{-3}) is the field-saturated volumetric soil water content, θ_i (L^3 L^{-3}) is the initial volumetric soil water content, b is a dimensionless empirical constant, and H is the applied constant head of water. Setting b = 0.55 for infiltration gives an error of less than 10% in S_H. The first term in equation (3:8) gives the sorptivity, S_0, for H = 0 and the second term gives the increase in sorptivity due to the positive (ponded) head, H. Note that either φ_m or S or α* are needed along with K_{fs} to predict and characterize ponded infiltration into unsaturated porous media. Note also that under saturated conditions, S_H = 0 because Δθ = 0 in (7) (i.e. $\theta_i = \theta_{fs}$). See Elrick and Reynolds (1992a) for the equation to obtain S using the Guelph Permeameter.

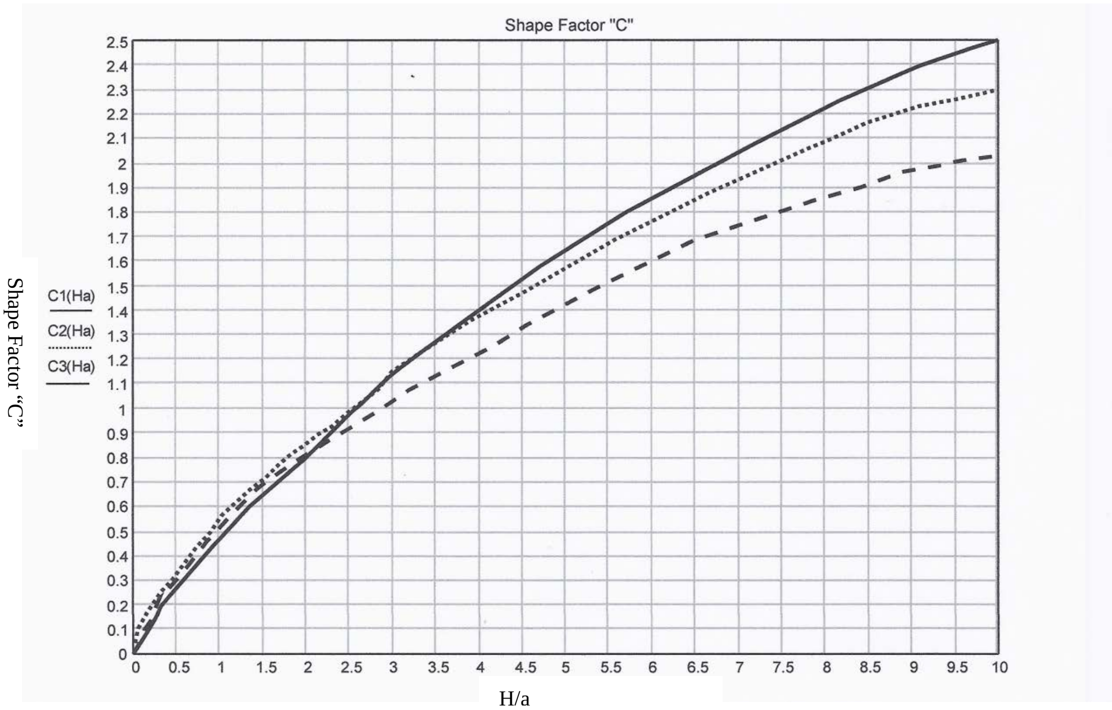
Governing Analytic Equations

The analysis of steady-state discharge from a cylindrical well in unsaturated soil, as measured by the Guelph Permeameter technique, accounts for all the forces that contribute to three-dimensional flow of water into soils: the hydraulic push of water into soil, the gravitational pull of liquid out through the bottom of the well, and the capillary "pull" of water out of the well into the surrounding soil.

Generalized Calculations – C- Factor

The C Factor is a numerically derived shape factor, which is dependent on the well radius and head H of water in the well. The Figure 3:8 below shows the "C" curves for three classes of soil. Empirical equations adapted from (Zang et al., 1998) were used to calculate the "C" values.

The upper curve, C1, is used for conditions where the estimated α* value is ≥ 0.12 cm-1, the middle curve, C2, for α* = 0.04 cm-1, and the lower curve, C3, for α* = 0.01 cm-1.



C1 (H/a) ▬▬▬	Sands	
C2 (H/a) …………	Structured loams and Clays	$[H = head\ height], [a = hole\ radius]$
C3 (H/a) ------------	Unstructured clays	

Source – Model 2800K1 Guelph Permeameter (Operating Instruction)

Figure 3:8 – "C" curves for the three classes of soil

"C" values can be read from Figure 3:8 or calculated directly from equations given below:

C1 = $\left(\dfrac{H/a}{2.074 + 0.093(H/a)}\right)^{0.754}$ C2 = $\left(\dfrac{H/a}{1.992 + 0.091(H/a)}\right)^{0.683}$

C3 = $\left(\dfrac{H/a}{2.081 + 0.121(H/a)}\right)^{0.672}$ ………………. 3:9

One-Head Analysis

$$K_{fs} = \frac{C_1 Q_1}{2\pi H_1^2 + \pi a^2 C_1 + 2\pi \dfrac{H_1}{\alpha^*}}$$ …………... 3:10

$$\phi_m = \frac{C_1 Q_1}{(2\pi H_1^2 + \pi a^2 C_1)\alpha^* + 2\pi H_1}$$ …………… 3:11

Where α^* is obtained from the site analysis and Table 3:8

Note that Q1 = XR1 or YR1, depending on whether the combination reservoir was used (X) or the inner reservoir was used (Y).

Two-Head Analysis

Kfs = $G_2Q_2 - G_1Q_1$

Where

$$G1 = \frac{H_2 C_1}{\pi\left(2H_1H_2(H_2 - H_1) + a^2(H_1C_2 - H_2C_1)\right)}$$ ……..…… 3:12

$$G2 = \frac{H_1 C_2}{\pi\left(2H_1H_2(H_2 - H_1) + a^2(H_1C_2 - H_2C_1)\right)}$$ ………..... 3:13

Note that Q1 = XR1 or YR1 and Q2 = XR2 or YR2.

$$\phi_m = G_3Q_1 - G_4Q_2$$ …………. 3:14

Where

$$\frac{(2H_2^2 + a^2C_2)C_1}{2\pi\left[2H_1H_2(H_2 - H_1) + a^2(H_1C_2 - H_2C_1)\right]}$$

G_3 = …..…… 3:15

$$G_4 = \frac{\left(2H_1^2 + a^2C_1\right)C_2}{2\pi\left[2H_1H_2\left(H_2 - H_1\right) + a^2\left(H_1C_2 - H_2C_1\right)\right]}$$ ………… 3:16

$$\alpha = K_{fs} / \Phi_m$$ …………… 3:17

Glossary

a	Well radius, in cm
C	Shape factor dependent primarily on the H/a ratio
C1,C2	C factor corresponding to H/a and $H_{2/a}$, respectively
GP	Guelph Permeameter
H1,H2	Well height for first and second measurements respectively, in cm
K	Hydraulic conductivity, in cm/sec.
K(Ψ)	Hydraulic conductivity/pressure-head relationship for unsaturated flow
K_{fs}	Field-saturated hydraulic conductivity (entrapped air present), in cm/sec.
R	Rate of fall of water in the Reservoir Tube of the Permeameter, in cm/min.
$\bar{R}$	Steady-state rate of fall
$\overline{R_1}$, $\overline{R_2}$	Steady State rate of fall corresponding to H1 and H2, respectively, and converted to cm/sec
S	Sorptivity, in cm/sec$^{1/2}$

α	Alpha Parameter, slope of the line relating the natural log of K, hydraulic conductivity, to Q, the soil water pressure head, in cm^{-1}
θ_i	Initial volumetric water content in the soil, in cm^3/cm^3
θ_{fs}	Field-saturated volumetric water content of the soil (entrapped air present), in cm^3/cm^3
ϕ_m	Metric flux potential in cm^2/sec
Ψ	Soil water pressure head, measured in cm of water.

The soil texture-structure categories for site-estimation of α* (adapted from Elrick et all., 1989) is given in Table 3:8 below.

Table 3:8 – Soil texture-structure categories for site-estimation of α*

Soil Texture – Structure Category	α* (cm^{-1})
Compacted, structures less, clayey silty materials such as land fill caps and liners, lacustrine or marine sediment, etc	1.01
Soils which are both both fine textured (clayey or silty) and unstructured, may also include some fine sands	0.04
Most structured soils from clays through loams also include unstructured medium and fine sands. The category most frequently applicable for agricultural	0.12
Coarse and gravelly sands, may also include some highly structured soils with large and/or numerous cracks, macropores etc	0.36

For an example, the test report for the sample 01 is given below.

FIELD TEST REPORT (GUELPH PERMEAMETER)
Stormwater Management Project

Date :-	3-May-10
LHS Area :-	Central Beckenham
Sample No :-	1
Dominant Soil Type(s) :-	G
Site Map(GPS) :-	X 401291
	Y 6456865

Investigator :- Dumal Kannangara

Testing method :- TWO HEAD ANALYSIS

Depth of the well hole :- 100 cm

Field Saturated Hydraulic Conductivity K_{fs} = 0.00056 cm/sec

Matric Flux Potential ϕ_m = 0.058069 cm^2/sec

Alpha Parameter α = 0.009650 cm^{-1}

3.6.3. Collection of undisturbed soil sample

Undisturbed soil samples are required especially for certain soil tests such as the permeability, hydrometer, liquid and plastic limit tests. The sieve analysis and particle size density tests only requires collecting the excavated soil, bagging and labelling them for ease of use later in the laboratory. Followings are the steps have been followed in order to collect the undisturbed soil samples:

1) Make sure all the parts of the drill bit of the machine auger is tightly fastened and that there is enough oil for the motor. Eyewear is not necessary but a good idea for your own safety from debris.

2) Place the machine auger over the existing excavated hole excavated from the Permeameter kit. Make sure the motor is turned on by pushing the power switch. Start the motor by pulling the ignition cord.

3) Start to pull the handle of the machine auger slowly to adjust to the torque which the machine auger generates while excavating. Tighten your grasp but do not push the auger into the ground while excavating as this may disrupt the soil trying to be collected. The self-weight of the machine auger should have enough force for the machine auger to drill into the earth. Steady the machine auger upright at all times.

4) Every so often, the machine auger will start to fill with excavated soil. If this soil is wet clay, a screw driver or some other object must be used to prize away the stuck soil from the machine auger drill catch. Dump the excavated material to the side of the borehole, not to close for dump material to re-enter borehole but not too far as excavated material needs to be close to re-fill the divot after sampling is finished (Figure 3:9, Figure 3:10).

Figure 3:9 - Fixing of extension bar

Figure 3:10 - Machine auger being used for excavation

5) Follow step 3 and 4, for as many times needed until the majority of the drill bit is submerged. Then proceed to change the drill bit by adding on

6) An extension of another 300mm. The reason for not using the extension from the start is that at a full 1.5m height with extension, the machine auger is uncontrollable as your arms would be raised around shoulder height. It is only controllable at waist or as high as chest height, which

means that drilling to a depth of 1.5m and collect undisturbed soil samples is not an easy task.

Figure 3:11 - Marking out 15cm for depth of cylinder to collect sample

7) When drill bit with extension is totally submerged remove machine auger and have the hammer and soil collector setup and installed.

8) Label the plastic sample cylinder where the undisturbed sample will be collected. Make sure the collector and the cylinder is clean with no traces of other material.

9) Before hammering, mark out the depth to show when the hammer should stop for the 15cm cylinder be full with its sample. To achieve this, take a screw driver to mark out the surface level across the 4inch borehole. Than measure up the hammer 15cm and mark it with a pen. When the mark is in line with the screw driver, the soil collector should have been hammered 15cm into the ground, resulting in the cylinder collecting 15cm worth of sample (Figure 3:11).

Figure 3:12 - Collecting the sample by hammering

10) Hold the hammer upright and force the collector down into the ground. Stop until the marked line is in line with the screw driver (Figure 3:12).

11) Remove the hammer extension and screw on the handle. Depending on the soil condition, pulling out the sample collector was easy and hard. If it is a clayey soil, used wooden blocks and set up a stable structure with a car’s wheel jack to sit on top. This will help to remove the soil collector. In especially clay, the collector is quite hard to remove after hammering due to all the pressure acting on the collector. Even with two men, trying to pull the handle and remove the soil collector was difficult. Hence a car wheel jack was used to slowly apply force to remove the soil collector. As the wheel jack is short, wooden blocks were used as the foundations of the jack as to apply force on the blocks when the jack was turned, while having a resultant force on the handle pushing it up and pulling the soil sample (Figure 3:13).

Figure 3:13 – Collecting a sample in clayey soil condition

Figure 3:14 – Collected undisturbed soil sample

12) The collected undisturbed soil samples were directly used for permeability testing at the laboratory. The Figure 3:14 shows the pictures taken of the samples immediately after measuring the permeability and the saturated weight. After measuring the fully saturated weight of the sample, soil sample were oven dried. Based on the Australian standard procedures, these soil samples were then separated in to smaller samples for future testing such as sieve analysis,

atterberg limits, particle density and the hydrometer tests. They were put in different bags and be labelled based on certain criteria needed for the laboratory tests, as shown in the picture below (Figure 3:15).

Figure 3:15 – Separated samples future laboratory testings

The pictures of the samples which are collected on site are shown in Figure B-1 under the Appendix B. These pictures were taken just after completing the falling head permeability text at the laboratory.

3.7. Laboratory Testings

In the laboratory, specific tests were chosen to provide insight on soil properties related to soil permeability, soil texture and soil structure. Introductions and methodologies of experiments such as the sieve analysis and hydrometer tests have also been included to also demonstrate other techniques to find soil structure and permeability.

Two types of tests are routinely performed on soils to determine its permeability:

1) **Constant Head Permeability Test** is performed on sands as the pore openings are large and hence high permeability (k >10-4 cm/s). Some of its applications are to calculate the seepage through earth dams,

embankments of canals, under sheet pile walls and estimate settlement in foundations and slope stability analysis (Texas 2010)

2) **Falling head Permeability Test** is performed on clays as the pore openings are small and hence low permeability (k <10-4 cm/s). It applies to settlements in structures above clay, methods for lowering water table, soil stabilization and design of recharge pits. The soil sample is first saturated under a specific head condition. The water is then allowed to flow through the soil without maintaining a constant pressure head.

Due to the nature of the soil tested on site, the falling head method was used at the laboratory scale to find the saturated hydraulic conductivity.

3.7.1. Falling head method

These following steps are to be completed for the falling head permeability test (Fullerton, 2008). The setup of the falling head Permeameter which was used for laboratory testing is shown in Figure 3:16.

1) The entire system, including the porous stones and tubing, must be saturated prior to the test. This can be done by forcing water through the system and allowing the apparatus to stand full of water for a while just before inserting the specimen.

2) If the cross-sectional area of the standpipe is not known, it must be measured. This is easily completed by weighing the amount of distilled water contained in a known length of tube. The mass of the water in grams is equal to the volume in ml. From these data, the area and diameter can be computed readily.

3) Measure the diameter and length of the sample. The cross sectional area can then be easily calculated using the simple area of a cylinder equation.

4) Place soil ring and specimen on bottom porous stone. Slide consolidometer over soil ring, then place the upper plate and fasten securely.

5) Insert top porous stone which applies some pressure in kPa. Record initial dial reading at time of zero seconds, to measure height change due to increasing load increments and pressure.

6) Close the bleeding valve at base of apparatus, this will allow air bubbles to be flushed out the system.

7) Now record initial dial reading and then apply the load. Than record the final dial reading.

8) Fill the standpipe, and record the height of the water in the tube, h_0.

9) Release the quick acting flow valve and the test is progressed. Record the height differences at time intervals pre-selected and not the other way around.

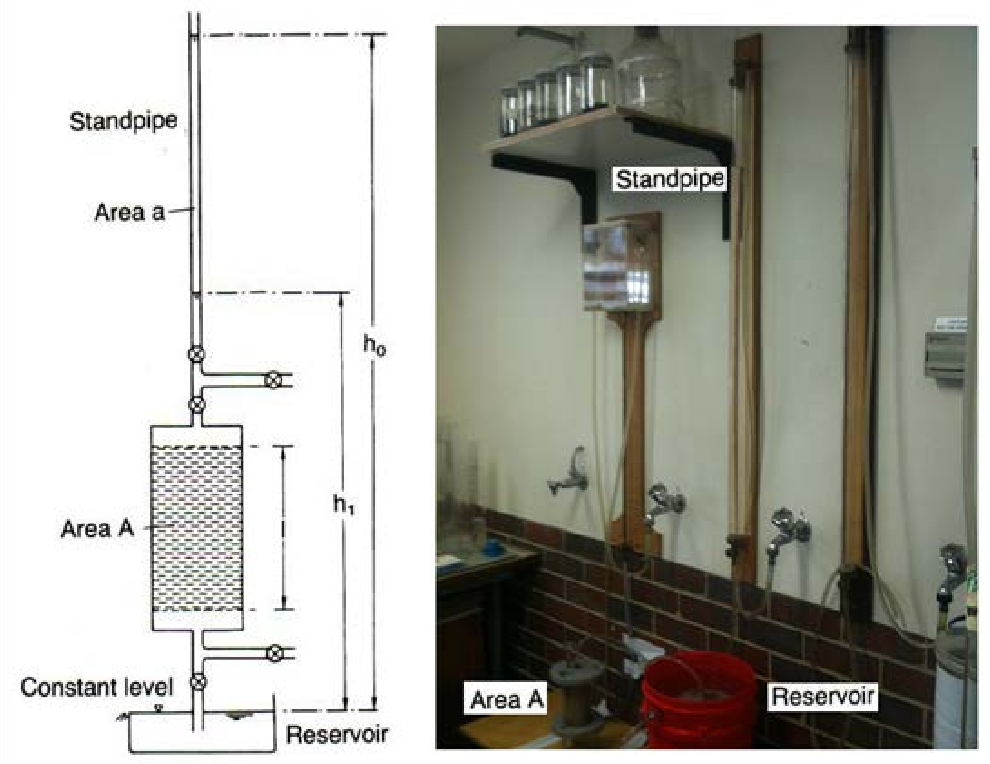


Figure 3:16- Falling Head Permeability Test

3.7.2. Particle size distribution test

The Sieve analysis test is used to determine the distribution of different grain size aspects of the engineering properties of a soil. For particles sizes less than 75μm, the sedimentation method, using the hydrometer have to be used. This analysis provides the grain distribution which is required for classifying the soil. Furthermore, the size distribution is usually of critical importance to the way a material behaves when used. Before performing the sieve analysis, the material has to be sufficiently dry so that it can pass through the set of sieves without clogging them. These are the equipment which will be required for this test (Figure 3:17)

- Balance
- Set of sieves of different sizes
- Sieve Brush
- Mechanical Sieve Shaker
- Trays

These are the steps to perform the Sieve analysis test: Coarse Sieving

1) Obtain by riffling or quartering, a representative sample of soil of mass dependent on the size of the largest particles present in the sample.
2) Oven-dry the soil and obtain its mass (m_1).
3) If the sample contains silt or clay, rub it vigorously to break any lumps.
4) Place the sample on the top sieve (the largest) of a nest of sieves down to 2.36 mm, the nest is placed in the mechanical shaker to vibrate for about 10 minutes till the mass of soil remaining on each sieve reaches a constant value.
5) The mass of soil retained on each sieve is measured from which the percentage of soil retained on each sieve is calculated. The mass of the soil passing the sieve 2.36 mm is also recorded (m_2).

6) The cumulative percentages retained on each sieve are calculated by addition of all individual percentages retained on that sieve and on all larger sieves.

7) The percentage passing each sieve is calculated as the difference between the cumulative percentage retained and 100%.

8) The percentages of soil passing through given sieves are then plotted on the semi-log graph provided against the corresponding sieve sizes.

Fine Sieving

Figure 3:17 - Sieve Analysis step by step test procedure

1) From the result of the coarse sieving, calculate the correction factor, F, for the fine sieving as follows:

$$F = \frac{m_2}{m_1} \qquad (3:18)$$

2) Mix the material passing the sieve 2.36 mm and obtain a representative sample, m_3, by riffling or quartering.

3) From the same material, obtain a second representative sample, m4, for the hydrometer test.

4) Wash the soil sample through the 0.075 mm sieve until the wash is clear.

5) Transfer the material retained on the 0.075 mm sieve to drying dish and oven dry the soil.

6) When the dried sample is cool, sieve it through sieves from 2.36 mm down to 0.075 mm for 10 minutes in the mechanical shaker.

7) Record the mass of material retained on each sieve, calculate % retained on each sieve and cumulative % retained and passing. Correct the calculation by multiplying by the factor F determined above.

8) Continue plot % passing versus sieve size on the semi-log graph from 2.36 mm onwards.

3.7.3. Particle size density and water absorption test

The Pycnometer bottle method is used to determine the particle density of a coarse-grained soil (retained on the 2.36 mm sieve).

These are the steps to perform the particle density test:

1) Immerse the test portion in water at room temperature for a period of not less than 24h. Remove the air entrapped in the aggregate by gentle agitation with a rod until no air bubbles rise to the surface.

2) Drain the water off the test portion and spread the aggregate on a flat impervious surface.

3) Surfaces dry the aggregate by exposing in to gently moving current of warm air. When the aggregate appears to be free flowing, fill the conical mould by loosely placing part of the test portion in it. Tamp the surface of the aggregate with the tamping tool 25 times.

4) Continue drying with constant stirring and retest at frequent interval using the procedure in steps (3) until the cone of aggregate slumps on removal of the mould. Slumping of the aggregate cone indicates that it has reached a saturated surface dry condition.

5) Immediately after the saturated surface-dry condition has been achieved, determine the mass (m_2) of the total test portion.

6) Place the test portion into the volumetric pycnometer. Fill to the 500ml mark. Determine the mass (m_3) of the flask and its contents.

7) Dry the aggregate in an oven at 105^oC to 110 ^oC to constant mass. Determine the mass (m_1) of dry aggregate.

8) Fill the flask with water at the same temperature as that measured in step (6) and determine the mass (m_4) of the filled flask.

9) Calculate the apparent particle density (ρ_a), particle density on a dry basis (ρ_{bd}), particle density on a saturated surface-dry basis (ρ_{bs}) and water absorption (w_a) of the aggregate from the following equations.

$$\rho_a = \frac{m_1 \times \rho_w}{m_4 + m_1 - m_3} \quad \text{………………} \quad (3:19)$$

$$\sigma_{bd} = \frac{m_1 \times \rho_w}{m_4 + m_2 - m_3} \quad \text{……………} \quad (3:20)$$

$$\rho_{bs} = \frac{m_2 \times \rho_w}{m_4 + m_2 - m_3} \quad \text{……………} \quad (3:21)$$

$$w_a = \frac{(m_2 - m_1) \times 100}{m_1} \quad \text{……………..} \quad (3:22)$$

Where ;

ρ_a = the apparent particle density

ρ_{bd} = the particle density on dry basis

ρ_{bs} = the particle density on saturated surface dry basis

w_a = the water absorption

m_1 = the dry mass of the test portion in grams

m_2 = the dry mass of the saturated surf-dry test portion in grams

m_3 = the mass of the flask filled with water and the test portion in grams

m_4 = the mass of the flask filled with water in grams

ρ_w = the density of water at the test temperature in grams

3.7.4. Soil Compaction – Dry density/moisture content and modified compaction test

The following procedure was conducted in accordance with the AS 1289.5.1.1-2003.

1) Prepare the sample in accordance with AS 1289.1.1

2) Split out four representative portions of the sieved soil, each of sufficient quantity to produce a compacted volume in excess of the volume of the mould.

3) Thoroughly mix each portion, adding water little by little so that the optimum moisture content is judged. Use essentially equal increments of moisture between portions and ensure that the moisture steps are not excessive for the soil type.

4) Allow the soil portions to cure for an appropriate time for the soil type and record the time of curing

5) Determine the mass (m_1) of the cleaned mould, plus baseplate. Then assemble the mould, collar and base plate and place the assembly on the rigid foundation

6) Take the portion of the soil, mix it thoroughly and compact it into mould in three layers. Compact each layer by uniformly distributed blows of the rammer falling freely from a height of 300mm.

7) Free the material from around the inside of the collar and then carefully remove the collar. Trim the surface of the specimen while the mould is still attached to the baseplate.

8) Determine the mass (m_2) of the mould and soil, with baseplate. Immediately remove the specimen from the mould, use a sample to determine the moisture content (w) of this sample in accordance with AS 1289.2.1.5.

9) Repeat the steps for the other portions of prepared soil to obtain at least four points, at least two of which must be dryer, and one wetter than optimum moisture content relation.

10) Calculate the density of wet soil (1), density of dry soil (2) and points for the chosen air voids line from the soil particle density

$$\rho = \left(\frac{m_2 - m_1}{V}\right) \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(3:23)}$$

$$\rho_d = \frac{100\rho}{100 + w} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(3:24)}$$

$$\rho_d = \frac{1 - V_a/100}{1/\rho_s + w/100} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(3:25)}$$

Where ρ = density of wet soil, in tonnes per cubic meter

ρ_d= density of dry soil, in tonnes per cubic meter

m_2= mass of the mould plus baseplate plus specimen, in grams

m_1= mass of the mould plus baseplate, in grams

V = measured volume of the mould, in cubic centimetres

w = moisture content of the specimen, in percent

ρ_s= soil particle density, in tonnes per cubic meter

3.8. Measuring the groundwater level during the onsite permeability test

As the groundwater table has direct relationship with the infiltration based stormwater management techniques, the variation of the groundwater table of the study area has monitored throughout the year especially during the rainy season. The existing bores located within the study area were used for data collection and the past data which has been collected by Department of Water (DoW) was considered in getting the maximum groundwater level. The methodology which was used in measuring the groundwater table at various bore holes across the City of Gosnells as follows:

1) Locate the borehole, and open the inlet box. Most of the inlet boxes require the use of spanners and wrenches to unscrew the plate (Figure 3:18 and Figure 3:19)

Figure 3:18- Common boreholes with inlet box

Figure 3:19- Inlet box

2) Remove all the contents of the inlet box and locate the inlet hole. Make sure the hole is empty and nothing is blocking it (Figure 3:20).

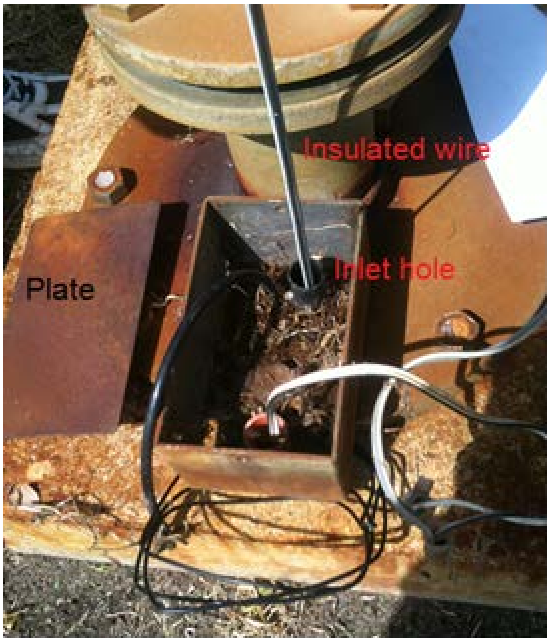


Figure 3:20 - Measuring groundwater levels

Figure 3:21 - Groundwater measuring instrument

3) Unravel the ammeter and its insulated wire and probes.

4) Set the ammeter to measure current in amps. Measuring the actual amps is not the main goal, however seeing current pass will mean there is a

circuit and that the probes have created a circuit with water acting as a conductor. When water is present acting as a conductor, this is the groundwater table and the height the prods have dropped from the height of the bore at the ground surface, will act as the height for the groundwater table.

5) Figure 3:21 - Insulated wires being lowered into the inlet hole.

6) Carefully lower down both positive (red) and negative (black) insulated wire, with one sitting and inch above the other. Weights can be used as well to make lowering the probes easier, although it is difficult to add weights as the inlet hole is so small and just managing to insert the probes is difficult enough.

7) Watch the ammeter, and stop lowering the probes as soon as a reading can be seen appearing on the ammeter gauge.

8) Be careful to not lose the spot at the borehole where the ammeter picked up a current. This is best done by marking that spot as to not forget the length of the insulated wire needed to measure.

9) Pull the insulated wire and probes up and with a measuring tape, measure from probe to the mark. This length will be the height of the groundwater table.

CHAPTER 4

4 GEOTECHNICAL ASSESSMENT OF SOIL PERMEABILITY IN RESIDENTIAL LAND DEVELOPMENT PROCESS WITH RESPECT TO THE STORMWATER MANAGEMENT

4.1. Introduction

The main factors affecting the performance of the infiltration based stormwater management systems are permeability of different soil layers and depth to the groundwater table. Due to lack of information on local soil properties, specifically permeability rates within the soils predominant in the areas, it is difficult to accurately assess stormwater retention/detention requirements without on-site soil testing of the targeting areas. Therefore, it is essential to identify the relationship between soil permeability and local soil properties and develop a more generalised solution for interpretation of the soil characteristics pertaining to on-site disposal or detention of stormwater runoff. This would support land development with guidance on the implementation of drainage strategies based on basic underlying parameters. This chapter mainly focuses on the validation of both onsite and laboratory permeability test results including the groundwater monitoring records, compare this to the available secondary data and identifying of suitable soil types and the suitable land areas for infiltration based stormwater management. At the end, a data inventory of soil permeability of selected land development areas are developed for use as the key input for the selection of best stormwater management strategies.

4.2. Saturated Hydraulic Conductivity at 1m level (Results obtained from Guelph Permeameter)

The onsite permeability test was conducted at selected field test sites and the results of the permeability values were recorded for each location. All the onsite permeability test results are summarized in

Table 4:1 to Table 4:12. The values in tables are recorded in (m/day) in each LHS suburb.

Table 4:1 – Onsite Permeability - Central Beckenham

Sample No	Field Saturated Hydraulic Conductivity (at 1 m level) Kfs (m/day)		
	Address	Soil Type	Hydraulic Conductivity
1	13, (Lot 101), Central Terrace	G	0.48
2	21, Mona Aona Avenue	G	0.01
3	113, Bickley Road	G	4.12
4a	21, Temby Street	A	0.00
4b	115 (Lot 87), William Street	G	0.00
4c	97, William Street	G	0.31
5a	30, Wickling Drive	H	0.26
5b	150(L0t 9), Bickley Road	G	3.06
6a	11, (Lot 58) Sullivan Street	G	5.54
6b	6 Lot 187), Carmichael Street	H	1.11
7a	424, Railway Parade	G	0.09
7b	424, Railway Parade	H	0.18
7c	Lot 85, Streatham Street	H	0.00
7d	Lot 85, Streatham Street	G	0.00
10b	66 (Lot 43), Dulwich Street	H	0.31
8	459, Sevenoake Street	G	0.00
A1	32, Temby Street	A	7.28
A2	13, Temby Street	A	3.24
A3	14, Lacey Street	A	4.21
H1	34, Wickling Drive	H	0.00

Table 4:2 - Onsite Permeability - Central Maddington

Sample No	Field Saturated Hydraulic Conductivity (at 1 m level) Kfs (m/day)		
	Address	Soil Type	Hydraulic Conductivity
27	61(Lot 167), Helm Street	D	0.00
28	5, Cedar Way	D	0.00
29	9(Lot 514), Conifer Street	D	0.29
30	2008(Lot 17), Albany Hwy	D	0.02
55	7 (Lot 26), Pitchford Avenue	D	0.29

Table 4:3– Onsite Permeability - Kenwick

Sample No	Field Saturated Hydraulic Conductivity (at 1 m level) Kfs (m/day)		
	Address	Soil Type	Hydraulic Conductivity
18a	17, (Lot 32) Dudley Road	G	0.00
18b	10 (Lot 13), Dudley Road	G	0.00
19a	31, Rayal Street	D	0.18
19b	27, Rayal Street	G	0.04
19c	27, Rayal Street	I	0.36
20a	44, (Lot 39,38), Wanaping Road	D	0.88
20b	14(Lot 21), Kenwick Road	G	0.12
21a	31 (Lot 2), Kenwick Road	G	0.00
21b	17, (Lot 33), Kenwick Road	G	0.09
22a	35, (Lot 19), Belmont Road	B	1.58
22b	43, Belmont Road	B	1.56
23a	93(Lot 600), Kenwick Road	B	0.11
23b	75, (Lot 5), Kenwick Road	G	0.00
24a	84, Belmont Road	B	3.24
24b	26, (Lot 301), Lalor Road	G	0.00
25a	Park next to 19 Gaskin road	G	0.00
25b	54 (Lot7), Belmont Road	B	4.11
25c	8, Duketon Way	G	0.10
26a	83, Belmont Road	B	2.52
26b	13 (Lot 58), Denford Street	G	2.32
26c	9 (Lot 56), Denford Street	B	0.00
I1	17, Royal Street	I	0.00

Table 4:4– Onsite Permeability - North Gosnells

Sample No	Field Saturated Hydraulic Conductivity (at 1 m level) Kfs (m/day)		
	Address	Soil Type	Hydraulic Conductivity
41	154 (Lot 49), Fremantle Road	B	9.40
42a	1, Hillegine Court	E	0.31
42b	116 (Lot 41), Fremantle Road	B	2.59
43	4 (Lot 20), Ailby Street	B	2.85
44	48 (Lot 156), Blanche Street	B	2.48
45a	44 (Lot 660), Terence Street	B	5.10
45b	63, Terence Street	G	0.10
46a	230 (Lot 1013), Hicks Street	B	2.44
46b	3 (Lot 11), Vera Street	F	0.00
46c	8 (Lot 58), Thursley Way	D	5.10
47a	4, Broadley Place	D	4.85
47b	12 (Lot 11), Harold Street	B	4.53
48a	2, Eileen Street	D	0.00
48b	6 (Lot 56), Eileen Street	B	0.13
48c	27 (Lot 52), Seaforth Avenue	F	0.19
49a	10 (Lot 74), Corbett street	B	2.19
49b	85 (Lot 24), James Street	B	5.54
50a	8 (Lot 7), Bexley Street	B	0.74
50b	5, Ecton Street	G	0.33
57a	135 (Lot 1) Dorothy Street	B	0.65
57b	170 (Lot 1101), Corfield Street	G	0.77
58	194 (Lot 11), Corfield Street	B	5.53
59a	40 (Lot 16), Digby Street	G	0.59
59b	5, Belyea Street	B	4.28
60a	15 (Lot 16), Trent Street	B	2.06
60b	106 (Lot 40), Walter street	G	11.64
61a	19, Digby Street	B	2.85
61b	7 (Lot 61), Mackay Cresent	G	1.53
F1	120, Astley Street	F	1.16
F2	29, Seaforth Avenue	F	1.45
E1	3, Mimy Court	E	0.22

Table 4:5– Onsite Permeability - Landford

Sample No	Field Saturated Hydraulic Conductivity (at 1 m level) Kfs (m/day)		
	Address	Soil Type	Hydraulic Conductivity
15a	17(Lot 285) Turley Way	B	4.28
15b	52, Langford Avenue	G	2.63
16a	5 (Lot 619) Simons Court	B	1.95
16b	2, Mudlark Close (Lot 300) Choseley Place	B	9.11
17	29, Langford Avenue	B	6.18

Table 4:6– Onsite Permeability - North Huntingdale

Sample No	Field Saturated Hydraulic Conductivity (at 1 m level) Kfs (m/day)		
	Address	Soil Type	Hydraulic Conductivity
53a	Nethercott Street	B	2.29
53b	21 (Lot 31), Mildenhall Street	B	0.63
54a	44 (Lot 8), Warton Road	B	4.72
54b	17 (Lot 10), Matilda Street	B	3.34

Table 4:7– Onsite Permeability - South Thornlie

Sample No	Field Saturated Hydraulic Conductivity (at 1 m level) Kfs (m/day)		
	Address	Soil Type	Hydraulic Conductivity
40a	19 (Lot 84), Argyle Court	G	2.34
40b	16, Hampton Court	G	6.47
40c	13 (Lot 87), Argyle Court	B	9.11

Table 4:8– Onsite Permeability - Outer Beckenham

Sample No	Field Saturated Hydraulic Conductivity (at 1 m level) Kfs (m/day)		
	Address	Soil Type	Hydraulic Conductivity
10a	16, (Lot 150) Faversham Street	G	0.00
11a	20 (Lot 445), Tooting Street	G	0.05
11b	13(Lot 158), Lunar Way	H	0.07
12a	74, Streatham Street	H	4.11
12b	6, Lowth Road	G	0.77
13a	131(Lot 51), Ladywell Street	G	0.00
13b	133(Lot 52), Ladywell Street	G	0.03
14a	27 (Lot 29), Highbury Crescent	C	0.00
14b	9 or 7, Highbury Crescent	G	0.00
9a	11 (Lot 105), Celebration Street	A	6.70
9b	26 (Lot 233), Jubilee Street	G	0.16
A4	88, Lacey Street	A	6.47
C1	40, Highbury Cresent	C	0.27

Table 4:9– Onsite Permeability - Thornlie West

Sample No	Field Saturated Hydraulic Conductivity (at 1 m level) Kfs (m/day)		
	Address	Soil Type	Hydraulic Conductivity
37	11 (Lot 212),Debenham Street	B	3.41
38	54, Yale Road	B	12.74
39	305 (Lot 151) , Spencer Road	B	2.23
64	7 (Lot 160), Kidman Court	B	7.07

Table 4:10– Onsite Permeability - South Gosnells

Sample No	Field Saturated Hydraulic Conductivity (at 1 m level) Kfs (m/day)		
	Address	Soil Type	Hydraulic Conductivity
51a	59 (Lot 4) Stennett Street	G	0.35
51b	33, Oakover Way	B	1.14
51c	54 (Lot 8), Kelleman Way	I	4.85
52a	9, Frankland Court	B	7.14
52b	49 (Lot 248), Ashburton Drive	G	0.07
52c	1, Nullagine Way	D	0.56
62a	40, Astinal Drive	G	1.85
62b	9, Dionne Place	D	1.36
62c	20 (Lot 248), Isdell Place	D	1.60
63a	181 (Lot 28), Corfield Street	G	1.03
63b	3 (Lot 49), Suthern River Road	B	0.33
63c	177, Corfild Street	D	0.44
I2	89, Ashbarton Drive (Ground)	I	0.02
I3	91, Ashbarton Drive (Ground)	I	0.01

Table 4:11– Onsite Permeability - Thornlie East

Sample No	Field Saturated Hydraulic Conductivity (at 1 m level) Kfs (m/day)		
	Address	Soil type	Hydraulic Conductivity
31a	17, Southdown Place	C	0.22
31b	24, Southdown Place	G	1.60
31c	14 (Lot 7), Southdown Place	B	7.24
32a	2, O’Dell Street	B	15.70
32b	8, Banksia Circle	B	2.42
33	306, Spencer Road	B	3.13
34	12, Malvin Ave	B	0.28
35	1(Lot 1870), Camberley Street	B	1.96
36	13 (Lot 491), Burnley Street	B	2.32
56	32A (SP Lot 2), Yale Road	B	10.65

Table 4:12– Onsite Permeability - Central Maddington (ODP)

Sample No	Field Saturated Hydraulic Conductivity (at 1 m level) Kfs (m/day)		
	Address	Soil Type	Hydraulic Conductivity
65a	7 Rand Street	E	0.77
65b	95, Attfield Street	D	0.01
66	51b, Orr Street	D	0.47
67a	19, Dellavanzo	E	0.00
67b	111, Attfield Street	D	0.37
68a	38, River Avenue	E	0.17
68b	30, River Avenue	C	0.11
69a	6, River Avenue	E	0.34
69b	9, Cowan Street	D	0.88
70	21, Kelvin Road	D	0.01
71	41 or 43, Kelvin Road	D	0.00
72	27, Weston Street	D	0.00
73	32, The Crescent	D	0.00
C2	34, River Avenue	C	0.23
C3	14, River Avenue	C	0.21

4.3. Saturated hydraulic conductivity at 1.5m level (Results obtained from the Falling head permeability tests)

The collected undisturbed soil samples were subjected to a series of laboratory test. 89 undisturbed soil samples were collected from the selected location out of 146 sampling locations. The falling head method calculation was used. The falling head calculation were analysed using a self-developed Microsoft Excel spread sheet. Other data required and recorded for the calculation are diameters of the sample, length of sample, cross sectional area of the sample cross sectional areas of the standpipe and height of datum of scale above water. Then the readings of the water level for each time interval were recorded against pressure head (Table 4:13).

Table 4:13 – Permeability calculation - Falling Head Method

Date	19-Aug-10	Investigator :-	Dumal Kannangarra
LHS Area	Langford		
Sample No	15b		
Dominant Soil Type	G		

PERMEABILITY TEST
(FALLING HEAD METHOD)

Diameter of the Sample	7.325	cm
Length of the Sample	14.4	cm
Cross sectional area of the stand pipe	7.1	cm^2
Height of the datum of the scale above tail water	37.5	cm
Cross sectional area of the sample	42.16	cm^2

Time/ (S)	Reading / (cm)	Pressure head (cm) (H)	log_e (H)
0	100	137.5	4.92
5	100	137.5	4.92
10	99.6	137.1	4.92
20	99.5	137	4.92
40	99	136.5	4.92
60	98.4	135.9	4.91
120	96.8	134.3	4.90

The readings are then used to plot a graph of time versus the logarithm of the pressure head (H) as shown in Figure 4:1. The gradient of this line is needed to be used an equation where:

$$\text{Hydraulic Conductivity, Kfs (cm/sec)} = \frac{\text{(Length of sample*Cs of Standpipe)}}{\text{(Kgradient * Cs of Sample)}}$$

Cs - Cross Section area

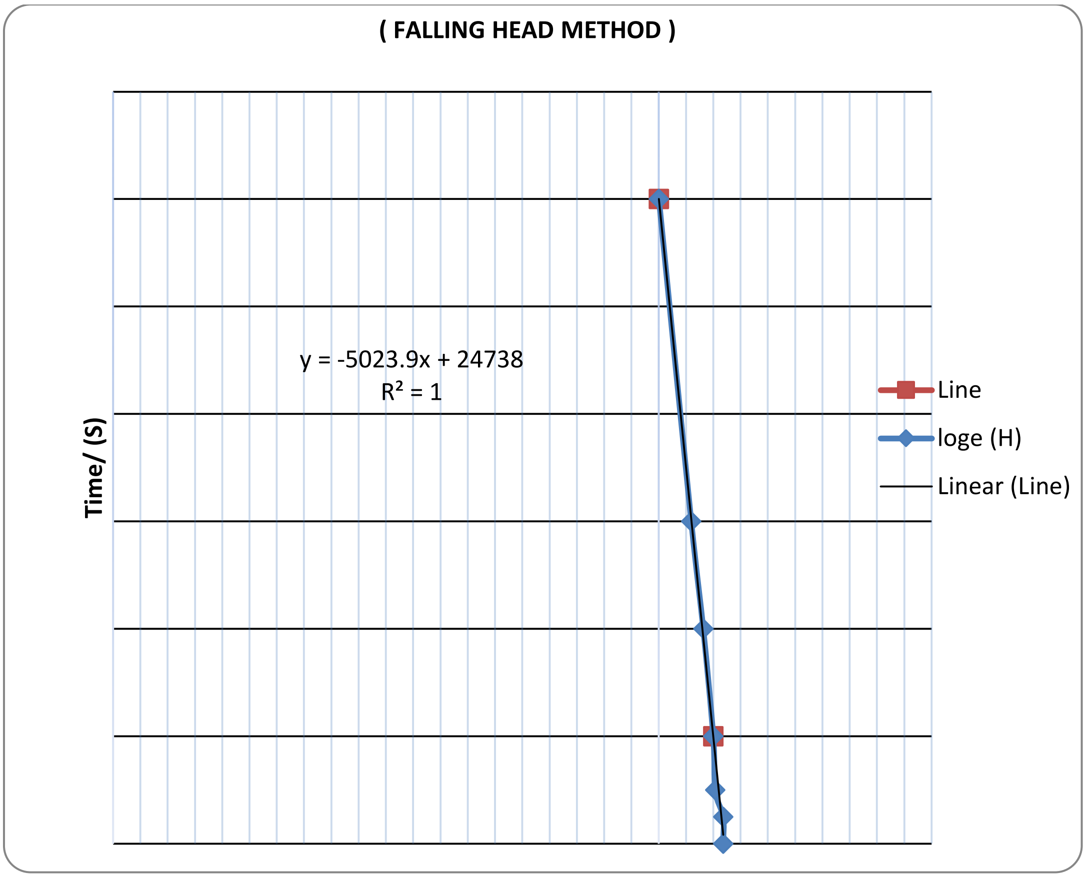


Figure 4:1 - Falling Head Method – Graph of Sample 15b

The gradient of the graph = - 5023

By substituting the gradient value in above equation

Hydraulic Conductivity, K_{fs} (cm/sec) = 0.0004828 cm/s

As an example, the test report for the sample 15b is given below.

LABORATORY TEST REPORT (FALLING HEAD METHOD)
Stormwater Management Project

Date	19-Aug-10	Investigator	Dumal Kannangara
LHS Area	Landford		
Sample No	15b		
Dominant Soil Type(s)	G		
Site Map(GPS)	X 399902		
	Y 6454339		

Length of the sample 14.4 cm

Saturated Hydraulic Conductivity Kfs = 0.0004828 cm/sec

All the laboratory permeability test results were summarized in Table 4:14 to Table 4:24. The hydraulic conductivity values in the tables are recorded in (m/day).

Table 4:14 – Permeability measured at laboratory - Kenwick

Sample No	Saturated Hydraulic Conductivity (at 1.5 m level) K_s (m/day)		
	Address	Soil type	Hydraulic Conductivity
18b	10 (Lot 13), Dudley Road	G	0.03
19c	27, Rayal Street	I	20.05
20a	44, (Lot 39,38), Wanaping Road	D	4.82
22a	35, (Lot 19), Belmont Road	B	7.35
26a	83, Belmont Road	B	10.76
I1	17, Royal Street	I	0.13

Table 4:15 – Permeability measured at laboratory - Central Beckenham

Sample No	Saturated Hydraulic Conductivity (at 1.5 m level) Ks (m/day)		
	Address	Soil type	Hydraulic Conductivity
1	13, (Lot 101), Central Terrace	G	0.01
2	21, Mona Aona Avenue	G	0.04
3	113, Bickley Road	G	0.03
4a	21, Temby Street	A	0.01
4b	115 (Lot 87), William Street	G	0.01
4c	97, William Street	G	0.02
5a	30, Wickling Drive	H	0.02
5b	150(L0t 9), Bickley Road	G	1.23
6a	11, (Lot 58) Sullivan Street	G	0.00
6b	6 Lot 187), Carmichael Street	H	1.78
7a	424, Railway Parade	G	0.00
7b	424, Railway Parade	H	0.00
7c	Lot 85, Streatham Street	H	0.01
10b	66 (Lot 43), Dulwich Street	H	0.18
8	459, Sevenoake Street	G	0.00
A1	32, Temby Street	A	1.16
A2	13, Temby Street	A	3.03
A3	14, Lacey Street	A	2.36
H1	34, Wickling Drive	H	0.02

Table 4:16 – Permeability measured at laboratory - Central Maddington

Sample No	Saturated Hydraulic Conductivity (at 1.5 m level) K_s (m/day)		
	Address	Soil type	Hydraulic Conductivity
27	61(Lot 167), Helm Street	D	0.00
28	5, Cedar Way	D	0.00
29	9(Lot 514), Conifer Street	D	0.00

Table 4:17 – Permeability measured at laboratory - Land ford

Sample No	Saturated Hydraulic Conductivity (at 1.5 m level) K_s (m/day)		
	Address	Soil type	Hydraulic Conductivity
15a	17(Lot 285) Turley Way	B	12.64
15b	52, Langford Avenue	G	0.42
16a	5 (Lot 619) Simons Court	B	8.29
17	29, Langford Avenue	B	12.49

Table 4:18 – Permeability measured at laboratory - North Gosnells

Sample No	Saturated Hydraulic Conductivity (at 1.5 m level) K_s (m/day)		
	Address	Soil type	Hydraulic Conductivity
42a	1, Hillegine Court	E	0.00
46a	230 (Lot 1013), Hicks Street	B	16.58
46b	3 (Lot 11), Vera Street	F	1.04
46c	8 (Lot 58), Thursley Way	D	3.00
47a	4, Broadley Place	D	4.84
48c	27 (Lot 52), Seaforth Avenue	F	0.08
49b	85 (Lot 24), James Street	G	0.42
57a	135 (Lot 1) Dorothy Street	B	1.36
57b	170 (Lot 1101), Corfield Street	G	4.96
58	194 (Lot 11), Corfield Street	B	0.41
59a	40 (Lot 16), Digby Street	G	0.78
59b	5, Belyea Street	B	2.76
60b	106 (Lot 40), Walter street	G	1.44
61b	7 (Lot 61), Mackay Cresent	G	0.13
F1	120, Astley Street	F	0.51
F2	29, Seaforth Avenue	F	1.45
E1	3, Mimy Court	E	0.00

Table 4:19 – Permeability measured at laboratory - North Huntingdale

Sample No	Saturated Hydraulic Conductivity (at 1.5 m level) K_s (m/day)		
	Address	Soil type	Hydraulic Conductivity
53b	21(Lot 31), Mildenhall Street	B	9.43
54a	44 (Lot 8), Warton Road	G	1.54
54b	17 (Lot 10), Matilda Street	B	10.76

Table 4:20 – Permeability measured at laboratory - Outer Beckenham

Sample No	Saturated Hydraulic Conductivity (at 1.5 m level) K_s (m/day)		
	Address	Soil type	Hydraulic Conductivity
10a	16, (Lot 150) Faversham Street	G	0.06
11b	13(Lot 158), Lunar Way	H	0.27
12a	74, Streatham Street	H	0.00
12b	6, Lowth Road	G	0.22
13a	131(Lot 51), Ladywell Street	G	0.00
14a	27 (Lot 29), Highbury Crescent	C	0.00
14b	9 or 7, Highbury Crescent	G	1.34
9a	11 (Lot 105), Celebration Street	A	0.00
A4	88, Lacey Street	A	5.60
C1	40, Highbury Cresent	C	0.21

Table 4:21 – Permeability measured at laboratory - South Gosnells

Sample No	Saturated Hydraulic Conductivity (at 1.5 m level) K_s (m/day)		
	Address	Soil type	Hydraulic Conductivity
51b	33, Oakover Way	B	2.21
51c	54 (Lot 8), Kelleman Way	I	3.60
52a	9, Frankland Court	B	6.63
52c	1, Nullagine Way	D	7.35
62b	9, Dionne Place	D	0.19
63b	3 (Lot 49), Suthern River Road	B	3.90
I2	89, Ashbarton Drive (Ground)	I	0.00
I3	91, Ashbarton Drive (Ground)	I	0.19

Table 4:22 – Permeability measured at laboratory - Thornlie East

Sample No	Saturated Hydraulic Conductivity (at 1.5 m level) K_s (m/day)		
	Address	Soil type	Hydraulic Conductivity
31a	17, Southdown Place	C	0.00
31c	14 (Lot 7), Southdown Place	B	11.04
32b	8, Banksia Circle	B	10.29
33	306, Spencer Road	B	8.54
34	12, Malvin Ave	B	11.25
35	1(Lot 1870), Camberley Street	B	10.34
36	13 (Lot 491), Burnley Street	B	14.70

Table 4:23 – Permeability measured at laboratory - Thornlie West

Sample No	Saturated Hydraulic Conductivity (at 1.5 m level) K_s (m/day)		
	Address	Soil type	Hydraulic Conductivity
39	305 (Lot 151), Spencer Road	B	6.49

Table 4:24 – Permeability measured at laboratory - Central Maddington (ODP)

Sample No	Saturated Hydraulic Conductivity (at 1.5 m level) K_s (m/day)		
	Address	Soil type	Hydraulic Conductivity
65a	7 Rand Street	E	0.00
67a	19, Dellavanzo	E	0.00
68a	38, River Avenue	E	0.00
68b	30, River Avenue	C	0.73
69a	6, River Avenue	E	0.01
69b	9, Cowan Street	D	0.08
70	21, Kelvin Road	D	0.00
71	41 or 43, Kelvin Road	D	0.00
73	32, The Crescent	D	0.02
C2	34, River Avenue	C	0.50
C3	14, River Avenue	C	0.57

4.4. Effect on Groundwater level fluctuation on soil permeability

Because groundwater level plays a major role in water sensitive urban design process, the methodology has been expanded to measure the maximum groundwater levels. The methodology used is given in the Section 3.8. Initially it was planned to collect the reading once a week during the rainy season, however due to the uneven rainfall behaviour and other factors beyond the control, groundwater readings were only undertaken twice during the rainy seasons.

For groundwater level monitoring, 35 Borehole (groundwater) locations were selected within or close to the study areas which are operating under park and environmental section of the City of Gosnells. The borehole type and name along with the exact locations of each borehole was taken using a global positioning system (GPS). Due to the difficulty in locating borehole positions especially in a large reserve GPS location coordinates of each of the monitoring site were recorded (refer Figure 4:2).

Groundwater levels are shown in Table 4:25, as two groundwater level measurements are before and after a main rainfall event, the groundwater level clearly show a groundwater increment due to the rainfall triggered groundwater recharge. Groundwater level differed from suburbs to suburb and also within suburbs from 0.1m to 4m. The groundwater levels at Risby Street, King Street, Brigham court, Miranda, Master Street, Aldington, Farnham place, Appledore Street and Crusader drive reserves were found at within the 2m level.

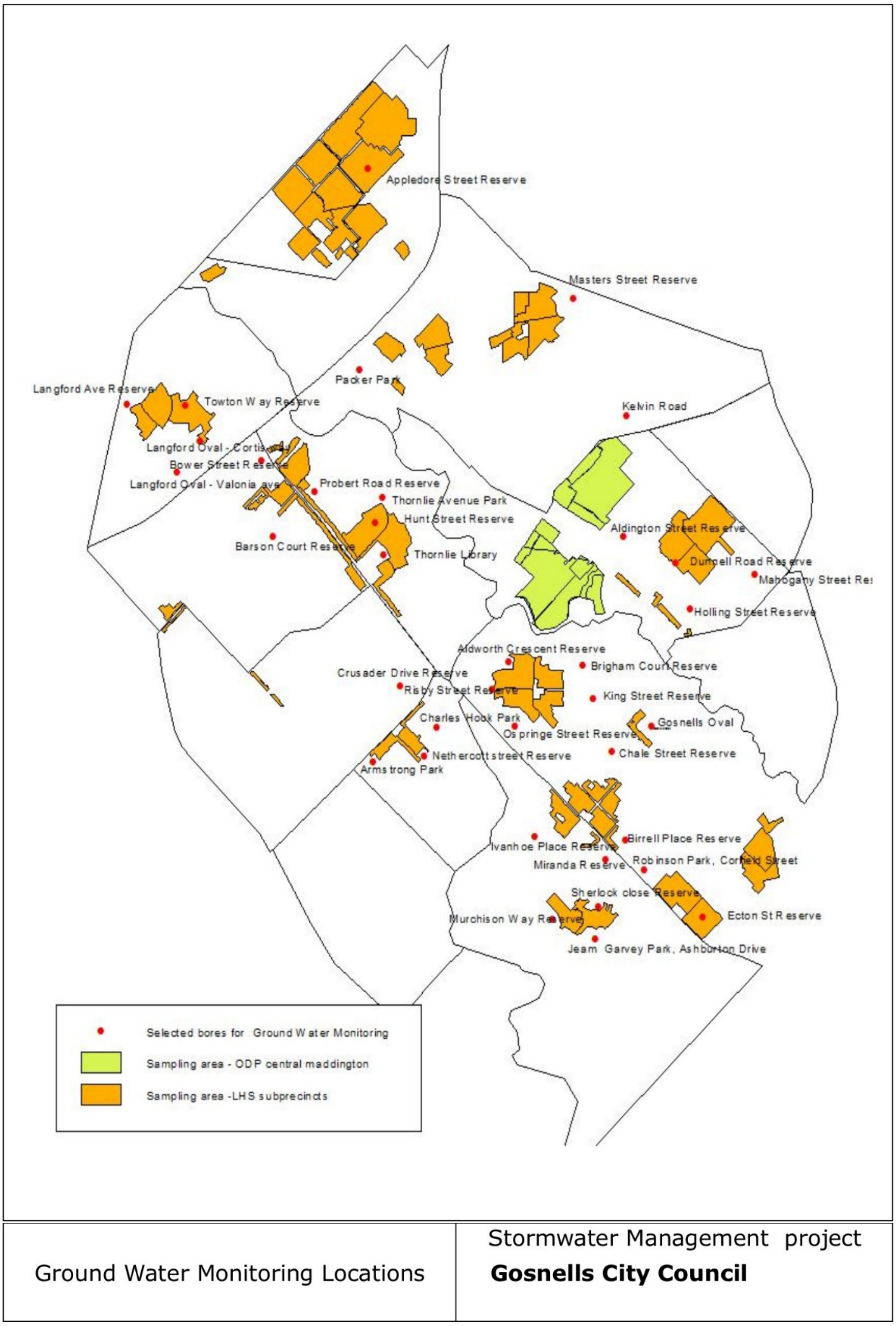


Figure 4:2 - Groundwater monitoring locations

Table 4:25 - Groundwater monitoring data

Selected Ground Water Monitoring Bores							
Last Updated 02 October 2010					GWL/m		
Gosnells	**Inlet**	**Depth**	**GPS Coordinates**		23-07-10	10-09-10	Drop
Jean Garvey Park, Ashburton Drive- SP6	25	106	404714	6449020	6.40		
Gosnells Oval	40	54	405285	6451048	7.34	4.80	2.54
Murchison Way Reserve	21	42	404196	6449163			
Birrell Park Reserve	17	24	404944	6449948		3.00	
Risby Street Reserve	31		403476	6451543	0.92	0.30	0.62
Ospringe Street Reserve	34		403767	6451152			
Aldworth Crescent Reserve	28		403631	6451878	7.43	6.80	0.63
King Street Reserve	20		404559	6451455	1.36	1.20	0.16
Brigham Court Reserve	30	44	404456	6451783	2.37	1.64	0.73
Ivanhoe Place Reserve	15	27	403949	6450101		3.10	
Chale Street Reserve	22		404854	6450907	3.33	3.10	0.23
Miranda Reserve			404720	6449759	2.22	1.95	0.27
Ecton St. Resreve			405802	6449211	5.30	4.90	0.40
Farnham Place Reserve			404996	6449375		1.40	
Kenwick							
Packer Park, Dudley Road - Stalker Turbine	42		401995	6454988	0.00	0.00	0.00
Masters Street Reserve	24				2.00	1.77	0.23
Beckenham							
Appledore Street Reserve	16		402146	6457000	1.40	1.28	0.12
Thornlie							
Probert Road Reserve	16		401590	6453612	4.16	3.82	0.34
Hunt Street Reserve	35	51	402160	6453298		5.94	
Crusader Drive Reserve	23	48	402461	6451539		1.72	
Thornlie Avenue Park	30	57	402183	6453808	3.79	2.95	0.84
Pirtridte park			400337	6453298	1.50		
Barson Court Reserve	11	21	401042	6453224		3.20	
Thornlie Library	30	51	402301	6452940	5.84	5.63	0.21
Langford							
Langford Oval - Cortis way	60	84	406533	6456902	15.21	14.00	1.21
Langford Oval - Valonia ave	56	93	399960	6453913	15.68	14.40	1.28
Towton Way Reserve	34		400131	6454550		8.50	
Langford Ave reserve (Foundation "HB"pump)		83	399454	6454506	16.08		
Aldington Street Reserve	28	42	404987	6453215	2.12	1.60	0.52
Dunnell Road Reserve	18	40	405531	6452662	3.40	2.80	0.60
Mahogany Street Reserve	16		406423	6452709	7.13	6.27	0.86
Kelvin Road (waste site trot track)	27		406533	6456902	15.79		
Maddington							
Holling Street Reserve	24	32	405707	6452057	8.40	4.40	4.00
Huntingdale							
Charles Hook Park - Stalker Turbine	28				2.37		2.37
Armstrong Park	12		402220	6450767		2.00	
Nethercott Street Reserve	24	78	402746	6450868			

Some permeability tests recorded zero hydraulic conductivity due to the shallow groundwater and interaction with the groundwater. The below

Table 4:26 shows those onsite test results which interacted with the groundwater table during the onsite testing.

Table 4:26– Permeability at groundwater intercepted locations

Sample	Permeability with groundwater interaction (m/day)	Soil Type	Average permeability of soil type (laboratory) (m/day)	Average permeability of soil type (onsite) (m/day)
7d	0.0	G	0.54	1.23
14a	0.0	C	0.34	0.17
23b	0.0	G	0.54	1.23
4a	0.0	A	2.03	4.65
26c	0.0	B	7.66	3.97
71d	0.0	D	1.69	0.79

As it clearly shows, the effect of groundwater level is critical when dealing with the infiltration based stormwater management. There is no infiltration capacity of any soil types if it interacts with the groundwater. The purpose of analysing the results with the groundwater level is to help designers to make correct decision in selecting the best stormwater management strategy. By knowing the groundwater levels, it would be easy to specify and recommend a better solution for the stormwater management. If groundwater level is high, there are very few options for stormwater management by infiltration in the area.

4.5. Defining the soil permeability categories for stormwater management

As the main outcome of the study, the recorded soil permeability values (both onsite testing and laboratory testing) should be categorised into groups to be used as an index for stormwater management decision making process. As explained in the Stormwater Management Manual of Western Australia (2004-2007), which is widely used, currently recommended and documented best practice stormwater management guideline in Western Australia, the observed soil permeability values are categorised into four grades: very rapid, rapid, moderate and slow permeable lands.

Table 4:27 - Hydraulic conductivity categories based on Stormwater Management Manual of Western Australia

Soil Permeability (m/day)	Grade
> 1.56	Very Rapid - VR
0.48 – 1.56	Rapid - R
0.12 - 0.48	Moderate - M
< 0.12	Slow - S

Apart from this basic categorisation of permeability groups into the currently using guidelines, further analysis is carried out to compare the recorded soil permeability values against the properties of major soil groups and subgroups in Australia, their soil-water characteristics and other secondary data and definitions available in the literature. Following sections explain the comparison of study results with these secondary data and information.

4.6. Validation of test results using the properties of soil groups and subgroups

As it has been clearly explained in the Chapter 2, there are many factors that greatly affect the permeability of any soil profile. The permeability of a soil sample varies from place to place even in test conducted under the same physical and environmental condition. Sometimes they are extremely localized, due to cracks and holes, and it is difficult to generalize representative values of permeability from actual measurement other than a particular range of it. By keeping all of those facts, which was reviewed under the literature in mind, the secondary data was used to validate the onsite and laboratory test results. Properties of basic soil groups and subgroups distributed in the study area are thoroughly considered and the observed permeability values re-examined against the properties of these soil groups and subgroups.

4.6.1. Identification of basic soil properties of different soil types within the study area

Nine types of soil super groups were identified from the Soil Groups of Western Australia (SGWA) (Schoknecht 2002) within the study area. Each soil type was examined at the sampling point. These soil super groups were named A, B, C, D, E, F, G, H and I for easy referencing instead of using their corresponding name and map unit locations. The soil types which can be found in Table 4:28 have been simply labelled to make it easier to identify throughout the analysis process, than using its soil supergroup name or dominant status. Each soil supergroup's compositions can be found in Table 4:29, comprising of different soil types. Each soil supergroup is explained further in this chapter surrounding its soil properties with different soil sub groups. These properties will be analysed based on their permeability capacities at 1 m and 1.5 m levels in vertically from the existing ground level.

Identification of different types of soils based on their permeability capacities would be one of the main objectives of this study and would be a very useful governing factor for water sensitive urban designers to select best stormwater management strategies.

Table 4:28 - Soil Groups distributed in LHS areas

Soil Type	Dominant Status	Dominant Soil Supergroup	Name
A	Dominant	420	Shallow Sands Supergroup
B	Dominant	440	Deep Sands Supergroup
C	Dominant	100	Wet or waterlogged soil Supergroup
D	Low Dominant	100500S400S	Wet or waterlogged soil Supergroup, loamy duplexes Supergroup, shallow and sandy duplexes Supergroup, shallow
E	Co Dominant	400S500S	Sandy duplexes Supergroup, Shallow & Loamy duplexes supergroup, shallow
F	Co Dominant	500S	Loamy duplexes supergroup, shallow
G	Co Dominant	100440	Wet or waterlogged soil Supergroup & Deep sand Supergroup
H	Sub Dominant	100	Wet or waterlogged soil Supergroup
I	Dominant	100	Wet or waterlogged soil Supergroup

Note – Dominant – more than 70 %, Co Dominant – two soil types are above 30 %, Sub Dominant- between 50 % and 70 %, Low Dominant – all below 30%, S – Shallow (0-30 cm), D – Deep (> 80 cm)

Duplex soil – A duplex soil is defined as a soil with texture or permeability contrast layer within the top 80 cm of the profile

Table 4:29 - Soil supergroup compositions in soil groups available in LHS areas

Referenced Notations	Composition of soil Supergroups							
	SGRPS1	%	SGRPS2	%	SGRPS3	%	SGRPS4	%
A	420	80	440	15	200	5		
B	440	100						
C	100	70	460	30				
D	100	30	500S	28	400S	27	400D	15
E	400S	30	500S	30	100	20	400D	20
F	500S	55	400S	25	400D	20		
G	100	40	440	34	400S	16	500S	5
H	100	52	440	25	540	23		
I	100	100						

Soil Supergroup 100 – Wet Soil

This soil supergroup contains 5 types of soil sub groups named saline wet soil, salt lake soil, semi-wet soil, tidal soil and wet soil. Although each soil group can be found in Western Australia, only the semi-wet soil, saline wet soil, and wet soil are the soil sub groups found in type C, D, E, G, H, and I.

Saline-wet soil (101)

A Saline-wet soil (soil sub group 101) is a seasonally waterlogged soil within 80cm for a major part of the year subject to secondary salinity. This soil sub group consists of sands, loams and clays.

Water repellence	Low
Soil structure decline	Low
Subsurface acidification	Low
Surface condition	Firm
Unrestricted rooting depth	Very Shallow
Available water storage	Low

Subsurface compaction	Low
pH 0-10cm	Neutral - acid
pH 50-80cm	Neutral
Soil permeability	Very slow
Soil workability	Poor
Wind erodibility	Low - moderate

Semi-wet soil (103)

A semi-wet soil (soil sub group 103) is a non-saline soil waterlogged from 30-80cm for a majority part of the year. This does not include a temporary perched watertable, which occurs when a wet surface or sub-surface layer is over dry clay. The topsoil is often dark grey, brown or black in colour. It covers sands, loams and clays and its alkalinity falls between acid to neutral in its pH values. Semi-wet soil occurs in extensive areas of duplex soil on the coastal and south west plains of WA.

Water repellence	Low - moderate
Soil structure decline	Low
Subsurface acidification	Moderate - high
Surface condition	Loose - firm
Unrestricted rooting depth	Moderate
Available water storage	Low - moderate

Subsurface compaction	Low
pH 0-10cm	Neutral - acid
pH 50-80cm	Neutral - acid
Soil permeability	Very slow
Soil workability	Good
Wind erodibility	Low - moderate

Wet soil (105)

A wet soil (soil sub group 105) is a non-saline soil waterlogged to < 30 cm for a major part of the year. Most of the profile (to less than 30 cm) is saturated for the major part of the year and its topsoil is dark grey, brown or black in colour. It covers sands, loams and clays and it is acid in ph readings .

Water repellence	Low - moderate	Subsurface compaction	Low
Soil structure decline	Low	pH 0-10cm	Acid- strong acid
Subsurface acidification	High	pH 50-80cm	Acid- strong acid
Surface condition	Loose to firm	Soil permeability	Very slow
Unrestricted rooting depth	Shallow - moderate	Soil workability	Poor
Available water storage	Low - moderate	Wind erodibility	Low - moderate

Soil Supergroup 200 – Rocky or Stony Soils

This soil supergroup contains 3 types of soil sub groups. They are Bare rock, Calcareous stony soil and Stony soil. Only the Bare rock type soil sub group is available in LHS areas in soil type A.

Bare rock (201)

A Bare rock (soil sub group 201) covers areas generally bare of soil on outcropping rock or bare rock surfaces which includes some areas with minimal soil development.

Water repellence	na	Subsurface compaction	na
Soil structure decline	na	pH 0-10cm	na
Subsurface acidification	na	pH 50-80cm	na
Surface condition	na	Soil permeability	na
Unrestricted rooting depth	na	Soil workability	na
Available water storage	na	Wind erodibility	na

Soil Supergroup 400 – Sandy Duplex

This soil supergroup contains 8 soil sub groups named alkaline grey shallow sandy duplex, alkaline grey deep sandy duplex, grey deep sandy duplex, grey shallow sandy duplex, red deep sandy duplex, red shallow sandy duplex, reticulate deep sandy duplex, yellow/brown deep sandy duplex and yellow/brown shallow sandy duplex. Although each soil sub group can be found in different parts of Western Australia, grey shallow sandy duplex, yellow/brown shallow sandy duplex and yellow/brown deep sandy duplex can be identified in the City of Gosnells areas. These soil sub groups can be seen in soil types D, E, and G.

Grey shallow sandy duplex (404)

A grey shallow sandy duplex (soil group 404) resides over non-alkaline sandy clay loam to clay at 30cm. It is grey in surface layers and various colours in subsoil. Ironstone gravel is often present, especially on top of clay. It can be found seasonally waterlogged over the clay and if found in exposed situations can be prone to wind erosion.

Water repellence	Moderate - high
Soil structure decline	Low
Subsurface acidification	Moderate
Surface condition	Loose
Unrestricted rooting depth	Shallow
Available water storage	Low

Subsurface compaction	Low - Moderate
pH 0-10cm	Acid
pH 50-80cm	Neutral to acid
Soil permeability	Slow
Soil workability	Good
Wind erodibility	High

Yellow/brown deep sandy duplex (407)

A yellow/brown deep sandy duplex (soil group 407) resides over sandy clay loam to clay at 30-80cm. It may often have some paler subsurface and various colours in the subsoil. Ironstone gravel is sometimes present, especially on top of clay. It is neutral subsoil but may lean towards acid to alkaline in its pH readings. If this sand is left bare to surface cover it can be prone to wind erosion.

Water repellence	High		Subsurface compaction	Low - moderate
Soil structure decline	Low		pH 0-10cm	Acid
Subsurface acidification	Moderate		pH 50-80cm	Nuetral – acid
Surface condition	Loose		Soil permeability	Moderately slow
Unrestricted rooting depth	Moderate		Soil workability	Good
Available water storage	Low - moderate		Wind erodibility	High

Yellow/brown shallow sandy duplex (408)

A yellow/brown deep sandy duplex (soil group 408) resides over sandy clay loam to clay at less than 30cm and it has various colours in its subsoil. Ironstone gravel is sometimes present, especially on top of clay. Its subsoil is neutral but may lean towards acid to alkaline in its pH readings. Seasonal water logging may occur above the clay layer. It occurs throughout the south-west of Western Australia, but is rarely common and dominant.

Water repellence	Moderate -high		Subsurface compaction	Low - moderate
Soil structure decline	Low		pH 0-10cm	Acid
Subsurface acidification	Moderate		pH 50-80cm	Nuetral – acid
Surface condition	Loose		Soil permeability	Slow
Unrestricted rooting depth	Shallow		Soil workability	Good
Available water storage	Low		Wind erodibility	High

Soil Supergroup 420 – Shallow Sand

This soil supergroup contains 4 soil sub groups named Calcareous shallow sand, Pale shallow sand, Red shallow sand and Yellow/ brown shallow sand. Only Yellow/ brown shallow sand can be identified in the City of Gosnells areas. This soil sub group can be seen only in soil type A.

Yellow/ brown shallow sand (424)

Water repellence	Moderate -high		Subsurface compaction	Low - moderate
Soil structure decline	Low		pH 0-10cm	Acid
Subsurface acidification	Moderate		pH 50-80cm	Nuetral – acid
Surface condition	Loose		Soil permeability	Slow
Unrestricted rooting depth	Shallow		Soil workability	Good
Available water storage	Low		Wind erodibility	High

Soil Supergroup 440 – Deep Sand

This soil supergroup contains 6 soil groups named brown deep sand, calcareous deep sand, gravelly pale deep sand, pale deep sand, red deep sand and yellow deep sand. Although, each soil group can be found in different parts of Western Australia, only brown deep sand and pale deep sand can be located in the City of Gosnells areas. Soil supergroup 440 has been found in soil type B and G.

Brown deep sand (441)

Brown deep sand (soil group 441) usually resides further than 80cm below the surface. It may often have brown or black colour topsoil, but brown within the first 30cm. It is sandy throughout and maybe humic. Its pH levels range from neutral to acid and is usually alluvial or lacustrine originated. It has a good physical property and is suitable for most agricultural land use.

Water repellence	Low - moderate
Soil structure decline	Low
Subsurface acidification	Low - moderate
Surface condition	Loose
Unrestricted rooting depth	Deep – very deep
Available water storage	Low - moderate

Subsurface compaction	Low - moderate
pH 0-10cm	Nuetral – acid
pH 50-80cm	Nuetral
Soil permeability	Moderately rapid
Soil workability	Good
Wind erodibility	High

Pale deep sand (444)

Pale deep sand (soil group 444) usually resides further than 80cm below the surface. It may often have white, grey or pale yellow topsoil within the first 30cm. Ironstone gravel maybe present but not in large quantities. Its pH levels range from neutral to acid however rock maybe present before or within the layer. It has poor fertility and water retention characteristics, is nutrient leaching but recharges groundwater. If exposed to surface, wind erosion is an issue.

Water repellence	High
Soil structure decline	Low
Subsurface acidification	Low - moderate
Surface condition	Soft - loose
Unrestricted rooting depth	Deep – very deep
Available water storage	Low

Subsurface compaction	Low - moderate
pH 0-10cm	Nuetral – acid
pH 50-80cm	Nuetral – acid
Soil permeability	Very rapid
Soil workability	Good
Wind erodibility	High

Soil Supergroup 500 – Loamy Duplex

This soil supergroup contains 7 soil groups named acid shallow duplex, alkaline red shallow loamy duplex, brown deep loamy duplex, grey shallow loamy duplex, red deep loamy duplex, red shallow loamy duplex and yellow/brown shallow loamy duplex. Although each soil group can be found in different parts of Western Australia, only the yellow/brown shallow(S) loamy duplex can be located in the City of Gosnells areas. Soil supergroup 500S has been found in soil type D and G.

Yellow/brown shallow loamy duplex (508)

A yellow/brown loam (soil group 508) resides over clay at less than 30cm. It may often have yellow or brown colour topsoil. Its pH levels range from neutral in the subsoil, although rarely acidic or alkaline. It has a firm to hard set surface. This soil is scattered throughout the south-west of Western Australia.

Water repellence	Low - moderate
Soil structure decline	Moderate
Subsurface acidification	Moderate
Surface condition	Hardsetting
Unrestricted rooting depth	Shallow
Available water storage	Low

Subsurface compaction	Low - moderate
pH 0-10cm	Nuetral – acid
pH 50-80cm	Nuetral
Soil permeability	Moderately slow
Soil workability	Fair to poor
Wind erodibility	Low

Brown loam earth (541)

This soil type is brown loamy earth (soil group 541) and it exists over clay at less than 30cm. It may often have grey or brown colour topsoil. Although rarely acidic or alkaline, its pH levels range from neutral to acid. Gravels may be present in subsoil. It has a firm to hard set surface. This soil is scattered throughout the south-west of Western Australia.

Water repellence	Nil
Soil structure decline	Moderate - High
Subsurface acidification	Low - High
Surface condition	Hardsetting
Unrestricted rooting depth	Shallow
Available water storage	Moderately Low

Subsurface compaction	Low - moderate
pH 0-10cm	Moderately– acid
pH 50-80cm	Slightly - acid
Soil permeability	Moderate
Soil workability	Fair to poor
Wind erodibility	Low

4.6.2. Spatial distribution of observed soil permeability in major soil groups

The defined soil permeability grades/categories based the Stormwater Management Manual of Western Australia (2004-2007), has been further analysed to match the related soil groups and subgroups in the area. Table 4:30 below, shows the related soil group for each permeability category.

Table 4:30 - Hydraulic conductivity categories (Category Group 1)

Coefficient of Permeability (m/day)	Grade	Related soil super groups
> 1.56	Very Rapid - VR	440, 420
0.48 – 1.56	Rapid - R	420, 400
0.12 - 0.48	Moderate - M	460, 500, 540
< 0.12	Slow - S	100, 200, 500

All the results collected from both testing approaches (onsite test using Guelph Permeameter and laboratory test using collected samples) are analysed to find the percentage of existence of each permeability grade in each soil type.

Onsite permeability tests results (The Guelph Permeameter kit)

Using the on-site tests (Guelph Permeameter), a total of 146 onsite test were conducted and the results have been summarized based on the above hydraulic conductivity categorization and are provided within the Table 4:31.

Table 4:31 – Percentage of existence (Onsite test results)

Soil Type	Onsite Tests					% of Existence			
	VR	R	M	S	Total	VR	R	M	S
A	5			1	6	83.3			16.7
B	38	5	4	1	48	79.2	10.4	8.3	2.1
C			5	1	6			83.3	16.7
D	2	4	7	10	23	8.7	17.4	30.4	43.5
E		1	4	1	6		16.7	66.7	16.7
F		2		1	3		66.7		33.3
G	11	6	13	13	43	25.6	14.0	30.2	30.2
H		1	5	1	7		14.3	71.4	14.3
I			1	3	4			25.0	75.0
Total	56	19	39	32	146	38.4	13.0	26.7	21.9

As per the percentage of Hydraulic Conductivity existence which represents the different permeability capacities of different soil supergroups. The soil types A and B show 83.3% and 89.6% respectively of high permeability values and represent Shallow and deep sand which are very similar to the literature review. Although it was expected that 100% would sit within the high level of permeability range of soil type B, 8.3% of moderate and 2.1% of slow permeability values were recorded. As they are composed of a combination of low permeable soils, such as Wet or waterlogged soil (100), Sandy duplexes (400) and Loamy duplexes (500), in different percentages, the soil type C, E, F, H and I clearly show that the respective permeability values are very low.

Laboratory permeability tests results (Falling Head Method)

89 undisturbed soil samples were collected at 1.5m depth from the selected locations out of the 146 sampling locations and the results have been summarized below in Table 4:32 based on the above hydraulic conductivity categorization.

Table 4:32 – Percentage of existence (Laboratory test results)

Soil Type	Onsite Test					% of Existence			
	VR	R	M	S	Total	VR	R	M	S
A	3	1		2	6	50.0	16.7		33.3
B	20	2	2		24	83.3	8.3	8.3	
C		3	`1	2	6		50.0	16.7	33.3
D	4		1	8	13	30.8		7.7	61.5
E				6	6				100
F		3			3		100		
G	1	4	3	12	20	5.0	20.0	15.0	60.0
H	1		2	4	7	14.3		28.6	57.1
I	1		2	1	4	25.0		50.0	25.0
Total	30	13	11	35	89	33.7	14.6	12.4	39.3

The soil types A and B shows 66.7% and 91.6% of high permeability values to represent Shallow and Deep sand which gives again very similar results to the literature review, as well as the onsite test results. As mentioned above, the expected value of 100% permeability for soil type B has deviated by 8.3% and this value is closer to the 10.4% when compared to the onsite test results. Whereas the soil types

C, D, F, H and I show that the laboratory permeability values taken at 1.5m depth are much higher than the onsite test results done at 1m depth.

However, the soil types A and B have very high infiltration capacities which is very important for implementing of infiltration based stormwater management strategies. When considering both test results, it can be concluded that the soil types C, E, F, H, shows permeability values ranging between with rapid, moderate and slow. According to the SGWA, these soil types are composed of Wet or waterlogged soil (100), Sandy duplexes soil (400) and Loamy duplexes soil (500) in different percentages. The results of the soil types A and B clearly show a close relationship to the soil supergroups 420 and 440 by giving 83.3%, 79.2% of very high permeability values from the onsite tests and 66.7% and 89.6% from the laboratory tests respectively. The literature review indicates that the soil types D and G should consist of combinations of many soil supergroups. As it is shown in the above tables, these two soil types are combinations of three or more permeability categories. Finally, the overall onsite test results have given evidence of the relationship between different soil types and the identified range of permeability categories.

It is well clear that the soil permeability varies with type of the soils. The above analysis is mainly follows the field test results to estimate the soil permeability of different soil types and compare them with available literature and evaluate the feasibility of minimizing the surface runoff component by implementing onsite infiltration based best management practices in land development areas. Results shows that soil type A and B which most of the test results lay on the rapid and very rapid permeability range are suitable for infiltration based stormwater management techniques. The rest of the soil types are suitable for detention based or combined solution of both retention and detention. Results of this research would be able to establish decision making tools, techniques, guidelines and recommendations to facilitate onsite stormwater detention, retention procedures and develop suitable drainage strategies targeting a sustainable stormwater management. Also, these results would assist land developers in their submission of development proposals as well as local and regional authorities in assessing development applications ensuring a sustainable stormwater management plan in developing areas.

4.6.3. Categorization and preliminary understanding of the Permeability test results based on the secondary data

For the analysis purpose, the same categorisation of soil permeability which has been used by the Soil Groups of Western Australia (SGWA) (Schoknecht 2002) was taken into consideration and it is given in the Table 4:33. It consists of seven categories starting from Very Rapid to Very Slow. Based on this classification system, tested soil samples were subjected to a comparison of both tested values from this research and the given soil super groups permeability categories in SGWA.

Table 4:33 - Hydraulic conductivity categories (SGWA) (Schoknecht 2002)

Coefficient of Permeability (m/day)	Grade	Legend
> 6	Very Rapid - VR	
3.12 - 6	Rapid - R	
1.56 - 3.12	Moderately rapid - MR	
0.48 - 1.56	Moderate - M	
0.12 - 0.48	Moderately Slow - MS	
0.012 - 0.12	Slow - S	
< 0.012	Very Slow - VS	

Both onsite and laboratory test results were categorized accordingly and then both test results were summarised as given in Table 4:34 and Table 4:35 according to different soil types. The following key points were identified during the preliminary analysis of identification of the relationship between soil permeability and respective soil types.

Table 4:34 - Onsite Test Results Summary

Soil Type	No of sampling locations identified	Additional locations selected	Total	No of permeability values within the range							Average Permeability(m/day)
				VR	R	MR	M	MS	S	VS	
A	2	4	6	3	2					1	4.65
B	48		48	10	13	15	5	3	1	1	3.97
C	3	3	6					4	1	1	0.17
D	22		22		2		4	7		10	0.79
E	5	1	6				1	4		1	0.30
F	1	2	3				2			1	0.70
G	43		43	2	3	6	6	5	8	13	1.23
H	6	1	7				1	4	1	1	0.28
I	1	3	4					1		3	0.01
Total	132	14	146	15	20	21	19	28	11	32	

Table 4:35 - Laboratory Test Results Summary

				No of permeability values within the range							
Soil Type	No of sampling locations identified	Additional locations selected	Total	VR	R	MR	M	MS	S	VS	Average Permeability(m/day)
A	3	4	6		1	2	1			2	2.03
B	42		24	16	2	2	2	2			7.66
C	3	3	6				3	1		2	0.34
D	23		13	1	2	1		1	2	6	1.69
E	5	1	6							6	0.00
F	2	2	3				3				0.77
G	43		20		1		4	3	5	7	0.54
H	9	1	7			1		2		4	0.33
I	2	3	4	1				2		1	0.08
Total	132	14	89	18	6	6	13	11	7	28	

Table 4:36 - Summary of SGWA Data

Soil Type	Composition of soil Supergroups											
	SGRPS1	**%**	**Grade**	**SGRPS2**	**%**	**Grade**	**SGRPS3**	**%**	**Grade**	**SGRPS4**	**%**	**Grade**
A	420	80	MR-M	440	15	R-M	200	5	na			
B	440	100	R- VR									
C	100	70	VS	460	30	M-MR						
D	100	30	VS	500S	28	M-S	400S	27	S-M	400D	15	S-M
E	400S	30	S-M	500S	30	M-S	100	20	VS	400D	20	S-M
F	500S	55	M-S	400S	25	S-M	400D	20	S-M			
G	100	40	VS	440	34	R-VR	400S	16	S-M	500S	5	M-S
H	100	52	VS	440	25	R-VR	540	23	M			
I	100	100	VS									

Soil type A

This type of soils can be found in Central and Outer Beckenham area. Except the sample 4a others got higher infiltration values. Sample 4a has given a permeability of 0 m/day and it has been found and proved that has given 0.0136 m/day which is similar result from the laboratory test. This showed that this soil type has some percentage of low permeable soil. According to the SGWA, there is 5 % of soil sub group 201 which is called Bare rock (Table 4:36) and it gives that this soil sub group represent zero permeability. Basically, the soil type A represents averagely Rapid (R) grade permeability at 1m depth and Moderately Rapid (MR) permeability at 1.5m depth (Figure 4:3).

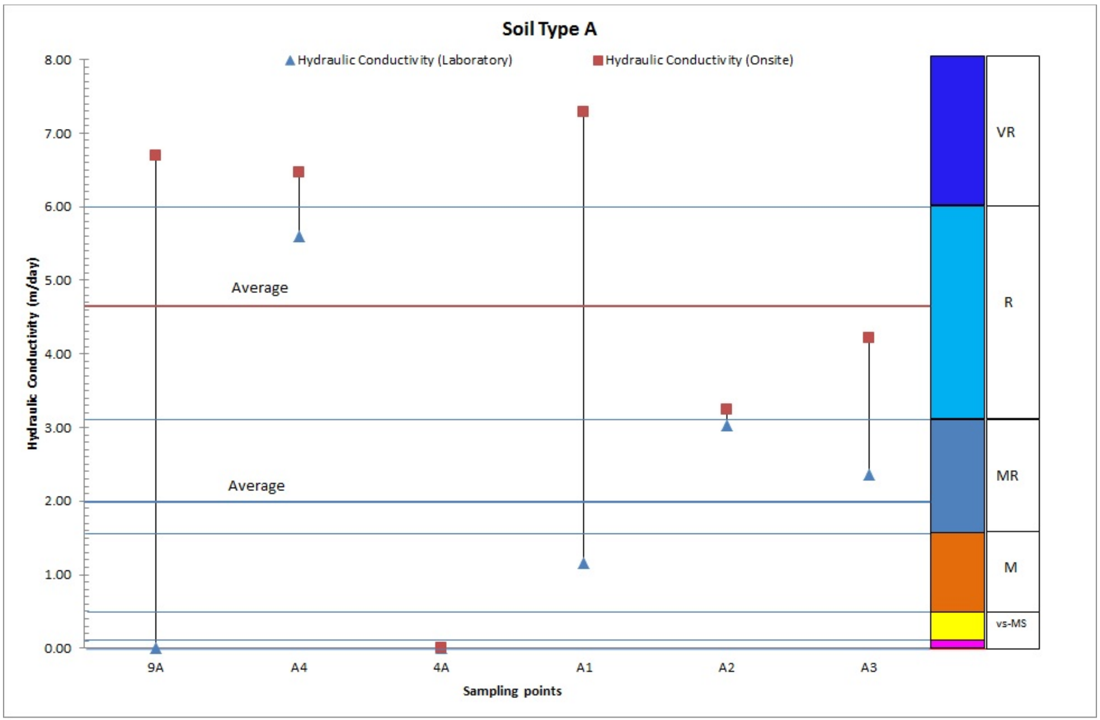


Figure 4:3 Average soil permeability at Laboratory and onsite in soil type A

Soil type B

This soil type is widely spreaded in LHS areas mainly in Kenwick, Landford, Gosnells, Thornlie and North Huntingdale. As is clearly represented in both test results and the SGWA, this soil type has very high permeable capacities. Samples tested at 23a, 26c, 63b, 34 and 48b location have given unexpected results with lower permeability capacities. During the testing it has been observed these place's soils were yellow sandy clayey and brown sandy clayey. The SGWA shows (Table 4:36) that this soil type represent Pale deep sand soil sub group (444) which has 100 % of Rapid-Very Rapid (R-VR) grade permeability. According to the onsite test result soil type B belongs to R grade averagely 4.54 m/day permeability and laboratory test results shows VR grade soil with averagely 7.66 m/day permeability. So that it is clear that soil type B has very high permeability capacity which is very useful for implementing of infiltration based stormwater management strategies (Figure 4:4).

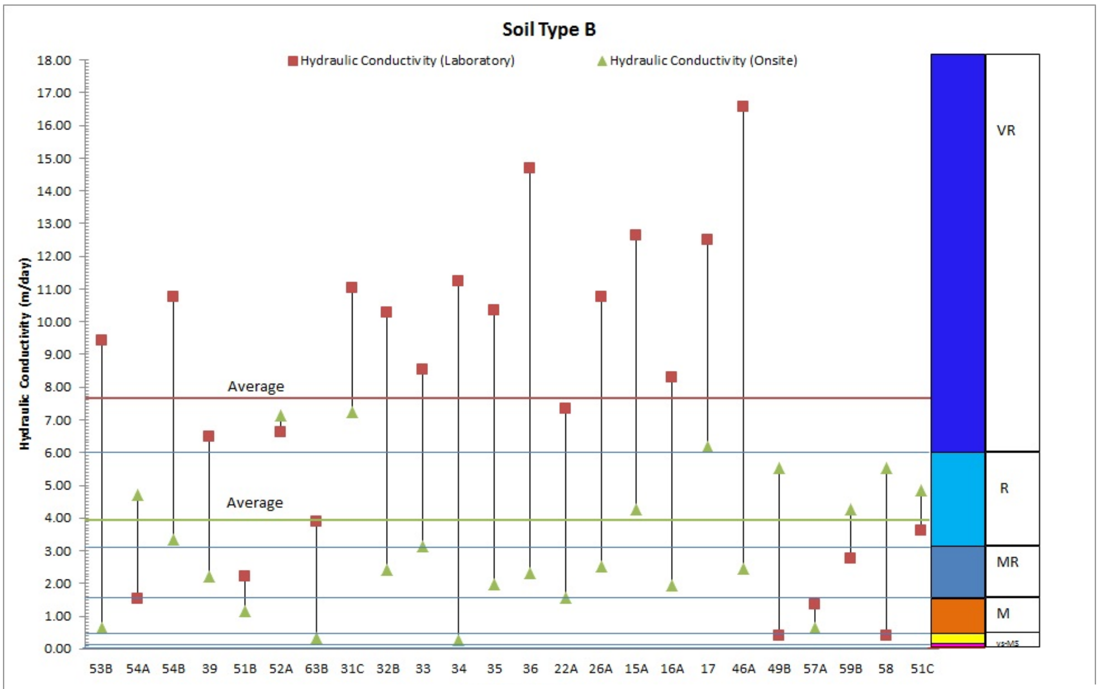


Figure 4:4 - Average soil permeability at Laboratory and onsite in soil type B

Soil type C

This soil type is widely spreaded in LHS areas mainly in Thornlie East, Outer Beckenham. As is clearly represented in both onsite, laboratory test results and the SGWA, this soil type has range of permeable capacities varing from moderate to very slow. During the testing, it has been observed that these place's soils were wet soil . The SGWA shows (Table 4:36) that this soil type represent 70% of Semi-Wet soil sub group (103) which represent very slow (VS) grade of permeability and 30% of Yellow sandy earth (464) which represent M-MR grade permeability. The laborotory samples which were tested at C2, C3 and 68b locations have given bit higher range of pemeability results which compare to the expected permeability capacity from a Semi-Wet soil. However the soil type C contains 30% of Sandy earth soil which has a (M-MR) range of soil permeability and that proves above variation. According to the onsite test result the soil type C is more representative of the moderately slow (MS) grade and averaging 0.17 m/day permeability and laboratory test results shows (MS) grade soil with averagely 0.34 m/day permeability. So that it is clear that soil type C has a very close relationship between the experimatal test results and the secondary data available (Figure 4:5).

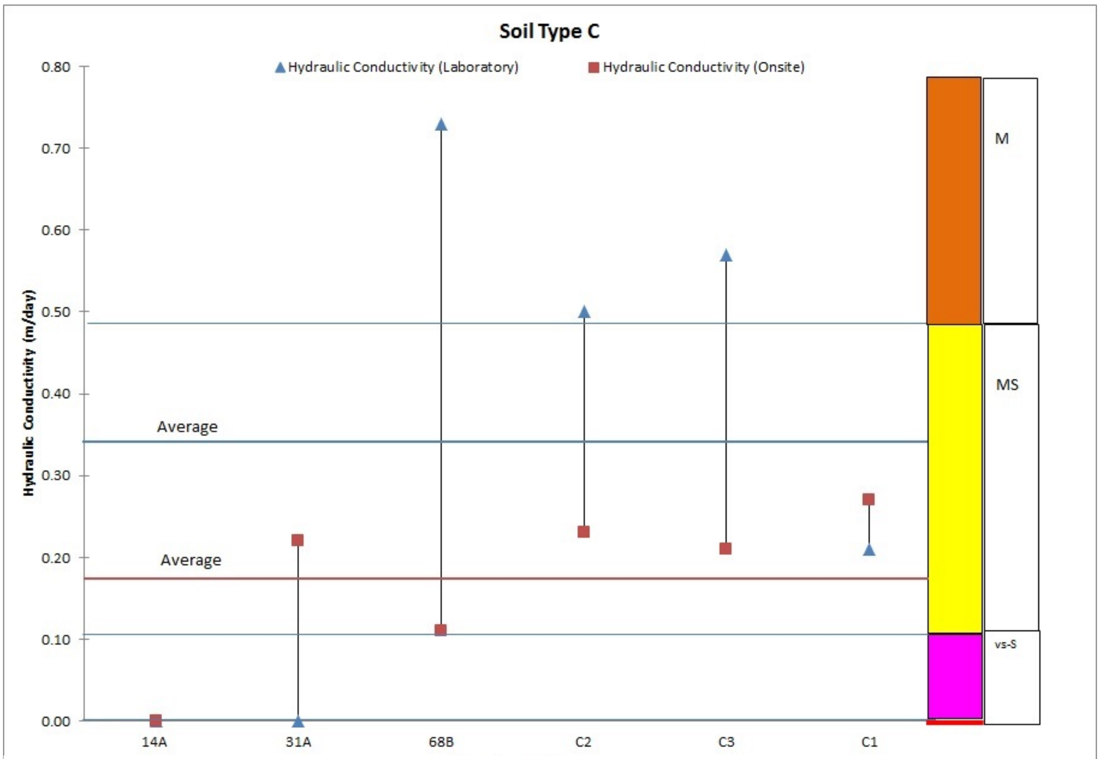


Figure 4:5 - Average soil permeability at Laboratory and onsite in soil type C

Soil type D

This type of soils can be found in Kenwick, Central Maddington, South and North Gosnells area. This soil type can be found in most of the locations in Central Maddington. The SGWA shows (Table 4:36) that this soil type consists of four defferent soil groups with the combination of various presentages. They are 30% of Wet soil super group (100) which has very slow (VS) permeability, 28% of Shallow Loamy Duplex soil super group (500S) that has moderate to slow (M-S) grade permeability, 27% of Shallow Sandy Duplex soil sub group (400S) that has (M-S) grade permiability and 15% of Deep Sandy Duplex soil sub group (400D) that has (M-S) grade soil permeability. Both onsite and laboratory permeability tests done at sampling locations 46c and 47a were extremely higher than the expected value. And also the laboratory test done at 20a and 52c were also higher than excepted permeability range. However, the average permeability values for laboratory tests conducted in soil type D is 1.69 m/day and this value is more representing of the shallow and deep sandy duplex soil sub groups. At the same time, tests conducted on site show an average permeability of 0.79 m/day value which is very similar to the results that are expected from wet soil sub groups (Table 4:36) Basically, the soil type D represents averagely MS-M grade permeability (Figure 4:6).

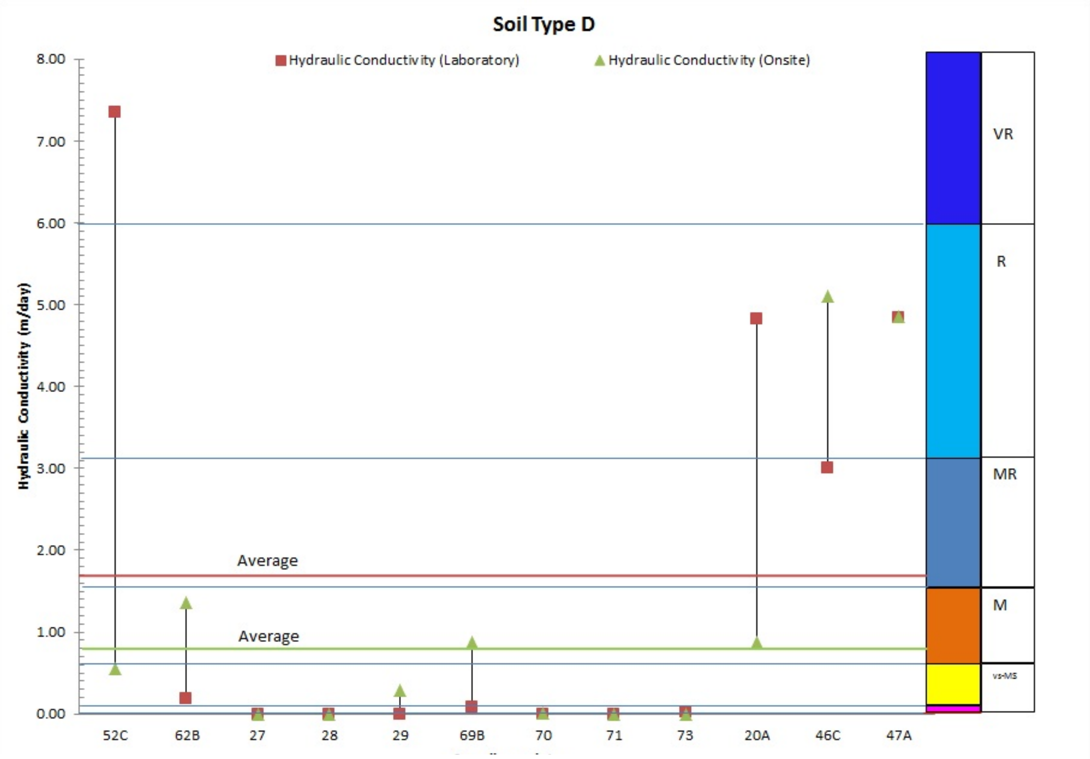


Figure 4:6 - Average soil permeability at Laboratory and onsite in soil type D

Soil type E

This soil type is widely spreaded in LHS areas mainly in Central Maddington and part of North Gosnells. As it clearly represented in both onsite, laboratory test results and the SGWA, this soil type has range of permeable capacities varing from slow to very slow. During the testing, it has been observed that these place's soils were very hard to dril and gives very dark brown claey soil. The SGWA shows (Table 4:36) that this soil type represent 30% of Yellow/brown shallow and deep sandy duplex sub group (407,408) which represent slow (S, MS) grades of permeability, 30% of Yellow/brown shallow loamy duplex(508) which represent MS grade permeability and 20% of wet soil supergroup 100 gives very slow permeability. All most all the tests conducted at 1.5m depths gave a zero permeability and the test conducted on site at 1m depths show considerably higher permeabilty values. According to the onsite test result the soil type E is more close to the slow (S) grade averaging 0.3 m/day permeability and laboratory test results shows VS grade soil with an average 0.0 m/day permeability. It is clear that the soil type E has a very close relationship between the experimented test results and the secondary data available (Figure 4:7).

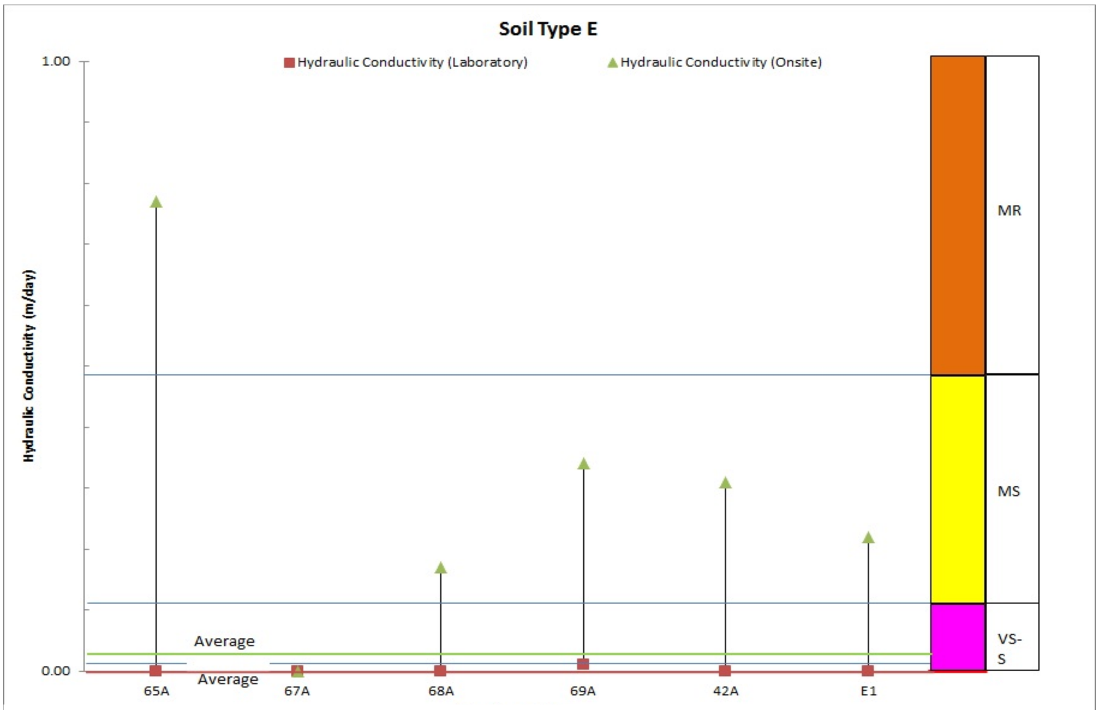


Figure 4:7 - Average soil permeability at Laboratory and onsite in soil type E

Soil type F

This type of soils can be found in only smaller scale in North Gosnells area. All the other test results are well matching with the permeability values given in secondary data except the onsite permeability test done at 46b, Sample 46b gives a permeability of 0 m/day and laboratory test results given as 1.04 m/day which is significant variation compared to the expected values. However, the rest of the test result showed that soil type F has some percentage of low permeable soil. According to the

SGWA, there are 55% of soil loamy duplexes, 25% and 20% of deep and shallow soil supergroups respectively (Table 4:36) According to the onsite test result the soil type E is more close to the Moderate (M) grade with a average 0.70 m/day permeability and laboratory test results shows Moderate (M) grade soil with an average 0.77 m/day permeability. Basically, the soil type F averagely represents slow to Moderate (M) grade permeability (Figure 4:8).

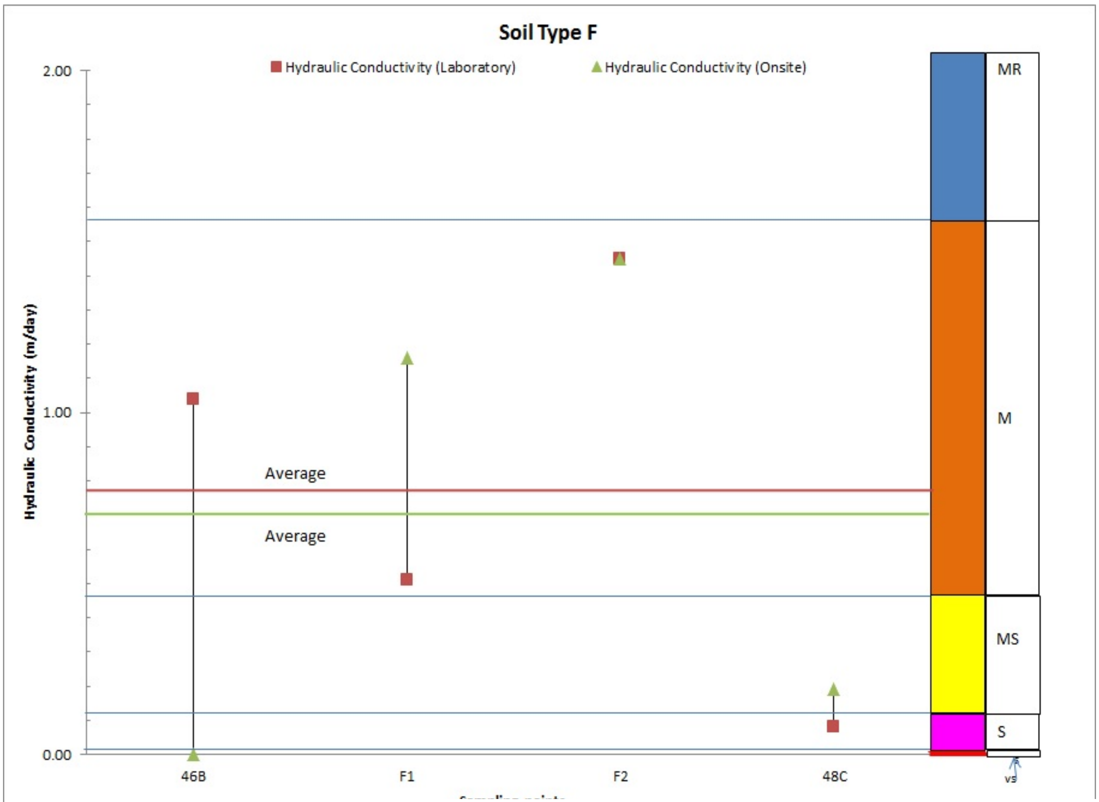


Figure 4:8 - Average soil permeability at Laboratory and onsite in soil type F

Soil type G

This soil type can be easily found in Central Beckenham, Outer Beckenham, Kenwick, North and South Gosnells and also spread in smaller areas in Thornlie East, Thornlie South, North Huntingdale and North Gosnells area. The SGWA shows (Table 4:36) that this soil type consists of four different soil groups with the combination of various presentages. They are 40% of Wet or Waterlogged soil super group (100) which has very slow (VS) grade permeability, 34% of Brown and Pale Deep Sand soil super group (440) that has Rapid (R) and Very Rapid (VR) grade permeability, 16% of Shallow Sandy Duplex soil super group (400S) that has (M-S) grade permiability and 5% of Shallow Loamy Duplex soil super group (500S) that has (M-S) grade soil permeability. The soil type G is a very important soil type to conduct this analysis of identifying the relationship between the test results and secondary data. Both onsite and laboratory permeability test reslts have clearly indicated that the permeability values have varied in a huge range from 0 m/day to 11.64 m/day (Figure 4:9). At the same time, the secodary data shows that the permeability of soil type G can be a conbination of four types of different soil super groups which varies the soil permeability from Very Slow to Very Rapid permeability (Table 4:36). The average permeability values for the laboratory tests conducted in soil type G is 0.54 m/day and this value is more represent active of the Wet or Waterlogged soil super group. At the same time, tests conducted on site show an average permeability of 1.23 m/day value which is very similar to the results that is expected from Shallow Sandy Duplex Soil Shallow Loamy Duplex soil super groups. Averagely, the soil type G represents MS-M grade permeability (Figure 4:9).

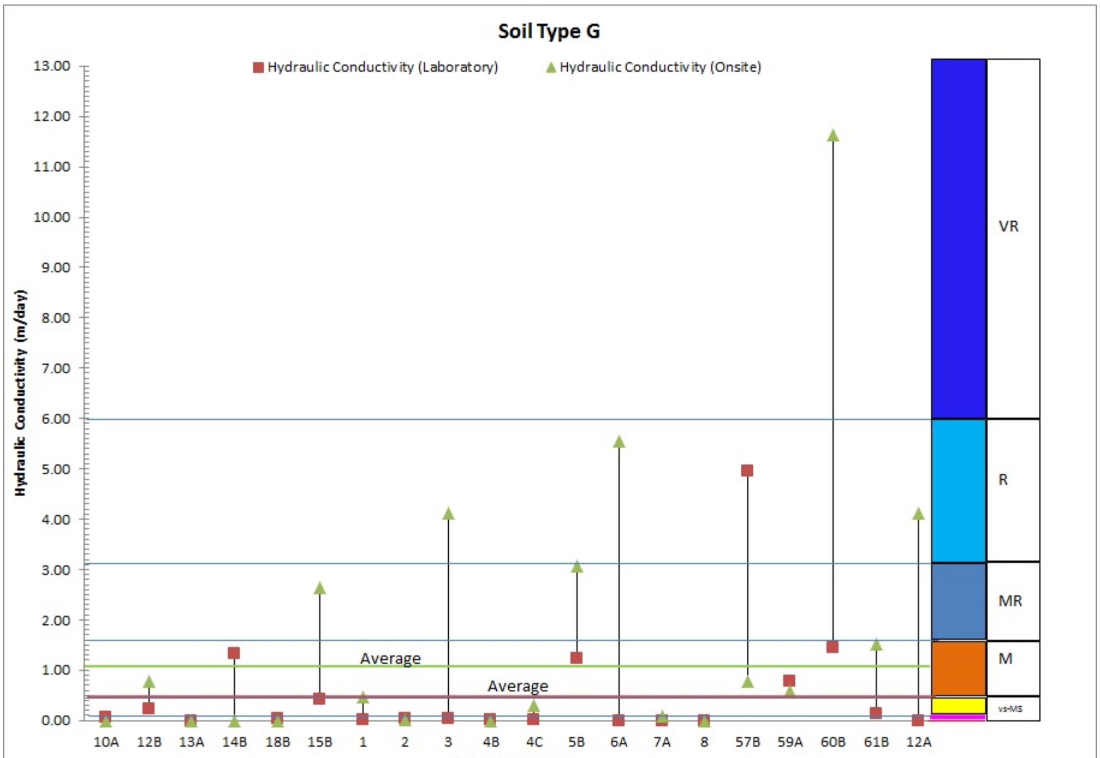


Figure 4:9 - Average soil permeability at Laboratory and onsite in soil type G

Soil type H

This type of soils can be found in Central and Outer Beckenham and area. The SGWA shows (Table 4:36) that this soil type consists of three different soil groups with the combination of various percentages. They are 52% of Wet soil super group (100) which has very slow (VS) permeability, 25% of Brown and Pale Deep Sand soil super group (440) that has Rapid (R) and Very Rapid (VR) grade permeability and 23% of Brown Loamy earth super group (540) that has (M) grade permeability. Both onsite and laboratory average permeability values shows a consistency with the value of 0.28m/day and 0.33m/day. Both tests conducted at the sampling locations 6B were considerably higher than the expected value from the SGWA. And also, the average permeability values for both laboratory and onsite tests were lower than the expected value of Moderate permeability. Based on above findings, it can be concluded that the sample 6B should represent more percentage of Deep Sand soil supper groups which gives very rapid (VR) and the rest of the samples 11B, 5A, 7B, 7C, 10B and H1should represent more percentage of Wet Soil Super groups which gives very slow (VS) permeability (Table 4:36). Basically, the soil type H represents averagely (VS-MS) grade permeability (Figure 4:10).

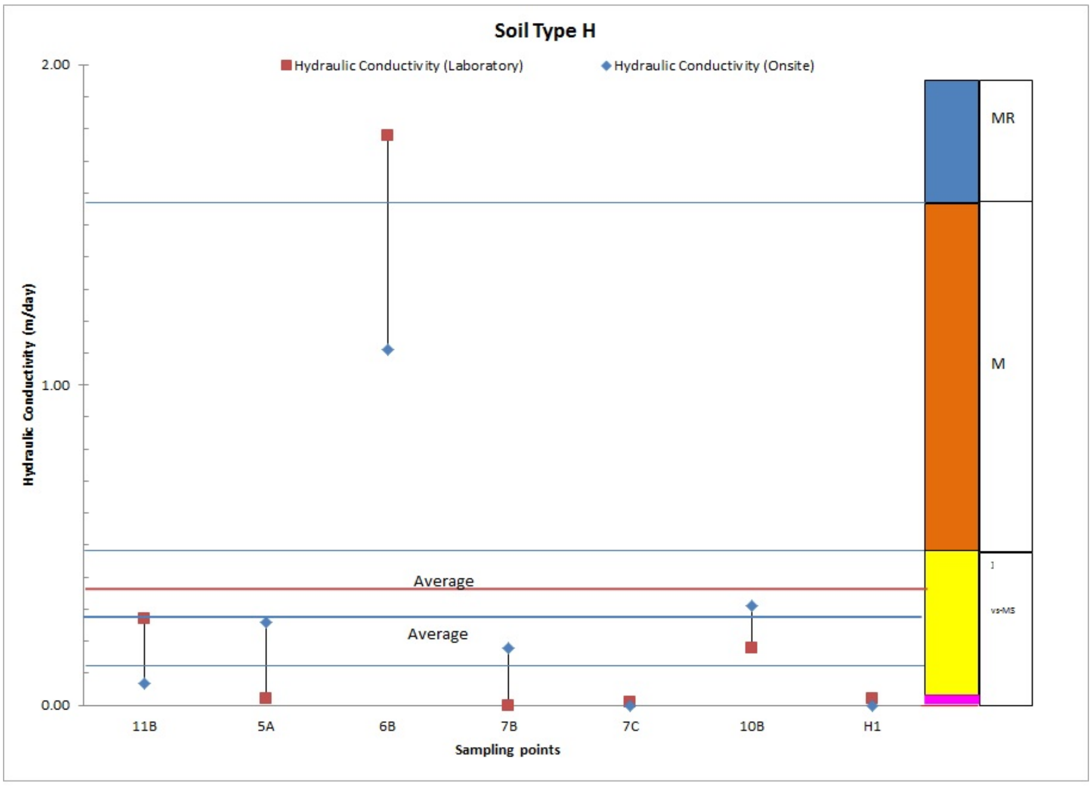


Figure 4:10 - Average soil permeability at Laboratory and onsite in soil type H

Soil type I

This soil type is not widely spreads in LHS it is found in a smaller area in Kenwick and South Gosnells. Both onsite and laboratory permeability test results that were taken at 19C are not fully alining with the rest of the samples tested at I2, I3 and I1 and comparing to the that of secondary data available at SGWA. Due to the above reaon, both averages were calculatted by neglecting both unexpected values received at sampling point at 19C. During the testing, it has been observed these place's soils were white sand upto first 300mmm and then meets cream colur sandy clay at the depth 1m and 1.5m. The SGWA shows (Table 4:36) that this soil type represent 100% Wet soil super group (100) which has Very slow soil permeability. According to the onsite test result soil type I belongs to Very slow (VS) grade averagely 0.01 m/day permeability and laboratory test results shows Slow (S) grade soil with average 0.08 m/day permeability (Figure 4:11). So that it is clear that soil type I has very slow permeability capacity which exactly show a good relationship with the secondary data available at SGWA.

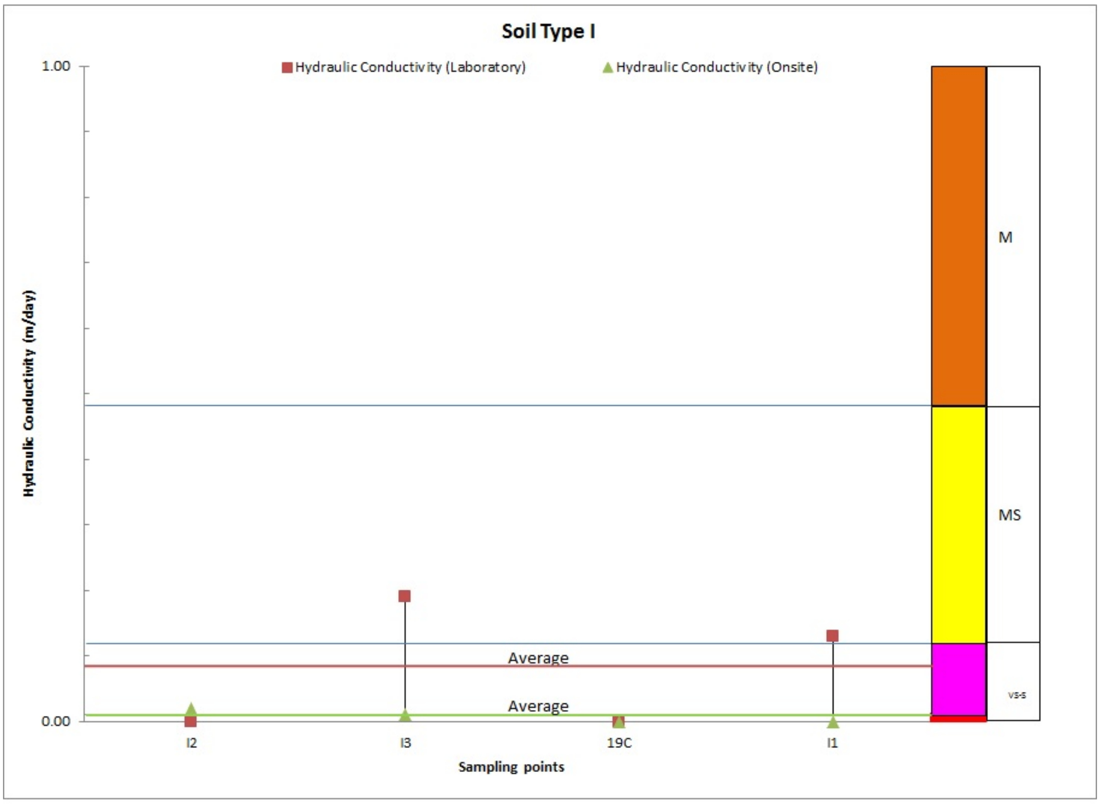
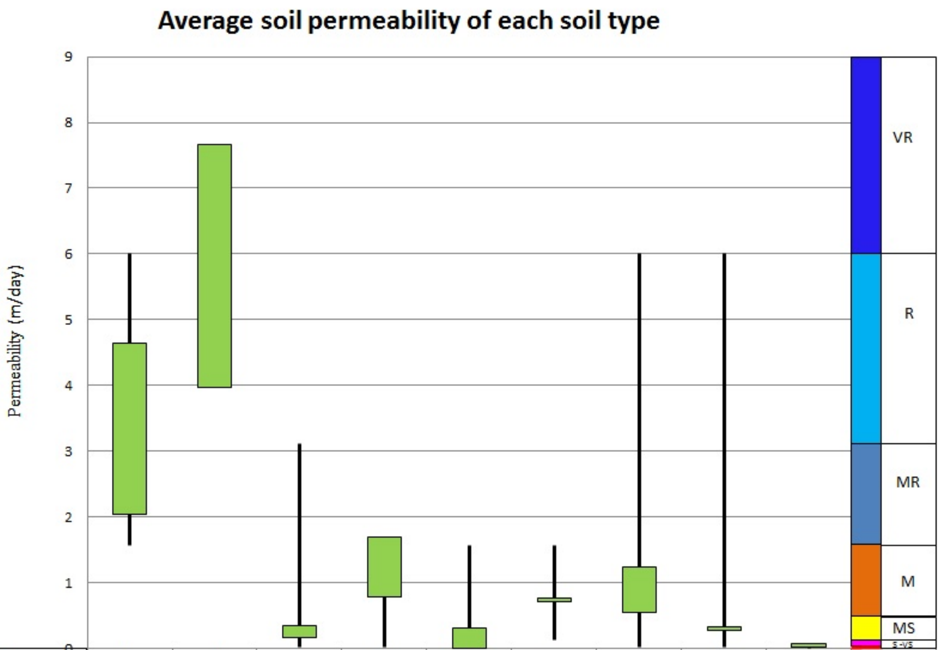


Figure 4:11 - Average soil permeability at Laboratory and onsite in soil type I

4.6.4. The total average soil permeability of each soil type

The Figure 4:12 shows that the total average soil permeability of both onsite and laboratory test results compared to the expected permeability range of each soil types that is given in SGWA. Except for soil types B, D, E and I, the rest of the soil type's average soil permeability are well within the expected range of soil permeability. The calculated average soil permeability values in soil type B, D and I (measured in laboratory) show a higher value than the expected maximum permeability of those soil types. Similarly, the calculated average soil permeability value in soil type E measured in laboratory shows a lower value than the expected minimum value of this soil type.



Soil Type	A	B	C	D	E	F	G	H	I	Category
Onsite Permeability	4.65	3.97	0.17	0.79	0.3	0.7	1.23	0.28	0.01	
SGWA Expected Maximum	6	6	3.12	1.56	1.56	1.56	6	6	0.012	
SGWA Expected Minimum	1.56	6	0.012	0.012	0.012	0.12	0.012	0.012	0	
Laboratory Permeabilty	2.03	7.66	0.34	1.69	0	0.77	0.54	0.33	0.08	

Figure 4:12 - Average permeability of each soil types

The total average permeability of soil types A, C, F, G and H are well within the expected permeability range of SGWA. The most important fact that all the above-mentioned soil types A, C, F, G and H were given lower range soil permeability even though they represent high range of soil permeability in the field.

Although the soil type A and B represent very high range of soil permeability values as compared to other soil types, the behavioural pattern between them is completely different to each other. The dominant soil supergroup in soil type A is Shallow Sands and its soil permeability drops with the depth. But, the dominant soil supergroup in soil type B is Deep Sand and its permeability increases with the depth.

The tested maximum and minimum saturated hydraulic conductivity of undisturbed samples collected at 1.5m depth were 15.7m/day and 0m/day respectively. Similarly, the maximum and minimum saturated hydraulic conductivity measured on site at 1m depth were 20.05 m/day and 0 m/day respectively.

4.6.5. Comparison of both onsite (Guelph Permeameter) and laboratory (Falling Head Method) test results against secondary data

In order to compare the onsite permeability which was taken at 1m from the ground level and the SGWA values at same levels, two major permeability groups were considered. They are VR-M and MS-VS with permeability ranging between > 0.48 and < 0.48 and clearly shown in the following Table 4:37.

Table 4:37 - Broader hydraulic conductivity categories (Category Group 3)

Coefficient of Permeability (m/day)	Grade	Legend
> 0.48	VR-R-MR-M	(blue)
< 0.48	MS-VS	(red)

Based on above broad permeability category, the validity of the onsite permeability test results were checked with the help of SGWA data. The SGWA data has been summarized and given in Table 4:37 above. By considering each and every soil types separately for the analysis, the permeability grade percentages were calculated and the results of the analysed data is given as a set of graphs as shown in Figure 4:13.

As it clearly showed that, the comparison of permeability distribution among the identified soil types is almost identical. Due to the lesser number of samples tested the results under soil type F has given an unexpected result. One of the interesting finding from above analysis is that, if the number of tested soil samples is high, then the results from the research is very much going to match with the SGWA data. For examples soil types B, D and G which has higher number of samples in the study area, match well with field data. Although the lesser numbers of samples have been tested under soil types A, C, D, E H and I, results showed more than 75 % matching each other.

Above analysis gives strong confident of identification of the different soil types and categorisation of soil types based on their infiltration capacities.

Figure 4:13 – Comparison of onsite & laboratory test results with secondary data

4.6.6. Soil permeability capacities at different depths

The main objective of this analysis is to identify the infiltration capacities at different depths and how they behave in a vertical soil profile. In order to achieve this objective, permeability tests were conducted at different depths at a same location. The one test was onsite test which was carried out at 1 m depth and the other one was carried out at the laboratory with a help of undisturbed soil sample collected at 1.5 m depth. More detail is provided in the methodology given in Chapter 03. Based on the different soil types and the permeability categories used in above analysis, both onsite and the laboratory test results are summarised in above given Table 4:34 and Table 4:35. The Figure 4:14 and the Figure 4:15 are represent the infiltrations capacities of all types of soil as an average figure which covered by the total LHS area.

Permeability Distribution of onsite tests at 1 m level (Considering all LHS)

VR-MR-M	51.37 %
MS-VS	48.63 %

Total no of samples : 146

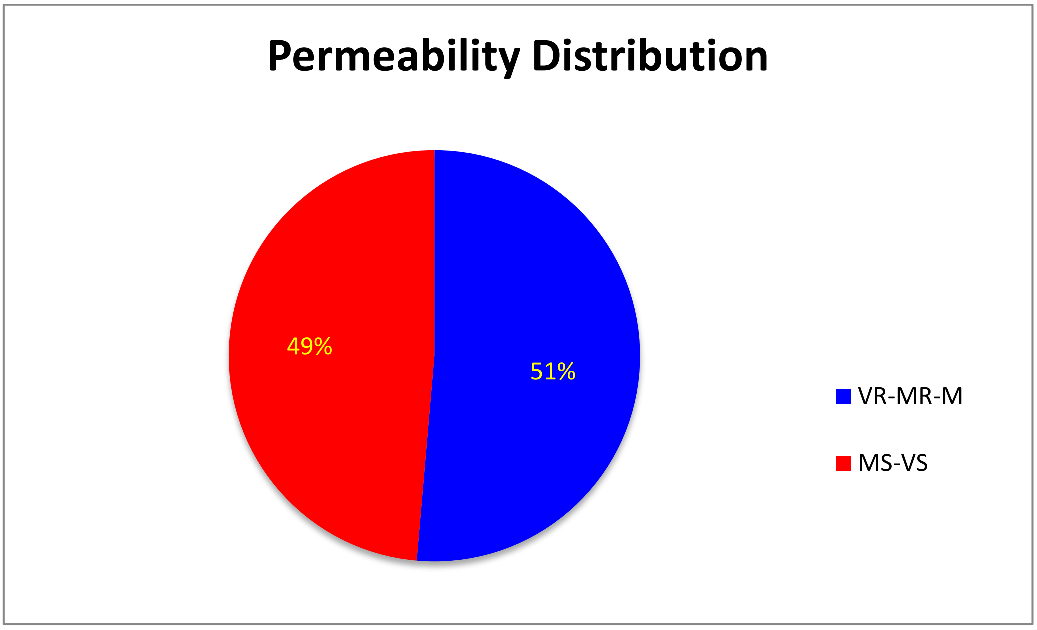


Figure 4:14 - Permeability distribution at 1m level

Permeability Distribution of laboratory tests at 1.5 m level (Covering full LHS)

VR-MR-M	48.31 %
MS-VS	51.69 %

Total no of samples : 89

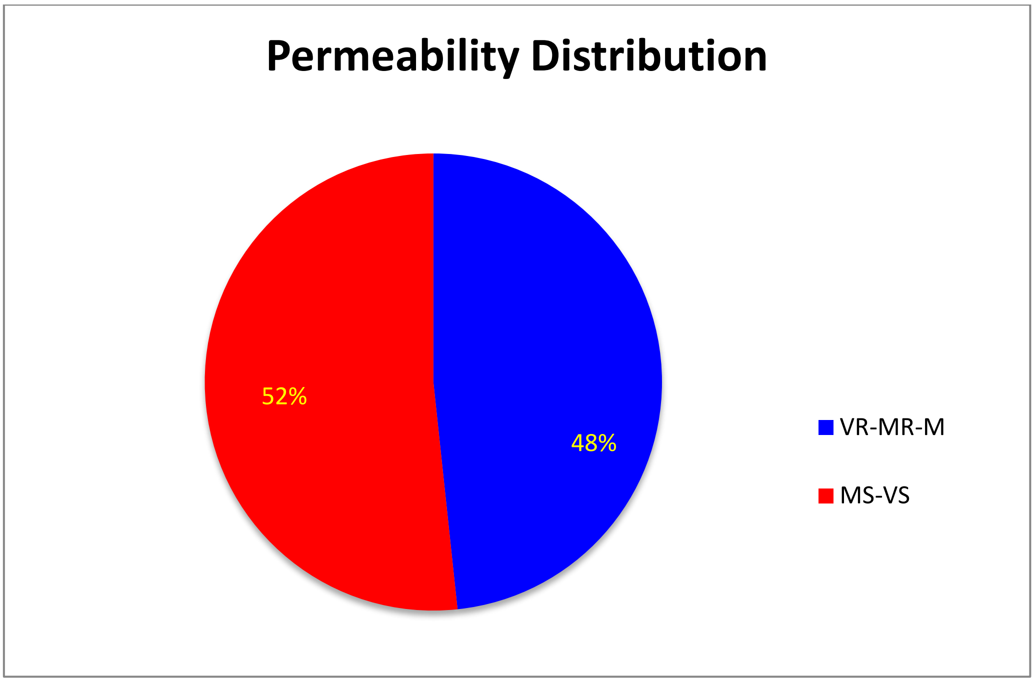


Figure 4:15 - Permeability distribution at 1.5m level

4.6.7. Integration of Study Results to City of Gosnells Interactive Online Mapping System

As a main application of the findings of the study, the study results were integrated to City of Gosnells online interactive maps (IntraMap). The study results (onsite and laboratory permeability test results) should be added in to a GIS format for further analysis of test results through graphical representation. Both onsite and laboratory test results are given in the following tables Table 4:38 to Table 4:49 with respective GPS co-ordinates. The minimum, maximum and average values have been calculated such that users of this data can access most relevant data depending on their design requirements.

The electronic version (shape file) of these plotting is attached to APPENDIX C. The hydraulics designers are being advised to use the minimum values as it gives a good safety factor to the design and the maximum values are in designs which focused at lot scale or close to the sampling locations (GPS Coordinates are given). The average figure can be used in designs which consider the large area such as sub precincts or sub division in preparing local and urban stormwater management plans. This point represent data set will be further generalized in to area represent data set for each and every sub precinct is given in the Section 4.8.

The City of Gosnells is currently referring to this data set for their drainage designs; drainage plans assessment and also LWMSs/UWMPs assessments. This data set is now readily available for publics through online mapping system. The Figure 4:16 which is given below shows a screen shot of a set of data presented on GIS. This online data set also includes type of soil, sampling locations and the tested permeability value at the sampling points. As a developer, it is a well-known fact that developing a clayey site is much more expensive than developing a sandy site. This is mainly due to the extra cost that involves in earth works, foundation and drainage design and installation. As a result, nowadays most of the developers and the property owners are so keen to know about the condition of the soil and the drainage strategy that can be applicable for the development site in advance to purchase the property and also prior to start developing.

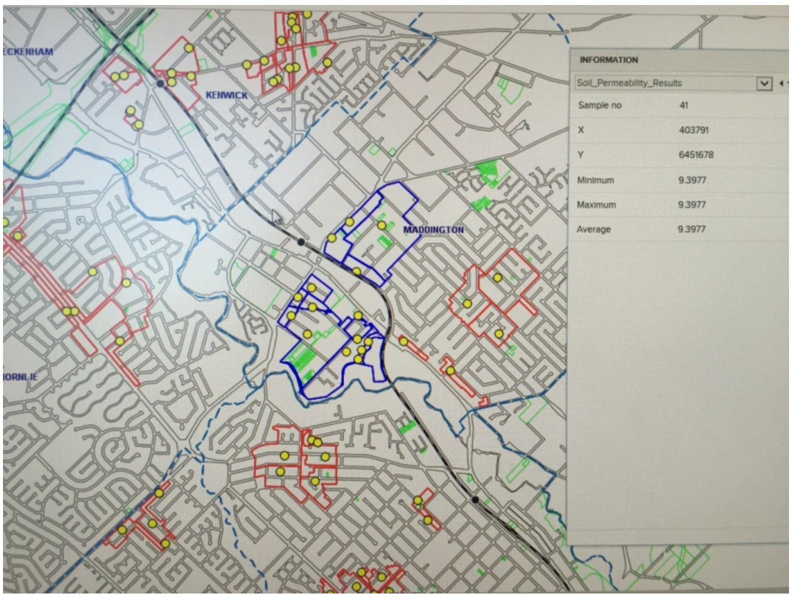


Figure 4:16 – Screen shot - data presented through GIS on City's homepage

Table 4:38-Minimum, Maximum and Average Permeability-Central Beckenham

Sample Area (LHS)	Sample No	GPS Coordinates		Saturated Hydraulic Conductivity Ks (m/day)		
		x	y	Minimum	Maximum	Average
Central Beckenham	1	401291	6456865	0.009	0.484	0.246
	2	401428	6456189	0.007	0.041	0.024
	3	401530	6456570	0.025	4.118	2.072
	4a	401519	6457168	0.000	0.014	0.007
	4b	401736	6457066	0.001	0.014	0.007
	4c	401577	6456969	0.025	0.312	0.168
	5a	401814	6456774	0.016	0.258	0.137
	5b	401753	6456650	1.229	3.058	2.144
	6a	401900	6456403	0.002	5.544	2.773
	6b	401746	6456185	1.107	1.780	1.443
	7a	401745	6456131	0.000	0.092	0.046
	7b	401830	6456188	0.000	0.183	0.092
	7c	401987	6456140	0.000	0.008	0.004
	7d	401928	6456232	0.000	0.000	0.000
	10b	402060	6456764	0.176	0.306	0.241
	8	401632	6456119	0.000	0.000	0.000
	A1	401667	6457188	1.157	7.277	4.217
	A2	401474	6457127	3.035	3.241	3.138
	A3	401346	6457108	2.361	4.209	3.285
	H1	401851	6456816	0.023	0.326	0.174

Table 4:39-Minimum, Maximum and Average Permeability-Central Maddington

Sample Area (LHS)	Sample No	GPS Coordinates		Saturated Hydraulic Conductivity Ks (m/day)		
		x	y	Minimum	Maximum	Average
Central Maddington	27	405502	6453090	0.000	0.002	0.001
	28	405801	6452812	0.000	0.004	0.002
	29	405780	6453338	0.000	0.285	0.143
	30	404902	6452735	0.022	0.022	0.022
	55	405345	6452466	0.285	0.285	0.285

Table 4:40-Minimum, Maximum and Average Permeability-Kenwick

Sample Area (LHS)	Sample No	GPS Coordinates		Saturated Hydraulic Conductivity Ks (m/day)		
		x	y	Minimum	Maximum	Average
Kenwick	18a	402297	6455149	0.003	0.003	0.003
	18b	402375	6455162	0.004	0.032	0.018
	19a	402475	6454706	0.182	0.182	0.182
	19b	402497	6454723	0.035	0.035	0.035
	19c	402418	6454834	0.362	20.051	10.206
	20a	402953	6455414	0.877	4.816	2.846
	20b	402798	6455186	0.124	0.124	0.124
	21a	402967	6455164	0.000	0.000	0.000
	21b	402796	6455110	0.092	0.092	0.092
	22a	403887	6455709	1.581	7.346	4.464
	22b	403879	6455657	1.560	1.560	1.560
	23a	403632	6455317	0.109	0.109	0.109
	23b	403474	6455272	0.000	0.000	0.000
	24a	403910	6455262	3.241	3.241	3.241
	24b	404206	6455306	0.002	0.002	0.002
	25a	404024	6455738	0.000	0.000	0.000
	25b	403922	6455606	4.107	4.107	4.107
	25c	403785	6455494	0.095	0.095	0.095
	26a	403861	6455250	2.518	10.760	6.639
	26b	403749	6455150	2.324	2.324	2.324
	26c	403709	6455123	0.001	0.001	0.001
	I1	402427	6454849	0.002	0.127	0.065

Table 4:41-Minimum, Maximum and Average Permeability-North Gosnells

Sample Area (LHS)	Sample No	GPS Coordinates		Saturated Hydraulic Conductivity Ks (m/day)		
		x	y	Minimum	Maximum	Average
North Gosnells	41	403791	6451678	9.398	9.398	9.398
	42a	404049	6451817	0.001	0.312	0.156
	42b	404175	6451663	2.589	2.589	2.589
	43	404081	6451437	2.854	2.854	2.854
	44	403753	6451531	2.477	2.477	2.477
	45a	405033	6451245	5.096	5.096	5.096
	45b	405128	6451055	0.096	0.096	0.096
	46a	406455	6450213	2.436	16.577	9.506
	46b	406689	6450191	0.000	1.042	0.521
	46c	406526	6450171	2.995	5.096	4.046
	47a	406506	6449810	4.836	4.851	4.844
	47b	406364	6449812	4.526	4.526	4.526
	48a	406635	6449723	0.003	0.003	0.003
	48b	406595	6449697	0.130	0.130	0.130
	48c	406623	6449629	0.076	0.194	0.135
	49a	405537	6449384	2.191	2.191	2.191
	49b	405787	6449406	0.425	5.535	2.980
	50a	405789	6449087	0.744	0.744	0.744
	50b	405834	6449273	0.326	0.326	0.326
	57a	404803	6450114	0.652	1.358	1.005
	57b	404572	6450160	0.765	4.958	2.862
	58	404805	6449935	0.414	5.531	2.973
	59a	404777	6450259	0.591	0.782	0.686
	59b	404765	6450390	2.756	4.281	3.519
	60a	404695	6450531	2.059	2.059	2.059
	60b	404513	6450580	1.440	11.640	6.540
	61a	404625	6450368	2.854	2.854	2.854
	61b	404465	6450446	0.128	1.529	0.828
	F1	406732	6450212	0.511	1.162	0.837
	F2	406649	6449621	1.447	1.453	1.450
	E1	404104	6451798	0.003	0.225	0.114

Table 4:42 -Minimum, Maximum and Average Permeability-Landford

Sample Area (LHS)	Sample No	GPS Coordinates		Saturated Hydraulic Conductivity Ks (m/day)		
		x	y	Minimum	Maximum	Average
Landlord	15a	399733	6454519	4.281	12.644	8.462
	15b	399902	6454339	0.417	2.630	1.524
	16a	399993	6454565	1.953	8.291	5.122
	16b	399989	6454013	9.112	9.112	9.112
	17	399621	6454466	6.180	12.488	9.334

Table 4:43-Minimum, Maximum and Average Permeability-North Huntingdale

Sample Area (LHS)	Sample No	GPS Coordinates		Saturated Hydraulic Conductivity Ks (m/day)		
		x	y	Minimum	Maximum	Average
North Huntingdale	53a	402699	6450878	2.293	2.293	2.293
	53b	402310	6451011	0.632	9.435	5.033
	54a	402651	6451349	1.542	4.719	3.131
	54b	402584	6451067	3.339	10.759	7.049

Table 4:44-Minimum, Maximum and Average Permeability -Outer Beckenham

Sample Area (LHS)	Sample No	GPS Coordinates		Saturated Hydraulic Conductivity (m/day)		
		x	y	Minimum	Maximum	Average
Outer Beckenham	10a	402160	6457016	0.000	0.064	0.032
	11a	402361	6457393	0.050	0.050	0.050
	11b	402499	6457501	0.072	0.269	0.170
	12a	402013	6456225	0.000	4.107	2.054
	12b	402004	6456461	0.223	0.771	0.497
	13a	402514	6456150	0.000	0.000	0.000
	13b	402534	6456165	0.028	0.028	0.028
	14a	400326	6455871	0.000	0.000	0.000
	14b	400504	6455939	0.000	1.337	0.668
	9a	401729	6457374	0.000	6.696	3.348
	9b	401967	6457353	0.156	0.156	0.156
	A4	401869	6457637	5.603	6.472	6.037
	C1	400260	6455868	0.210	0.265	0.238

Table 4:45-Minimum, Maximum and Average Permeability -South Gosnells

Sample Area (LHS)	Sample No	GPS Coordinates		Saturated Hydraulic Conductivity (m/day)		
		x	y	Minimum	Maximum	Average
South Gosnells	51a	404415	6449326	0.346	0.346	0.346
	51b	404741	6449223	1.141	2.212	1.677
	51c	404741	6449104	3.601	4.851	4.226
	52a	404367	6449104	6.633	7.135	6.884
	52b	404292	6449235	0.072	0.072	0.072
	52c	404174	6449417	0.564	7.346	3.955
	62a	404215	6450372	1.845	1.845	1.845
	62b	404301	6450164	0.190	1.356	0.773
	62c	404298	6450066	1.600	1.600	1.600
	63a	404627	6450045	1.029	1.029	1.029
	63b	404633	6449980	0.326	3.899	2.113
	63c	404577	6450059	0.438	0.438	0.438
	I2	404702	6449033	0.001	0.017	0.009
	I3	404705	6449012	0.013	0.192	0.102

Table 4:46-Minimum, Maximum and Average Permeability-South Thornlie

Sample Area (LHS)	Sample No	GPS Coordinates		Saturated Hydraulic Conductivity (m/day)		
		x	y	Minimum	Maximum	Average
South Thornlie	40a	400979	6451597	2.344	2.344	2.344
	40b	401075	6451506	6.472	6.472	6.472
	40c	400942	6451650	9.112	9.112	9.112

Table 4:47-Minimum, Maximum and Average Permeability-Thornlie West

Sample Area (LHS)	Sample No	GPS Coordinates		Saturated Hydraulic Conductivity (m/day)		
		x	y	Minimum	Maximum	Average
Thornlie West	37	401111	6453602	3.407	3.407	3.407
	38	401200	6453510	12.741	12.741	12.741
	39	401833	6453032	2.230	6.492	4.361
	64	400880	6453553	7.074	7.074	7.074

Table 4:48-Minimum, Maximum and Average Permeability-Thornlie East

Sample Area (LHS)	Sample No	GPS Coordinates		Saturated Hydraulic Conductivity (m/day)		
		x	y	Minimum	Maximum	Average
Thornlie East	31a	401204	6454081	0.000	0.219	0.110
	31b	401257	6454154	1.600	1.600	1.600
	31c	401116	6454112	7.237	11.043	9.140
	32a	401214	6453924	15.696	15.696	15.696
	32b	401285	6453837	2.419	10.288	6.354
	33	401901	6453029	3.126	8.537	5.832
	34	402069	6453388	0.276	11.245	5.760
	35	402367	6453287	1.957	10.342	6.150
	36	402302	6452755	2.315	14.699	8.507
	56	401408	6453708	10.651	10.651	10.651

Table 4:49-Minimum, Maximum and Average Permeability-Central Maddington

Sample Area (LHS)	Sample No	GPS Coordinates		Saturated Hydraulic Conductivity (m/day)		
		x	y	Minimum	Maximum	Average
Central Maddington (ODP)	65a	403858	6452978	0.000	0.771	0.386
	65b	403922	6453153	0.010	0.010	0.010
	66	404047	6453241	0.472	0.472	0.472
	67a	404005	6452810	0.000	0.001	0.001
	67b	404056	6453058	0.365	0.365	0.365
	68a	404371	6452642	0.000	0.165	0.083
	68b	404513	6452660	0.106	0.729	0.418
	69a	404474	6452764	0.006	0.345	0.175
	69b	404476	6452978	0.085	0.877	0.481
	70	404232	6453704	0.002	0.007	0.005
	71	404397	6453852	0.000	0.000	0.000
	72	404700	6453819	0.000	0.000	0.000
	73	404466	6453390	0.000	0.017	0.008
	C2	404576	6452734	0.226	0.504	0.365
	C3	404477	6452570	0.208	0.573	0.391

4.7. Generalization of point based onsite and laboratory permeability test results in to an aerial average

As explained above the Stormwater infiltration is a best practice method to operationally and sustainably handle urban drainage. However, until recently, stormwater management strategies have failed to adequately consider the criticality of spatially varying soil permeability values and their implications on drainage designs. The City of Gosnells in Western Australia was keen in developing a stormwater strategy for minimizing the cost for future upgrades due to urbanization.

As explained in Table 4:27, the permeability results were categorized into four main permeability groups against different soil types. A color coding has been introduced to the category for graphical representation. Finally, with the help of the existing soil maps, point representing hydraulic conductivity data has been generalized logically in order to develop the hydraulic conductivity maps representing the areal average in an electronic shape file form by using a GIS Arc view mapping software.

The following key assumptions were considered in calculating Saturated Hydraulic conductivity for each and every sub precinct. There are two or more values allocated for same sub precinct as it contains many soil types.

- Both onsite and the laboratory test results were considered by giving first priority to the onsite measurements. In some cases, although the soil seems permeable, the onsite test results gave a permeability of zero due to the presence of ground water within the one-meter level. In that instances the laboratory test results become primary indicator. This prioritization is considered as more reasonable approach when generalizing the point based test results in to area represent. However, the effect of groundwater level on permeability should be considered secondly before making the final decision on soil permeability.

- Some test results have to be neglected due to onsite test failures due to the effect of ground water and the laboratory test failures due to disturb samples. Details are provided under remarks in the results tables.

- In order to calculate the average permeability value of sub precincts, unrealistic readings in the test results have been neglected. These readings can occur due to an experimental errors.

- The sampling points identified initially were changed during the onsite testing due to access permission and at the mapping stage.

- Some values have been assumed logically due to the above reason mentioned.

- If two or more values come under one soil type within the same sub precinct, the average value has been considered.

Based on the set of assumptions mentioned above, the permeability values were calculated for each and every sub precincts depending on their soil types and those recorded in Table 4:50 to Table 4:61. Then the calculated average soil permeability data set were converted in to digital format of "shapefile" by using ArcView 3.2 (Map info). Finally, permeability distribution maps were developed to represent areal average permeability values for each and every suburb.

Table 4:50 – Aerial Average Permeability - Landford

Sample Area (LHS)	Sub Precincts	Sample No	Reference Soil Type	Average Permeability Value Ks (m/day)
Landford	A	15a	B	4.28
		15b	G	2.63
	B	16a	B	5.53
		16b		
			G	9.11
	D	17	B	6.18

Table 4:51 – Aerial Average Permeability - Central Beckenham

Sample Area (LHS)	Sub Precincts	Sample No	Reference Soil Type	Average Permeability Value Ks (m/day)
Central Beckenham	A	1	G	0.01
	B	2	G	0.01
	C	3	G	0.03
	D	4a	A	4.91
		A1		
		A2		
		A3		
		4b	G	0.00
		4c		
	E	5b	G	3.06
		5a	H	0.30
		10b		
		H1		
	F	6a	G	5.54
		6b	H	1.11
	G	7b	H	0.09
		7c		
		7a	G	0.09
		7d		
	H	8	G	0.00

Table 4:52 – Aerial Average Permeability - Central Maddington

Sample Area (LHS)	Sub Precincts	Sample No	Reference Soil Type	Average Permeability Value Ks (m/day)
Central Maddington	A	27	D	0.00
	B	28	D	0.00
	C	29	D	0.29
	D	30	D	0.02
	F	55	D	0.29

Table 4:53 – Aerial Average Permeability - Kenwick

Sample Area (LHS)	Sub Precincts	Sample No	Reference Soil Type	Average Permeability Value Ks (m/day)
Kenwick	A	18a	G	0.00
		18b		
			D	0.88
	B	19a	D	0.18
		19b	G	0.03
		19c	I	0.18
		I1		
	C	20a	D	0.88
		20b	G	0.12
	D	21a	G	0.05
		21b		
			D	0.88
	E	22a	B	1.57
		22b		
			G	0.10
	F	23a	B	0.11
		23b	G	0.00
	G	24a	B	3.24
		24b	G	0.00
	H	25a	G	0.00
		25b	B	4.11
		25c	G	0.10
	I	26a	B	2.52
		26b	G	2.32
		26c	B	0.00

Table 4:54 – Aerial Average Permeability - North Gosnells

Sample Area (LHS)	Sub Precincts	Sample No	Reference Soil Type	Average Permeability Value Ks (m/day)
North Gosnells	A	41	B	9.40
	B	42a	E	0.27
		E1		
		42b	B	2.59
	C	43	B	2.85
	D	44	B	2.48
	E	45a	B	5.10
		45b	G	0.10
	F	46a	B	2.44
		46b	F	0.58
		F1		
		46c	D	5.10
	G	47a	D	4.85
		47b	B	4.53
	H	48a	D	0.10
		48c		
		48b	B	0.13
		F2	F	1.45
	I	49a	B	3.86
		49b		
			G	0.33
	J	50a	B	0.74
		50b	G	0.33
	K	57a	B	0.65
		57b	G	0.76
	L	58	B	5.53
	M	59a	G	0.59
		59b	B	4.28
	N	60a	B	2.06
		60b	G	11.64
	O	61a	B	2.85
		61b	G	1.53

Table 4:55 – Aerial Average Permeability - North Huntingdale

Sample Area (LHS)	Sub Precincts	Sample No	Reference Soil Type	Average Permeability Value Ks (m/day)
North Huntingdale	A	53a	B	1.46
		53b		
			G	1.46
	B	54a	B	4.03
		54b		
			G	6.47

Table 4:56 – Aerial Average Permeability - Outer Beckenham

Sample Area (LHS)	Sub Precincts	Sample No	Reference Soil Type	Average Permeability Value Ks (m/day)
Oouter Beckenham	A	9a	A	6.58
		A4		
		9b	G	0.16
	B	10a	G	0.06
			H	0.31
	C	11a	G	0.05
		11b	H	0.07
	D	12a	G	2.44
		12b		
	E	13a	G	0.01
		13b		
			H	0.00
	F	14a	C	0.27
		C1		
		14b	G	0.00

Table 4:57 – Aerial Average Permeability - South Gosnells

Sample Area (LHS)	Sub Precincts	Sample No	Reference Soil Type	Average Permeability Value Ks (m/day)
South Gosnells	A	51a	G	0.35
		51b	B	3.00
		51c		
		I2	I	0.02
		I3		
	B	52a	B	7.13
		52b	G	0.07
		52c	D	0.56
	C	62a	G	1.84
		62b	D	1.48
		62c		
			B	0.33
	D	63a	G	1.03
		63b	B	0.33
		63c	D	0.44

Table 4:58 – Aerial Average Permeability - Thornlie East

Sample Area (LHS)	Sub Precincts	Sample No	Reference Soil Type	Average Permeability Value Ks (m/day)
Thornlie East	A	31a	C	0.22
		31b	G	1.60
		31c	B	7.24
	B	32a	B	9.06
		32b		
			G	1.60
	C	33	B	3.13
	D	34	B	1.96
	E	35	B	1.96
	F	36	B	2.31
	G	56	B	10.65

Table 4:59 – Aerial Average Permeability - South Thornlie

Sample Area (LHS)	Sub Precincts	Sample No	Reference Soil Type	Average Permeability Value Ks (m/day)
South Thornlie	A	40a	G	2.34
		40b	G	6.47
		40c	B	9.11

Table 4:60 – Aerial Average Permeability - Thornlie West

Sample Area (LHS)	Sub Precincts	Sample No	Reference Soil Type	Average Permeability Value Ks (m/day)
Thornlie West	A	37	B	3.41
	B	38	B	12.74
	C	39	B	2.23
	E	64	B	7.07

Table 4:61 – Aerial Average Permeability - Central Maddington (ODP)

Sample Area (LHS)	Sub Precincts	Sample No	Reference Soil Type	Average Permeability Value Ks (m/day)
Central Maddington (ODP)	A	65a	E	0.00
		65b	D	0.01
	B	66	D	0.47
	C	67a	E	0.00
		67b	D	0.37
	D	68a	E	0.00
		68b	C	0.18
		C2		
		C3		
	E	69a	E	0.34
		69b	D	0.08
	F	70	D	0.01
	G	71	D	0.00
	H	72	D	0.00
	I	73	D	0.02

4.8. Identify the suitable areas for infiltration based onsite stormwater management and explore further development opportunities

Based on the calculated average permeability values given in the above tables, the permeability distribution maps are developed which represent areal average values for each and every sub precincts covering all the suburbs. These graphical representations of data are greatly helpful for property owners, developers, geotechnical engineers, hydrologic design engineers and also local authorities to get a rough idea about the suitable stormwater management strategy and especially the rough estimate about the drainage cost that would be involved in the development.

The following key steps have been taken in to consideration when developing the permeability distribution maps in order to represent the areal average permeability values.

- Both onsite and laboratory test results were considered by giving first priority to the onsite measurements.

- Some test results have to be neglected due to onsite test failures due to the effect of ground water and the laboratory test failures due to disturb samples. Details are provided under remarks in the results tables.

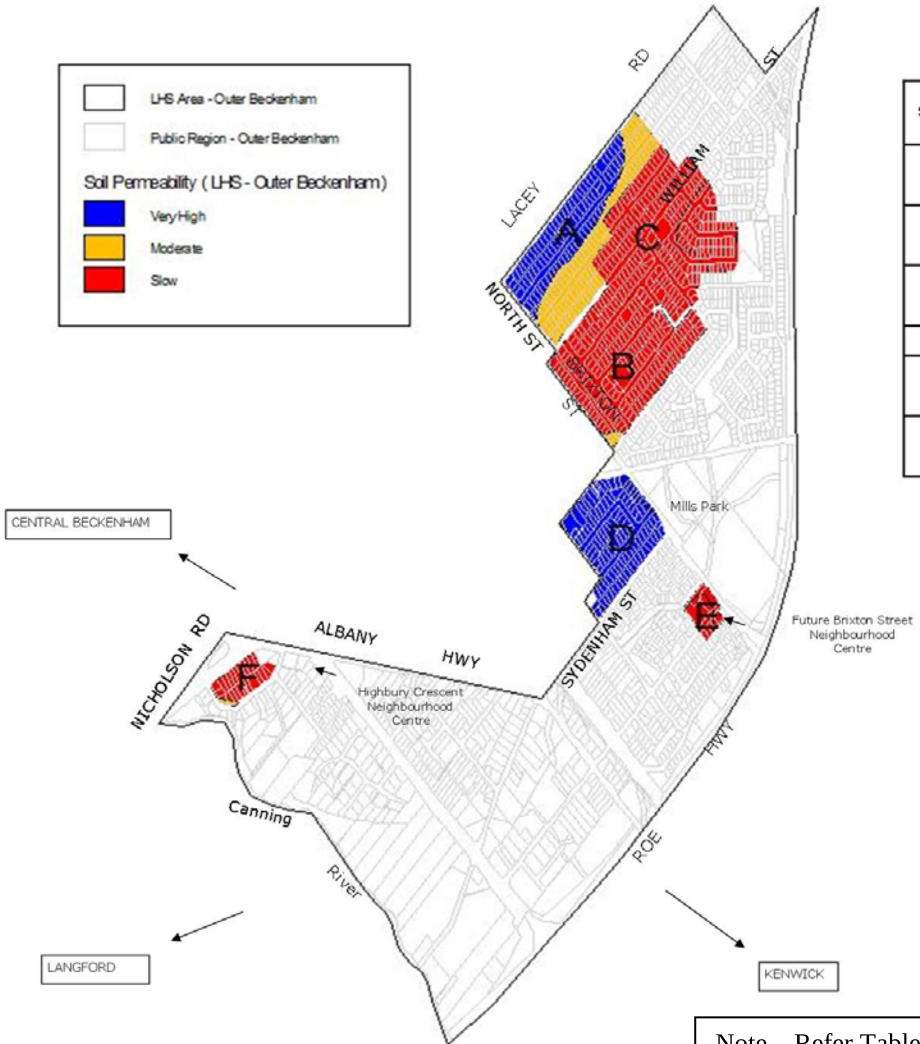
- In order to calculate the average permeability value to sub precincts, unrealistic readings in the test results have been neglected logically. These readings can occur due to the experimental errors.

- The sampling points identified initially were changed during the onsite testing due to access permission.

- Some data relates to the sampling locations had to be changed at the mapping stage due to the change of boundaries of the particular sampling points.

- The average value has been considered if two or more permeability values come under one soil type within the same sub precinct.

These permeability distribution maps were developed to represent each suburb. This would be easy for future reference as well as for clear data presentation. The table given on the map shows the details about sub precinct areas, its dominant soil type and the calculated category of permeability. Also, the note which is given in the bottom right-hand corner shows further reference to select the best stormwater management strategy to suit the development area and also design guidelines. These maps are given below from Figure 4:17 to Figure 4:28.



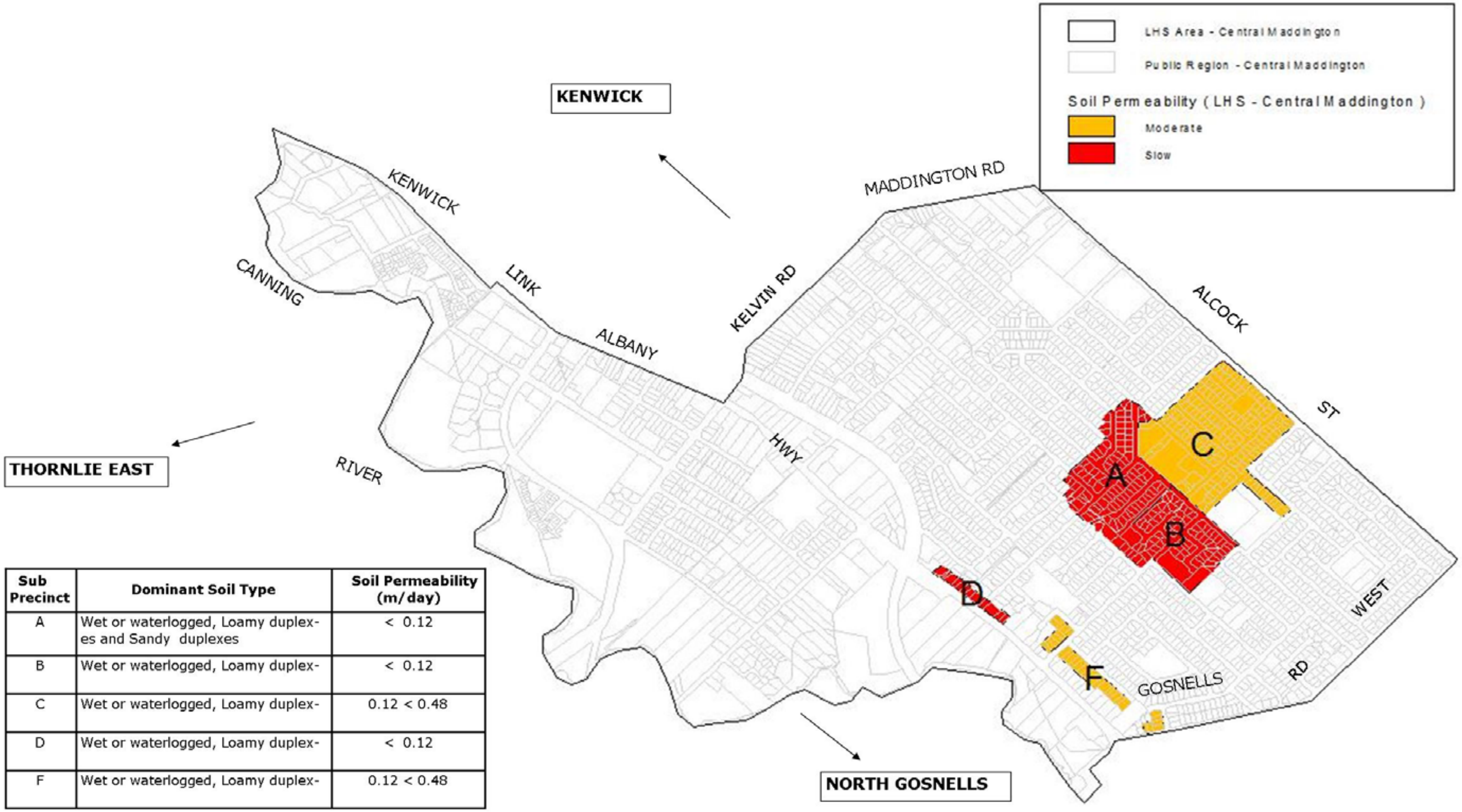
Sub Precinct	Dominant Soil Type	Soil Permeability (m/day)
A	Shallow sands	> 1.56
	Wet or waterlogged & Deep sands	0.12 < 0.48
B	Wet or waterlogged & Deep sands	< 0.12
	Wet or waterlogged	0.12 < 0.48
C	Wet or waterlogged & Deep sands	< 0.12
	Wet or waterlogged	< 0.12
D	Wet or waterlogged & Deep sands	> 1.56
E	Wet or waterlogged & Deep sands	< 0.12
	Wet or waterlogged	< 0.12
F	Wet or waterlogged	0.12 < 0.48
	Wet or waterlogged & Deep sands	< 0.12

Note – Refer Table 7.2 for selecting of Best Stormwater Management Strategy
Refer Table 7.3 for Reference Guidelines

Figure 4:17 – Permeability Distribution Map – Outer Beckenham

LOCAL HOUSING STRATEGY PLAN

Outer Beckenham Housing Precinct



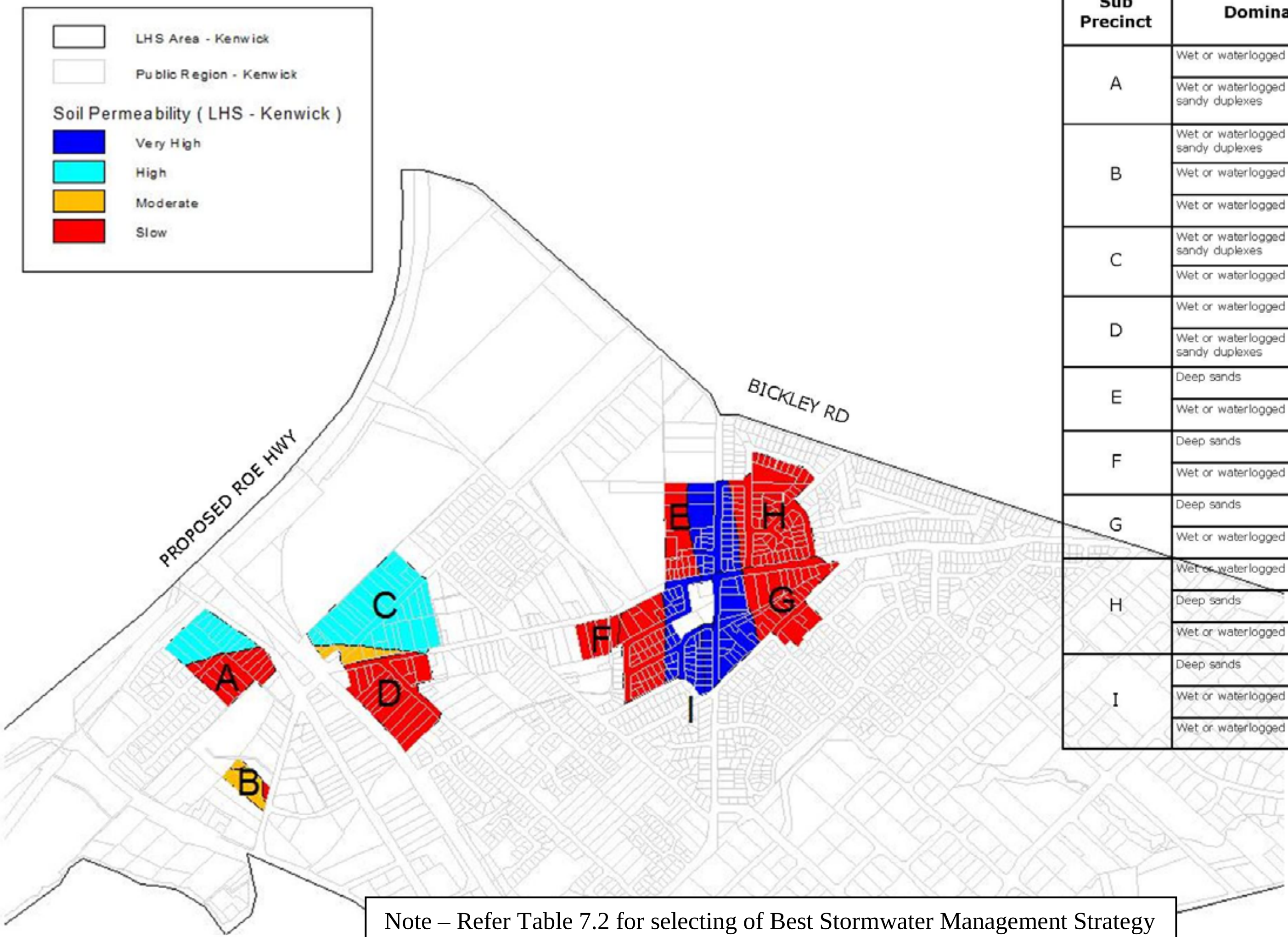
Sub Precinct	Dominant Soil Type	Soil Permeability (m/day)
A	Wet or waterlogged, Loamy duplexes and Sandy duplexes	< 0.12
B	Wet or waterlogged, Loamy duplex-	< 0.12
C	Wet or waterlogged, Loamy duplex-	0.12 < 0.48
D	Wet or waterlogged, Loamy duplex-	< 0.12
F	Wet or waterlogged, Loamy duplex-	0.12 < 0.48

Note – Refer Table 7.2 for selecting of Best Stormwater Management Strategy
Refer Table 7.3 for Reference Guidelines

Figure 4:18 – Permeability Distribution Map – Central Maddington

LOCAL HOUSING STRATEGY PLAN

Central Maddington Housing Precinct



Sub Precinct	Dominant Soil Type	Soil Permeability (m/day)
A	Wet or waterlogged soil & Deep sand	< 0.12
	Wet or waterlogged s, loamy duplexes and sandy duplexes	0.48 < 1.56
B	Wet or waterlogged s, loamy duplexes and sandy duplexes	0.12 < 0.48
	Wet or waterlogged soil & Deep sand	< 0.12
	Wet or waterlogged soil & Deep sands	0.12 < 0.48
C	Wet or waterlogged s, loamy duplexes and sandy duplexes	0.48 < 1.56
	Wet or waterlogged soil & Deep sands	0.12 < 0.48
D	Wet or waterlogged soil & Deep sands	< 0.12
	Wet or waterlogged s, loamy duplexes and sandy duplexes	0.48 < 1.56
E	Deep sands	> 1.56
	Wet or waterlogged soil & Deep sands	< 0.12
F	Deep sands	< 0.12
	Wet or waterlogged soil & Deep sands	< 0.12
G	Deep sands	> 1.56
	Wet or waterlogged soil & Deep sands	< 0.12
H	Wet or waterlogged soil & Deep sands	< 0.12
	Deep sands	> 1.56
	Wet or waterlogged soil & Deep sands	< 0.12
I	Deep sands	> 1.56
	Wet or waterlogged soil & Deep sands	> 1.56
	Wet or waterlogged soil & Deep sands	< 0.12

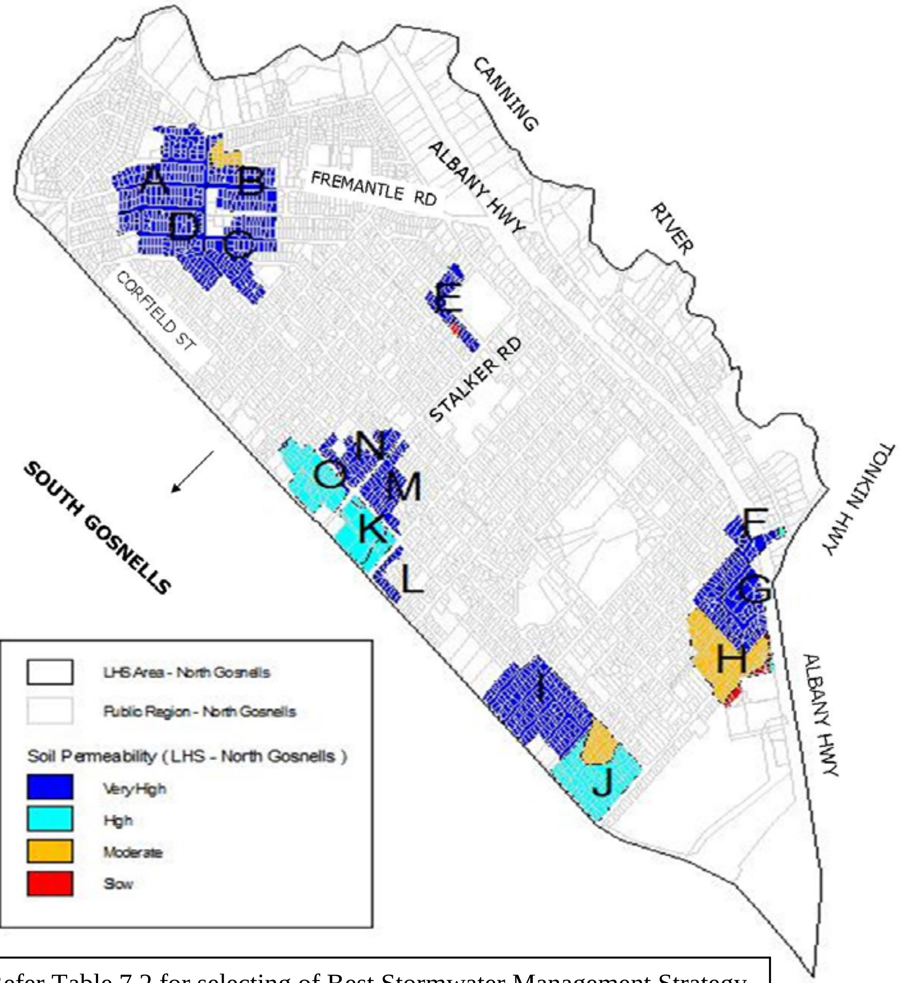
Note – Refer Table 7.2 for selecting of Best Stormwater Management Strategy
Refer Table 7.3 for Reference Guidelines

Figure 4:19 – Permeability Distribution Map – Kenwick

LOCAL HOUSING STRATEGY PLAN

Kenwick Housing Precinct

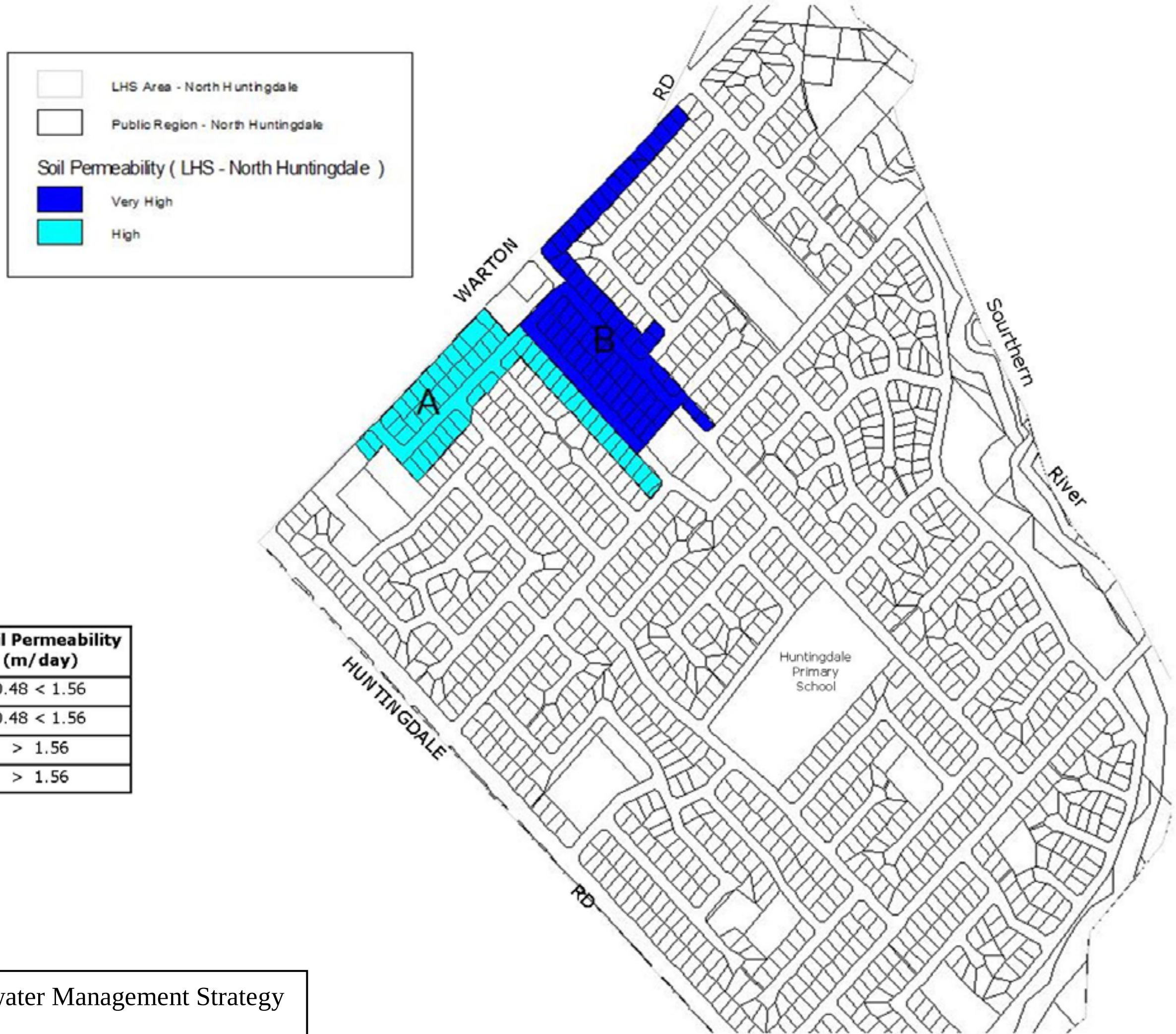
Sub Precinct	Dominant Soil Type	Soil Permeability (m/day)
A	Deep sands	> 1.56
B	Sandy duplexes and Loamy duplexes	0.12 < 0.48
	Deep sands	> 1.56
C	Deep sands	> 1.56
D	Deep sands	> 1.56
E	Deep sands	> 1.56
	Wet or waterlogged & Deep sands	< 0.12
F	Deep sands	> 1.56
	Loamy duplexes	0.48 < 1.56
	Wet or waterlogged, Sandy duplexes and Loamy duplexes	> 1.56
G	Wet or waterlogged, Sandy duplexes and Loamy duplexes	> 1.56
	Deep sands	> 1.56
H	Wet or waterlogged, Sandy duplexes and Loamy duplexes	< 0.12
	Deep sands	0.12 < 0.48
	Loamy duplexes	0.48 < 1.56
I	Deep sands	> 1.56
	Wet or waterlogged & Deep sands	0.12 < 0.48
J	Deep sands	0.48 < 1.56
	Wet or waterlogged & Deep sands	0.12 < 0.48
K	Deep sands	0.48 < 1.56
	Wet or waterlogged & Deep sands	0.48 < 1.56
L	Deep sands	> 1.56
M	Wet or waterlogged & Deep sands	0.48 < 1.56
	Deep sands	> 1.56
N	Deep sands	> 1.56
	Wet or waterlogged & Deep sands	> 1.56
O	Deep sands	> 1.56
	Wet or waterlogged & Deep sands	0.48 < 1.56



Note – Refer Table 7.2 for selecting of Best Stormwater Management Strategy
Refer Table 3.3 for Reference Guidelines

Figure 4:20 – Permeability Distribution Map – North Gosnells

LOCAL HOUSING STRATEGY PLAN
North Gosnells Housing Precinct



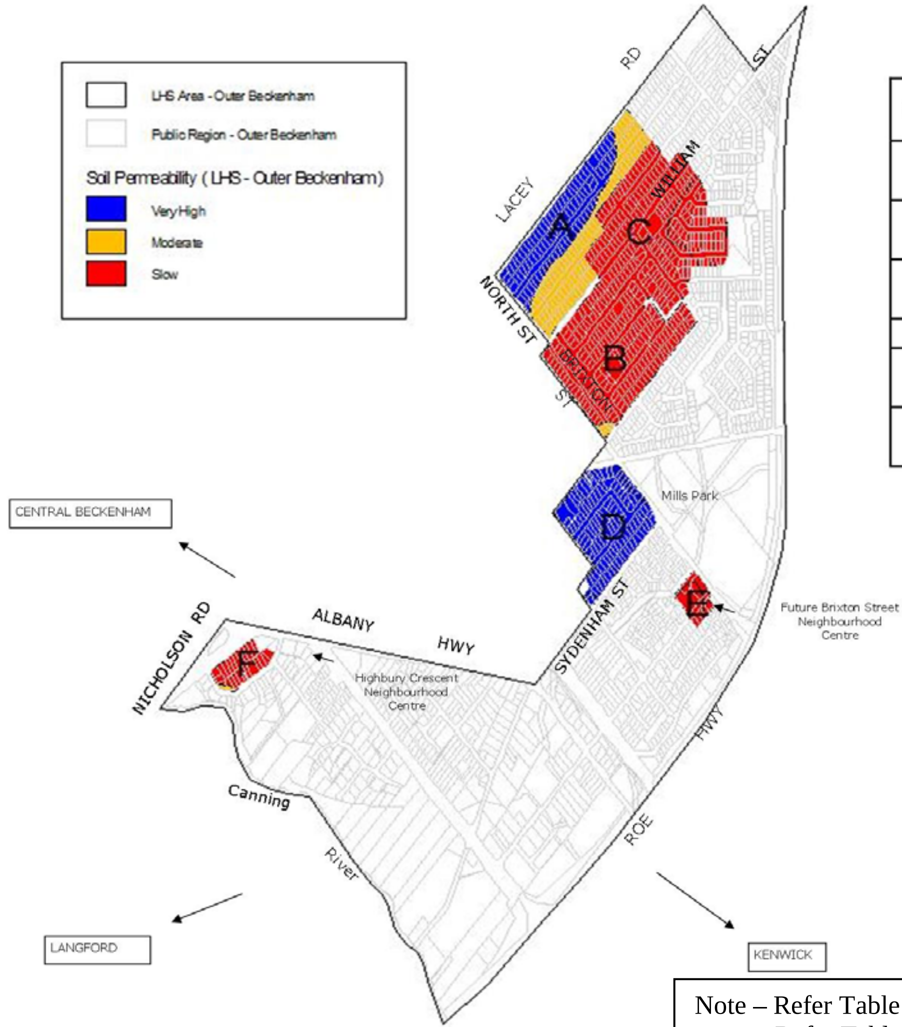
Sub Precinct	Dominant Soil Type	Soil Permeability (m/day)
A	Deep sands	0.48 < 1.56
	Wet or waterlogged & Deep sands	0.48 < 1.56
B	Deep sands	> 1.56
	Wet or waterlogged & Deep sands	> 1.56

Note – Refer Table 7.2 for selecting of Best Stormwater Management Strategy
Refer Table 7.3 for Reference Guidelines

Figure 4:21 – Permeability Distribution Map – North Huntingdale

LOCAL HOUSING STRATEGY PLAN

North Huntingdale Housing Precinct



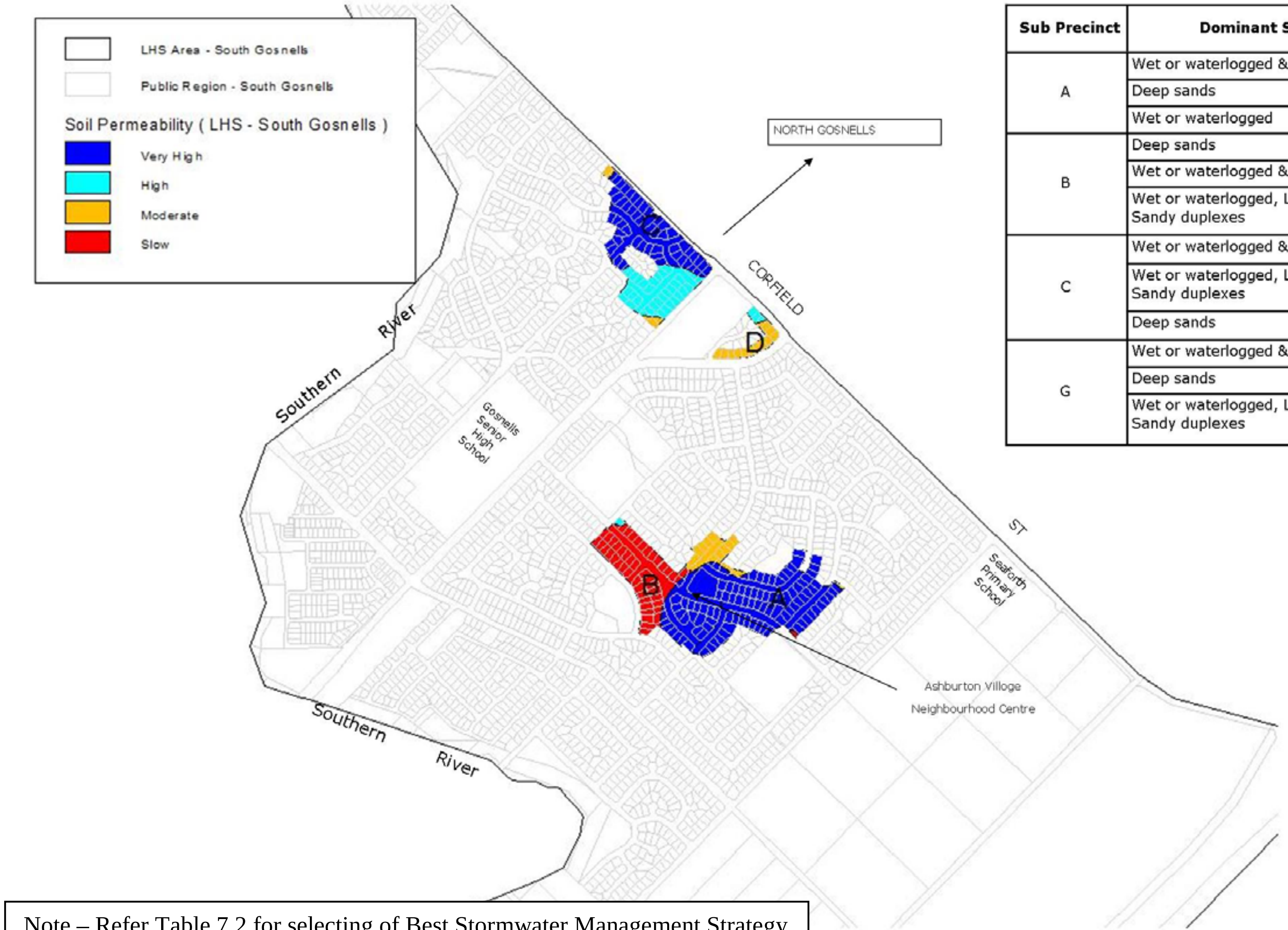
Sub Precinct	Dominant Soil Type	Soil Permeability (m/day)
A	Shallow sands	> 1.56
	Wet or waterlogged & Deep sands	0.12 < 0.48
B	Wet or waterlogged & Deep sands	< 0.12
	Wet or waterlogged	0.12 < 0.48
C	Wet or waterlogged & Deep sands	< 0.12
	Wet or waterlogged	< 0.12
D	Wet or waterlogged & Deep sands	> 1.56
E	Wet or waterlogged & Deep sands	< 0.12
	Wet or waterlogged	< 0.12
F	Wet or waterlogged	0.12 < 0.48
	Wet or waterlogged & Deep sands	< 0.12

Note – Refer Table 7.2 for selecting of Best Stormwater Management Strategy
Refer Table 7.3 for Reference Guidelines

Figure 4:22 – Permeability Distribution Map – Outer Beckenham

LOCAL HOUSING STRATEGY PLAN

Outer Beckenham Housing Precinct



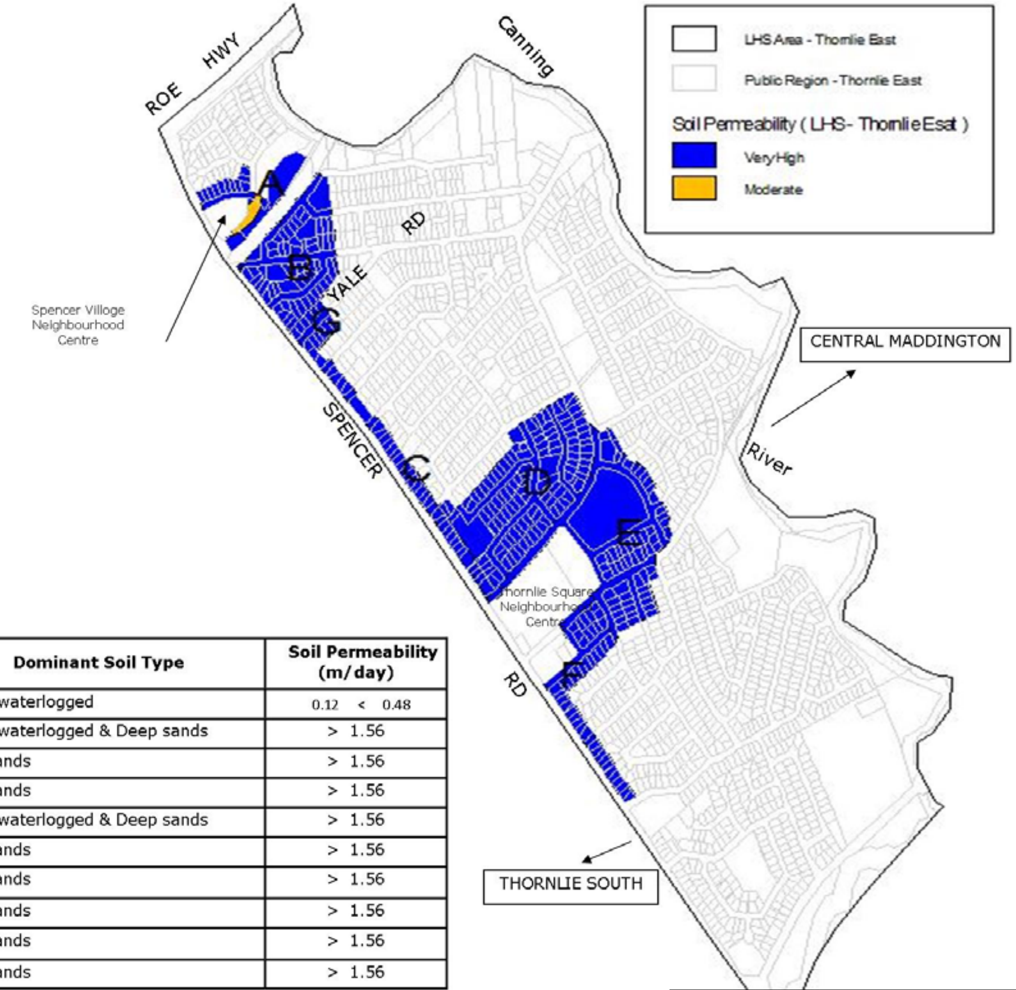
Sub Precinct	Dominant Soil Type	Soil Permeability (m/day)
A	Wet or waterlogged & Deep sands	0.12 < 0.48
	Deep sands	> 1.56
	Wet or waterlogged	< 0.12
B	Deep sands	> 1.56
	Wet or waterlogged & Deep sands	< 0.12
	Wet or waterlogged, Loamy duplexes & Sandy duplexes	0.48 < 1.56
C	Wet or waterlogged & Deep sands	> 1.56
	Wet or waterlogged, Loamy duplexes & Sandy duplexes	0.48 < 1.56
	Deep sands	0.12 < 0.48
G	Wet or waterlogged & Deep sands	0.48 < 1.56
	Deep sands	0.12 < 0.48
	Wet or waterlogged, Loamy duplexes & Sandy duplexes	0.12 < 0.48

Note – Refer Table 7.2 for selecting of Best Stormwater Management Strategy
Refer Table 7.3 for Reference Guidelines

Figure 4:23 – Permeability Distribution Map – South Gosnells

LOCAL HOUSING STRATEGY PLAN

South Gosnells Housing Precinct



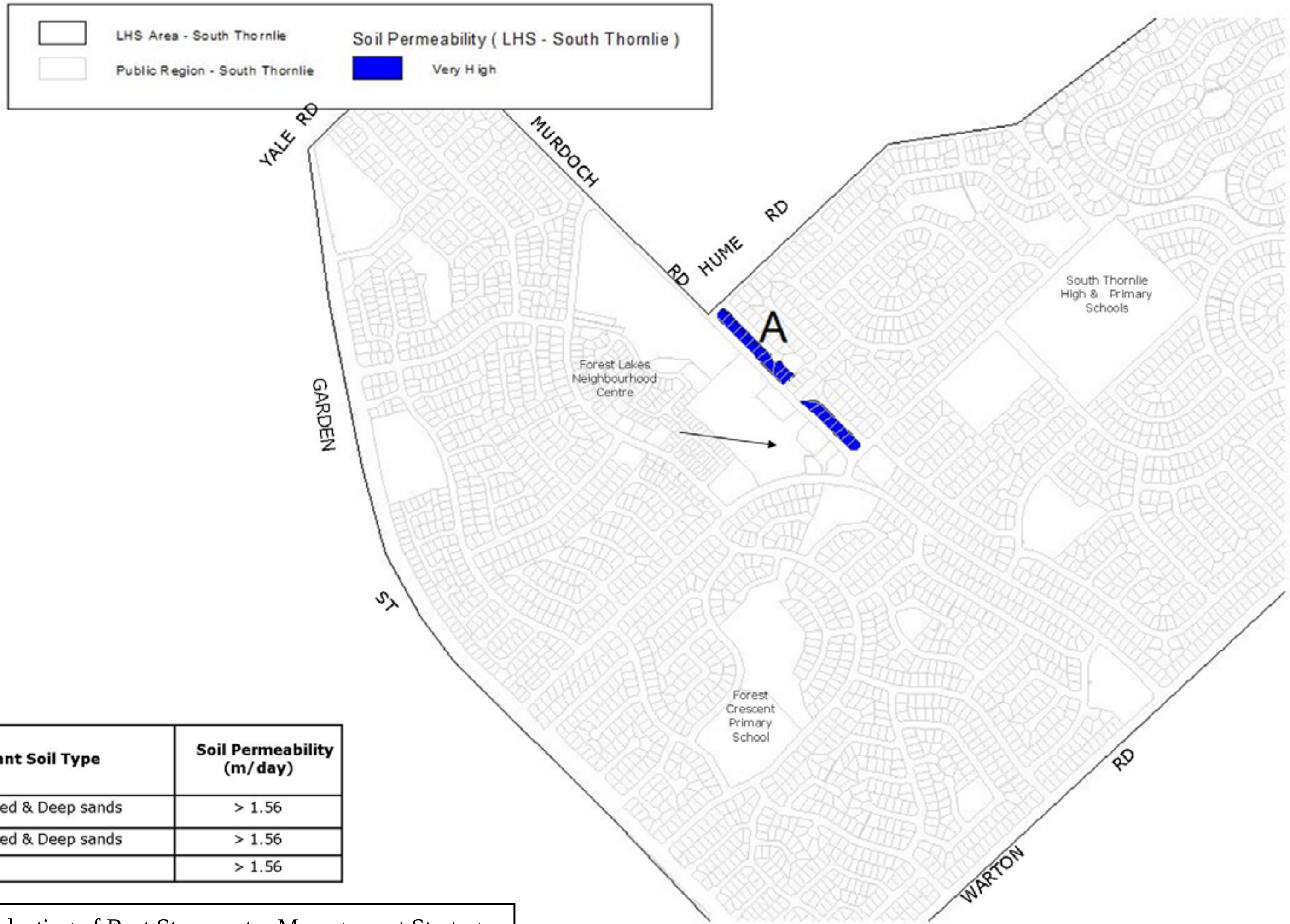
Sub Precinct	Dominant Soil Type	Soil Permeability (m/day)
A	Wet or waterlogged	0.12 < 0.48
	Wet or waterlogged & Deep sands	> 1.56
	Deep sands	> 1.56
B	Deep sands	> 1.56
	Wet or waterlogged & Deep sands	> 1.56
C	Deep sands	> 1.56
D	Deep sands	> 1.56
E	Deep sands	> 1.56
F	Deep sands	> 1.56
G	Deep sands	> 1.56

Note – Refer Table 7.2 for selecting of Best Stormwater Management Strategy
Refer Table 7.3 for Reference Guidelines

Figure 4:24 – Permeability Distribution Map – Thornlie East

LOCAL HOUSING STRATEGY PLAN

Thornlie East Housing Precinct



Sub Precinct	Dominant Soil Type	Soil Permeability (m/day)
A	Wet or waterlogged & Deep sands	> 1.56
	Wet or waterlogged & Deep sands	> 1.56
	Deep sands	> 1.56

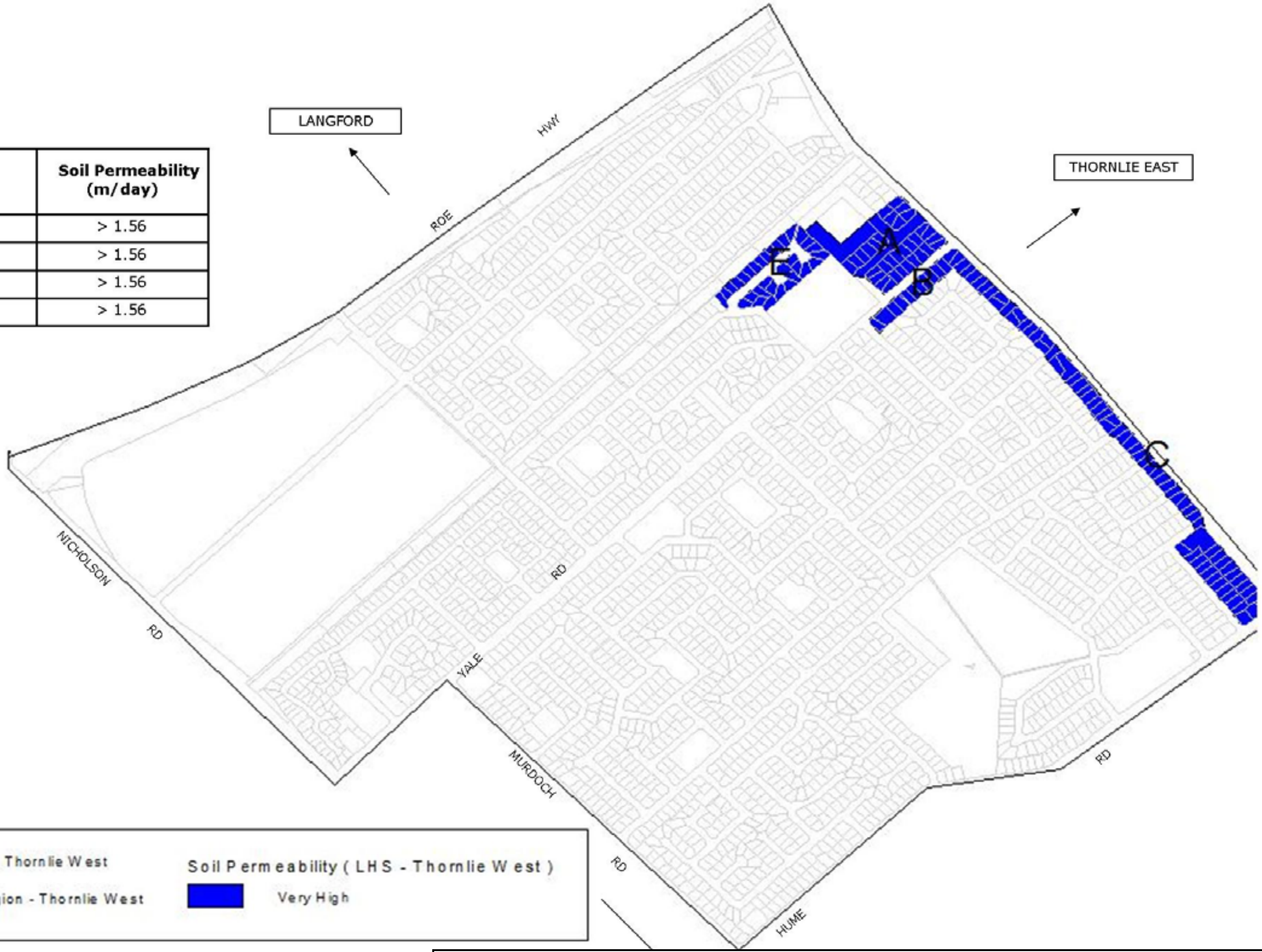
Note – Refer Table 7.2 for selecting of Best Stormwater Management Strategy
Refer Table 7.3 for Reference Guidelines

Figure 4:25 – Permeability Distribution Map – South Thornlie

LOCAL HOUSING STRATEGY PLAN

South Thornlie Housing Precinct

Sub Precinct	Dominant Soil Type	Soil Permeability (m/day)
A	Deep sands	> 1.56
B	Deep sands	> 1.56
C	Deep sands	> 1.56
E	Deep sands	> 1.56



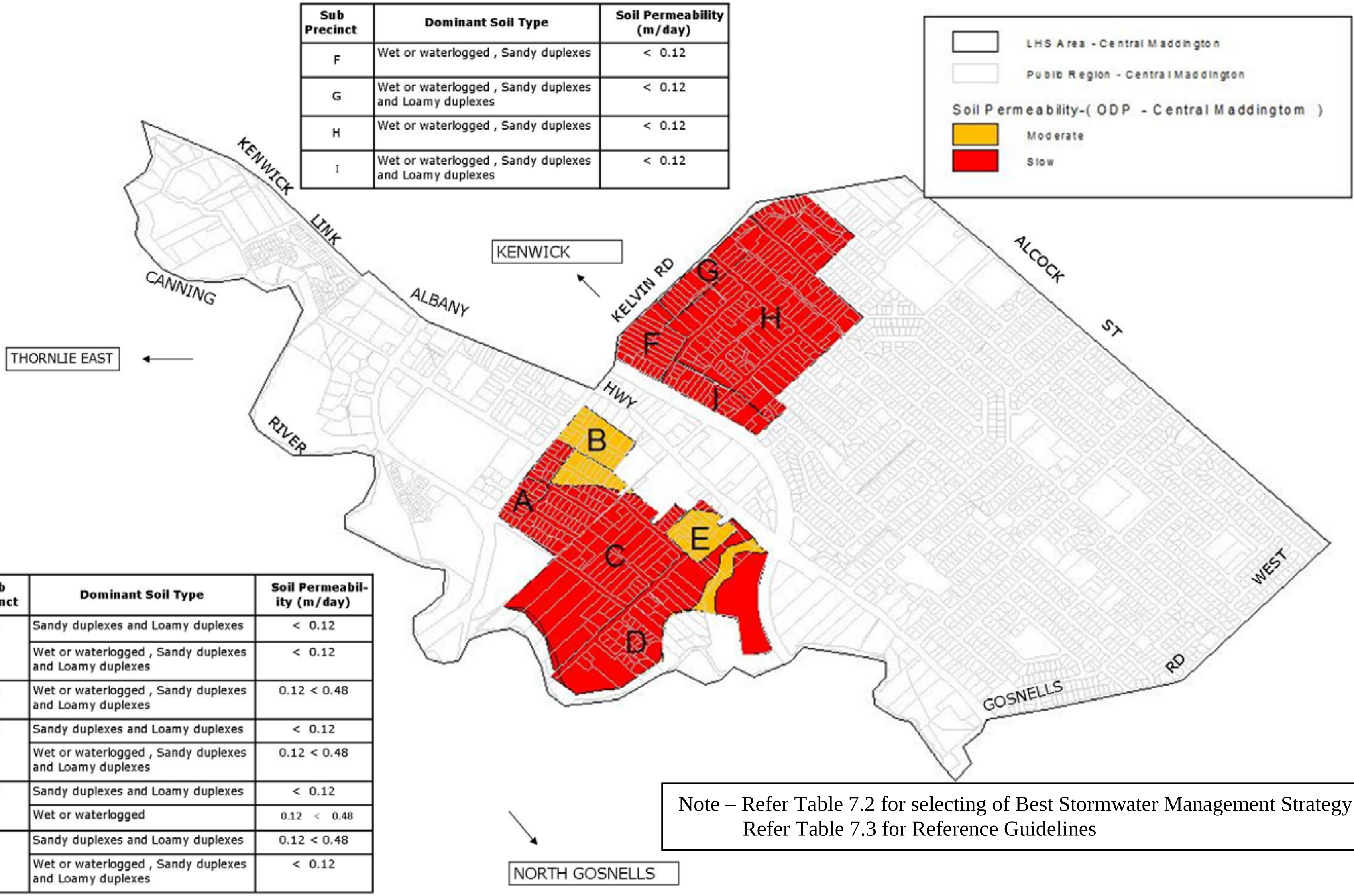
Note – Refer Table 7.2 for selecting of Best Stormwater Management Strategy
Refer Table 7.3 for Reference Guidelines

Figure 4:26 – Permeability Distribution Map – Thornlie West

LOCAL HOUSING STRATEGY PLAN

Thornlie West Housing Precinct

Sub Precinct	Dominant Soil Type	Soil Permeability (m/day)
F	Wet or waterlogged , Sandy duplexes	< 0.12
G	Wet or waterlogged , Sandy duplexes and Loamy duplexes	< 0.12
H	Wet or waterlogged , Sandy duplexes	< 0.12
I	Wet or waterlogged , Sandy duplexes and Loamy duplexes	< 0.12



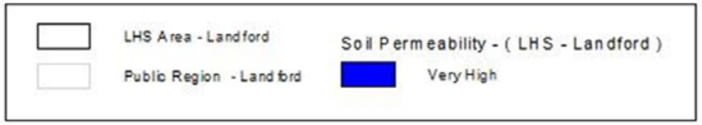
Sub Precinct	Dominant Soil Type	Soil Permeability (m/day)
A	Sandy duplexes and Loamy duplexes	< 0.12
	Wet or waterlogged , Sandy duplexes and Loamy duplexes	< 0.12
B	Wet or waterlogged , Sandy duplexes and Loamy duplexes	0.12 < 0.48
C	Sandy duplexes and Loamy duplexes	< 0.12
	Wet or waterlogged , Sandy duplexes and Loamy duplexes	0.12 < 0.48
D	Sandy duplexes and Loamy duplexes	< 0.12
	Wet or waterlogged	0.12 < 0.48
E	Sandy duplexes and Loamy duplexes	0.12 < 0.48
	Wet or waterlogged , Sandy duplexes and Loamy duplexes	< 0.12

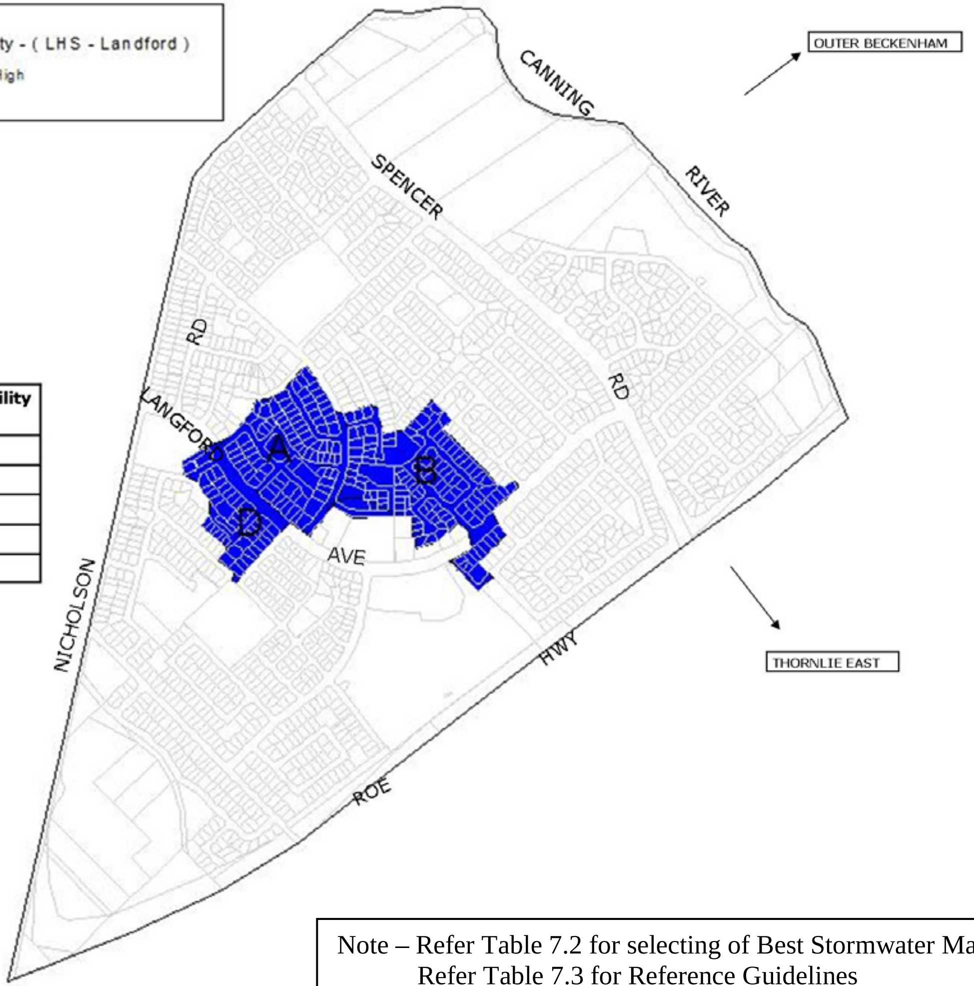
Note – Refer Table 7.2 for selecting of Best Stormwater Management Strategy
Refer Table 7.3 for Reference Guidelines

Figure 4:27 – Permeability Distribution Map – Central Maddington

OUTLINE DEVELOPMENT PLAN

Central Maddington Housing Precinct





Sub Precinct	Dominant Soil Type	Soil Permeability (m/day)
A	Deep sands	> 1.56
	Wet or waterlogged & Deep sands	> 1.56
B	Deep sands	> 1.56
	Wet or waterlogged & Deep sands	> 1.56
D	Deep sands	> 1.56

Note – Refer Table 7.2 for selecting of Best Stormwater Management Strategy
Refer Table 7.3 for Reference Guidelines

Figure 4:28 – Permeability Distribution Map – Landford

LOCAL HOUSING STRATEGY PLAN

Landford Housing Precinct

Further the test results have been used to develop a map (Figure 4:29) which shows the permeability distribution within the City of Gosnells' selected local housing strategy area.

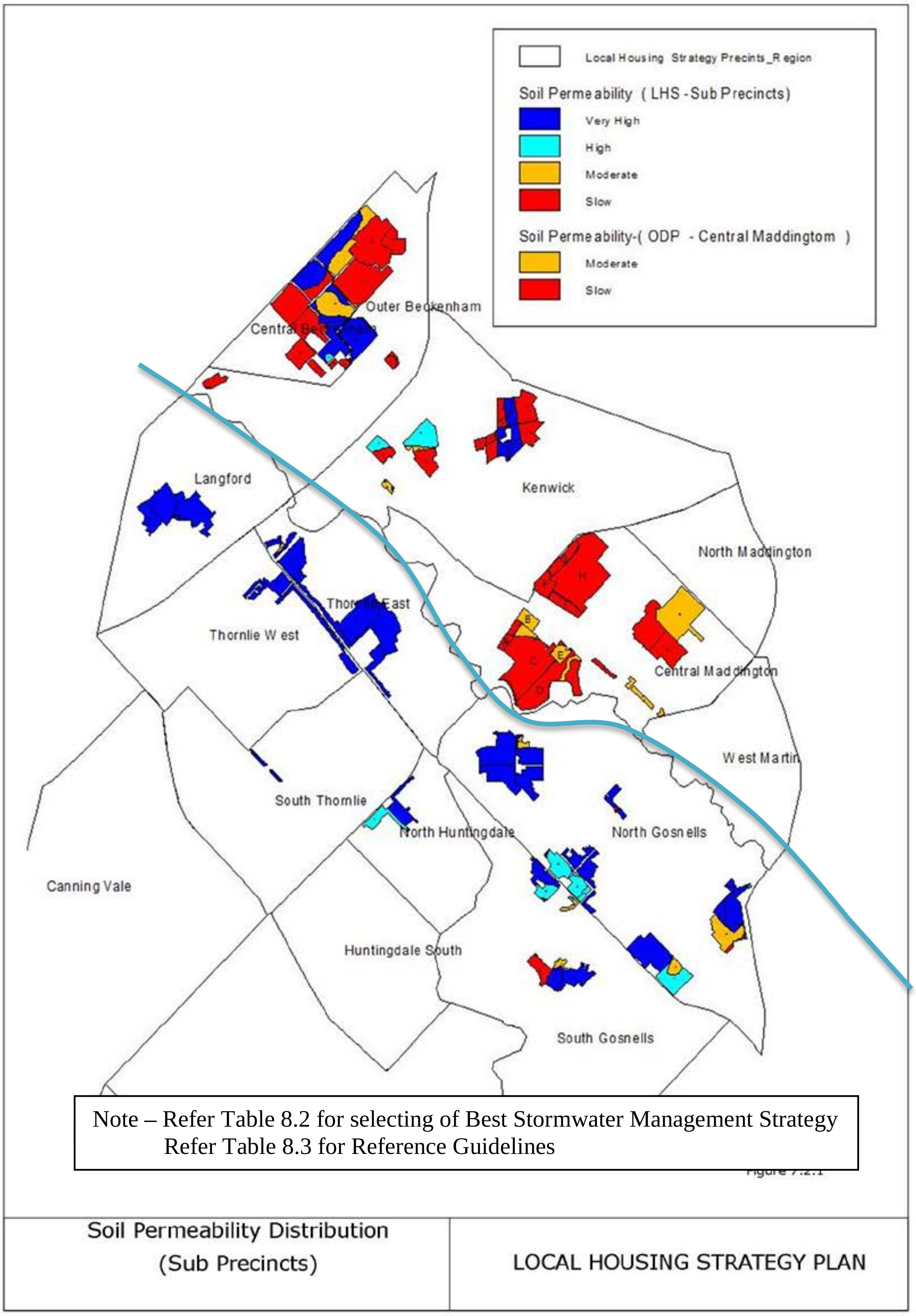


Figure 4:29 – Permeability Distribution Map – All the Sub Precincts

4.9. Conclusions

This chapter discusses the behavioural pattern of saturated hydraulic conductivity as a function of type of soil, depth, and the effect of groundwater, it also discusses validation of the test results through identification of basic soil properties, categorization and preliminary understanding the result compare with the secondary data. Further this chapter is extended to analysis the average saturated hydraulic conductivity of different soil types to compare the both onsite and laboratory test results and finally to understand the soil permeability at different depths. The whole comparison analysis and validation process was mainly focused on step-by-step identification and prioritisation of the factors that may affect to the saturated soil permeability.

As is illustrated in the figures Figure 4:14 and Figure 4:15, there is significant change of permeability in vertical soil profile (from 1m to 1.5 m). Even though the change is only 3% within a half a meter, the trend shows reduction infiltration capacities over depth. Based on this analysis, it can be concluded that the infiltration capacity of the soil gradually decreases with depth.

One of the main applications of the findings is integration of study results to online interactive maps (IntraMap). The study results (onsite and laboratory permeability test results) are added in to a GIS format for further analysis of test results through graphical representation. As per the onsite and laboratory test results which are given in the tables Table 4:38 to Table 4:49**,** the minimum, maximum and average values have been calculated such that users of this data can access most relevant data depending on their design requirements. The hydraulics designers are being advised to use the minimum values as it gives a good safety factor to their design and the maximum values for the designs which focused at lot scale or close to the sampling locations. The average figure can be used in designs which consider the large area such as sub precincts or sub division in preparing local and urban stormwater management plans.

The data set has been further generalized in to an area represent data set for each and every sub precincts under each and every suburb and series of permeability maps have been produced to identify the suitable areas for infiltration based stormwater management. These maps are readily available for all the interested parties to refer.

CHAPTER 5

5 EVALUATION OF INFILTRATION BASED STORM WATER MANAGEMENT CONCEPT AS A SUSTAINABLE APPROACH IN URBAN LAND DEVELOPMENT

This chapter presents the assessment of the infiltration based stormwater management concept as a sustainable approach to manage runoff generated due to urban land development process. Basically, land development areas can be categorised into two main types; "infill developments" and "greenfield developments". The "infill development" stands for the use of vacant land and property within a built-up area for further construction or development, whereas, the "greenfield development" stands for the use of large vacant land block within an undeveloped area for construction or development for residential or commercial purpose. The broader definition of greenfield development generally encompasses non-productive land, habitats and productive farmland on the urban periphery (fringe development). This is also commonly referred to as 'broad acre' land development which is generally located on the fringe of the metropolitan area or near townships. Infill development can be defined in various ways including 'urban consolidation', 'medium density housing', 'redevelopment' or 'high rise development'. Infill tends to be defined as: 'the more intensive use of land for residential development in urban areas' (InfraPlan 2013).

Both infill and greenfield land developments created much of the land surface to be covered by impervious materials. This leads to reduce infiltration and accelerated runoff, which has potential to result in localised flooding. Therefore, traditionally the requirement for urban stormwater management of such areas was capturing runoff collected in the catchment and transporting it as quickly as possible downstream to avoid flooding. However, this stormwater management concept was not a sustainable approach due to bad flooding experiences that occurred in the downstream of the development area. As a result, researcher, scientist and hydrologist have focused on alternative sustainable methods of urban stormwater management in infill or greenfield land development areas.

As an alternative solution to this huge cost involvement process, local city councils search opportunities for stormwater runoff from developing lots to be managed within those developing lots. In order to achieve this target, it is important to identify the different soil properties and development of a typology of suitable stormwater management strategies with respect to applicable infiltration capacities. However, with the lack of detailed information on local soil properties it is difficult to assess the adequacy of stormwater retention/detention requirements within each new development. Then it is important to have area based permeability values rather than having point based permeability. This section of the thesis explains how the point based data set has been generalized logically and practically in to area based data set over the different soil groups.

As discuss in previous chapters, there are many factors that affect the infiltration process. It is very important to study broadly about infiltration systems for maintaining sustainable, environmental friendly storm water management systems to be adopted in the future. The main factors effecting the performance of the infiltration based storm water management systems are permeability of different soil types in layers and depth to the groundwater table. Due to lack of information on local soil properties, specifically permeability rates within the predominant soils in the areas, it is difficult to accurately assess storm water retention/detention requirements without on-site soil testing of the targeting areas. Therefore, it is essential to develop mapping of the soil characteristics pertaining to on-site disposal, retention or detention of storm water runoff. This would support in land development process by providing proper guidance on implementation of drainage strategies based on basic underlying soil parameters.

This study does not intend to categorize greenfield or infill development as good or bad given that the benefits, costs and impacts of these two types of development can vary widely depending on where they are applied (city, inner and middle ring metropolitan areas, on the metropolitan periphery and in townships and peri-urban areas) and in what form. Both types of development have significantly contributed to housing choice and a broad housing market over the past few decades. There are lot of recent discussions about urban renewal and density increase, urban stretch and re-zoning between planners, engineers, legislators, state and local government agencies, community groups and residents. The engineers and storm water managers are more concentrated on the proposed land use changes, imperviousness and how much runoff would be generated as a result of proposed residential zoning and what would be the best method of practice to manage that runoff. So, this chapter aims to assess the infiltration based stormwater management concept as a sustainable approach to manage the additional runoff that generated due to infill and Greenfield land development processes.

5.1. Analysis of a clean sand fill requirement with respect to the foundation design and the stormwater management in Greenfield subdivision process.

5.1.1. Introduction: Why we need an extensive fill?

The Greenfield development is the formation of planned communities on previously undeveloped land. This land may be rural, agricultural or unused areas on the borders of urban areas. Unlike urban infill developments, where there is little or no proper suburban planning, greenfield development is about efficient urban planning that aims to provide practical, affordable and sustainable living spaces for growing urban populations. The planning takes future growth and development into account as well as seeks to avoid the various infrastructure issues that plague existing urban areas.

As many people enjoy living near by the water, the Coastal areas and land next to rivers and wetlands are usually high in demand. As a result, many of our wetlands have already been converted from natural places into highly developed areas. In the worst cases, wetlands have been drained totally removing this habitat type from the local area. The current development trend is purchasing a cheap land parcel which is mostly the remaining multi use wetlands. They are low lying areas where the groundwater fluctuates rapidly and sits on low line areas. On the other hand, these soggy, unusable and less value Multi-use wetlands are cheaper to purchase with compare to the other lands. Therefore, developers are more concerned on developing these lands than other lands.

A piece of land that looks gorgeous to the developer's eye may look like trouble to an experienced civil consultant engineers. Issues such as soil type, the presence of ledge, high water tables, and poor drainage are just some of the issues that can complicate construction of subdivision and drive up costs. Some issues, such as the slope of the site are obvious. If the site drops over the width of the land, you will need a retaining wall on the low side (or a stepped-down foundation). Soil types are less obvious, but certain types of problem soils can make a site challenging and expensive to build on. The other main concern is the shallower groundwater that often is the most difficult site issue to manage. The surface water, including runoff from rain, can cause erosion and flooded low line areas if not properly managed. Subsurface water can interfere with septic systems and flood basements, often in the spring or rainy season when the water table is highest. Both issues can be dealt with using proper grading and drainage techniques.

However, most of the site problems can be overcame by an experienced and engineered solution and some of these solutions can be turned into assets with a little creativity. Most of the drainage issues that occurs due to a shallower groundwater condition can be overcome by providing a proper groundwater and surface water separation strategy. An extensive clean sand fill with a properly designed subsoil drainage system would be an ideal solution, if the intercepted groundwater is clean or has a proper solution to treat the runoff before it discharges in to the receiving water body. The subsoil drainage is laid at or above the Average Annual Maximum Groundwater level (AAMGL) and mostly below the Maximum Groundwater Level (MGL). The level at which the subsoil is laid is called Assessed Groundwater Level or Critical Groundwater Level (CGL).

The depth of clean sand fill is mainly decided on the proposed groundwater and the surface water drainage strategy for the entire development and the minimum soil classification requirement for building foundations. Both of these criteria are to be fulfilled based on the geotechnical report recommendations. The geotechnical investigation is one of the major actions to be followed during the early stage in the subdivision process.

The main purpose of the geotechnical investigation is to provide the following for residential subdivision purposes:

- Site classification in accordance with AS 2870-2011 Residential slabs and footings;

- An assessment of subsurface soil profile and groundwater conditions across the proposed area of development;
- Recommendations for stormwater drainage design; and
- Recommendations on earthworks and site preparation

As clearly explained above, the minimum clean sand fill requirement for a particular subdivision is totally dependent on whichever critical is relevant for purpose. This is on either fill required for minimum site classification for slabs and footing or the fill required for separation of the groundwater level from the critical element of the stormwater management strategy use for the site. The next two sections will review the current and common practice of the standard fill requirement under residential slabs and footing and shallower groundwater conditions.

5.1.2. Minimum fill requirement due to Residential Slabs and Footing designs

Australian standard AS 2870-2011 for Residential Slabs and Footings provides guidance on site classification for residential slabs and footing design based on the expected ground surface movement and depth of expected moisture changes. Table 5:1 below shows the categories of different class of soils that are required for different kind of foundations.

Table 5:1-The categories of different class of soils

Clause 2.1.2 Table 2.1	
Class	Foundation
A	Most sand and rock sites with little or no ground movement from moisture changes
S	Slightly reactive clay sites, which may experience only slight ground movement from moisture changes (0<ys⩽20mm)
M	Moderately reactive clay or silt sites, which may experience moderate ground movement from moisture changes (20<ys⩽40mm)
H1	Highly reactive clay sites, which may experience high ground movement from moisture changes (40<ys⩽60mm)
H2	Highly reactive clay sites, which may experience very high ground movement from moisture changes (60<ys⩽75mm)
E	Extremely reactive sites, which may experience extreme ground movement from moisture changes (ys>75mm)
Clause 2.1.3 Classification of other Sites	
P	Sites which include soft or unstable foundations such as soft clay or silt or loose sands, landslip, mine subsidence, collapsing soils and soils subject to erosion, reactive sites subject to abnormal moisture conditions and site that cannot be classified in accordance to Table 2.1

The above site classification informs the design engineers in the design of footing and foundation. However, the cost involves with construction of footing and foundations dramatically varies from footing designed for A class soil to E class soil. It is mainly due to this reason that some of the councils require all the subdivision's earth work process to be designed according to their own policy framework. This is to ensure that subdivision and development earthworks are undertaken to a minimum standard.

The following earthwork requirements relate to all subdivisions and developments :(Source: - Policy No CP 2.4.1- Earthwork Conditions for Subdivision and Developments - City of Gosnells)

- All land that is to be subdivided or developed is required to have a minimum site foundation standard of Class S for lots that are less than or equal to 400m2, as defined in the Australian Standard for Residential Slabs and Footings (AS 2870). A geotechnical report shall be provided to demonstrate that Class S standard has been achieved.

- To achieve the minimum site classification all earthworks are to be completed in accordance with the Institute of Public Works Engineering Australia (WA Division) Sub-divisional Guidelines (as amended) and the City of Gosnells' addendum to the Institute of Public Works Engineering Australia (WA Division) Subdivisional Guidelines (as amended).

- All filling material is to be properly consolidated clean, coarse, clay-free sand that is free from foreign matter [Filling specification provided in the IPWEA Guidelines section. 2.3.1].

- In accordance with AS 2870-2011 provided that all unsuitable materials are removed and replaced with engineer-controlled sand fill materials in accordance with the earthwork recommendations.

5.1.3. Minimum fill required for selected infiltration based best management strategy at shallower groundwater condition

This section discuss how the author has achieved best groundwater management practices within the City of Gosnells local government area with the help of the knowledge gain through 8 years of this thesis study and lesson learnt from last 8 years working as a development Engineer. In a shallower groundwater condition, the groundwater management strategy becomes more critical than the surface runoff management and need to be addressed carefully. The depth of the minimum fill requirement is mainly dependent on two things.

1. The depth of the stormwater management strategy that has been selected for the development at lot scale and the street scale.

2. The required minimum separation to the physical infrastructure, residential footings and to the invert of the stormwater management measures. (This minimum separation is 300mm and however this can be 500mm depending on the other site constraints).

The Figure 5:1 shows an example of calculating the minimum fill requirement. If the soak well is the critical element out of the selected stormwater management strategies for the development, and the depth of the soak well is 1.5m then, the total separation would be 2m.

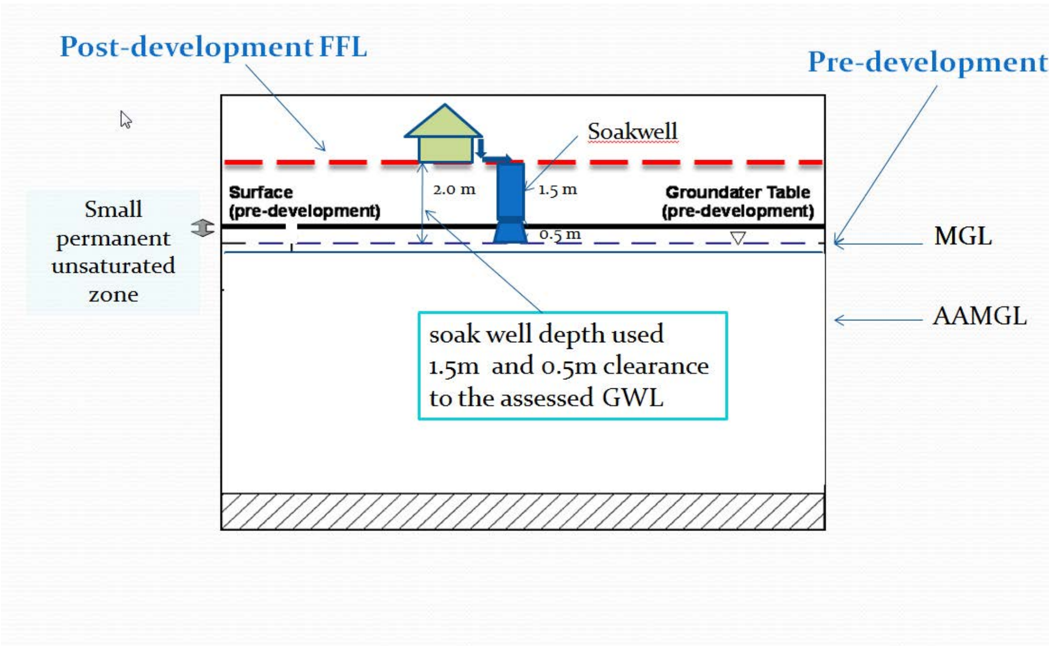


Figure 5:1 - Example of calculating minimum separation that required from finish floor level to the assessed groundwater level

Figure 5:2 explains the different types of groundwater management strategies that are currently been practised widely, which follow the current and minimum standard. This chart would be an ideal tool for selecting a best groundwater management strategy depending whether it requires use of subsoil or not, and if so whether the subsoil requires treatment before it discharges in-to the receiving water body. It is important to pick up the right groundwater management strategy at the beginning of the subdivision and planning process at the Local Water Management Strategy

(LWMS) stage as it may be too late to correct the wrong decision made at the end. Wrong management strategy may greatly affect to the sustainability of the subdivision and lead to the whole drainage system not functioning properly. This may result in to some environmental issues such as localize flooding, submerge drainage system, mosquito breeding etc.

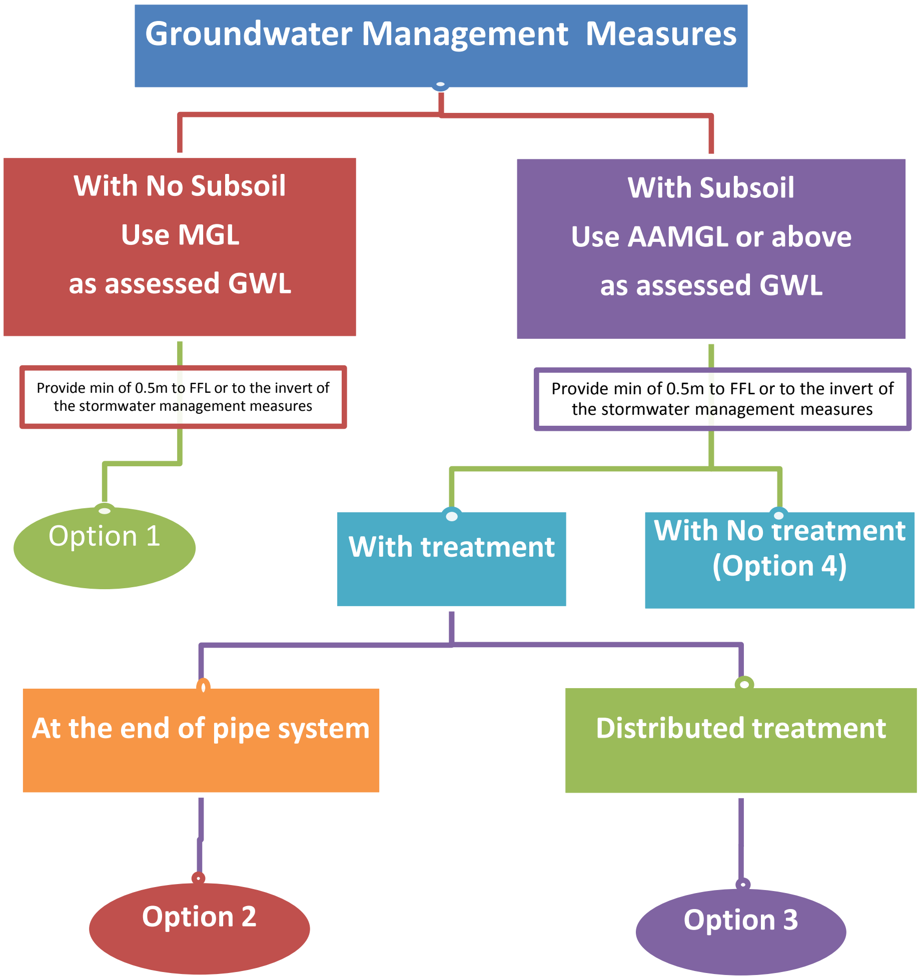


Figure 5:2 - Flowchart for selecting of best groundwater management strategy

These four different groundwater management strategies were used within the same subdivision area to overcome some of the lessons learn from the experience of groundwater management techniques used in different stages of subdivisions. This large-scale subdivision is located in shallower groundwater condition area within the City of Gosnells and also at the vicinity of a river. And also, the seasonal groundwater fluctuation is very high within the area.

Catchment characteristics of the development site

- Very little relief
- Very shallow groundwater
- Evapotranspiration accounts from most water loss
- Long travel times to drainage channels
- Large residence times for pollutants
- Legacy nutrients

The below picture (Figure 5:3) shows the typical groundwater condition within the development area where four different ground water management strategies were used to control the post development groundwater level rise.

Figure 5:3 – Groundwater condition at the development site during winter period

Option 1 – With No Sub soil (Use MGL as assessed Groundwater Level)

The option 1 is clear and straightforward. This can be applicable to any of the development site easily. With the previous experience of the City of Gosnells subsoil's drainage practice, this strategy is the most sustainable. However, this option requires considerable amount of imported clean sand fill as compared to the other two options. The Maximum Groundwater level (MGL) for the site is considered as assessed Groundwater levels and then the sand pad levels of the finished subdivision need to be set at 0.5m above the MGL levels. If the site is prepared accordingly, then there is no requirement of subsoil drainage for the development which is free of additional sub soil treatments or any other infrastructure that are normally require in subdivision with sub soil drainage. The fill requirement compare to the existing ground levels is demonstrated in the Figure 5:4.

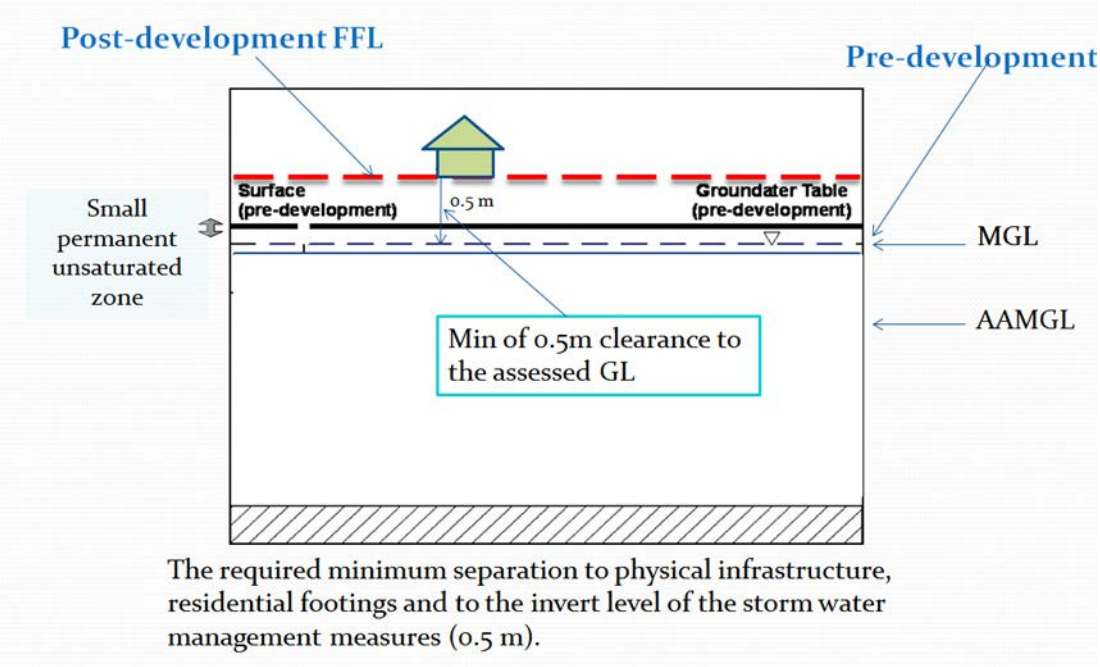


Figure 5:4 – With No Sub soil (Use MGL as assessed Groundwater level)

Option 2 – With Sub soil (Use AAMGL or above as assessed Groundwater Level) Treatment is at the end of the pipe system

This is the most common and widely used groundwater management strategy. This strategy requires less fill as compare to the option 1. This strategy was the most cost-effective method until option 3 is invented for groundwater management, option 3 proves more effective as compared to the other two options. It was recently developed by the City as part of collaborative research with other government and research institutions. With option 2, the sub soil drainage pipes are set at AAMGL or above (below the MGL) such that it intercepts the groundwater during the winter months of the year to control the groundwater rise above the designed assessed groundwater level.

The Figure 5:5 below shows how the subsoil drains can help control the groundwater levels and also it shows saving on depth of fill (drawdown) as compared to option 1. If the intercepted groundwater is highly polluted, then the only option available for treating the polluted groundwater is by exposed to ground surface and use bio-filtration system at the end of the system for treatment. Due to this reason, the requirement of subsoil system should be properly pre-assessed at the early stage of drainage assessment. If the treatment options are not available at the end of the system, then the only solution available is pumping back to the upstream catchment.

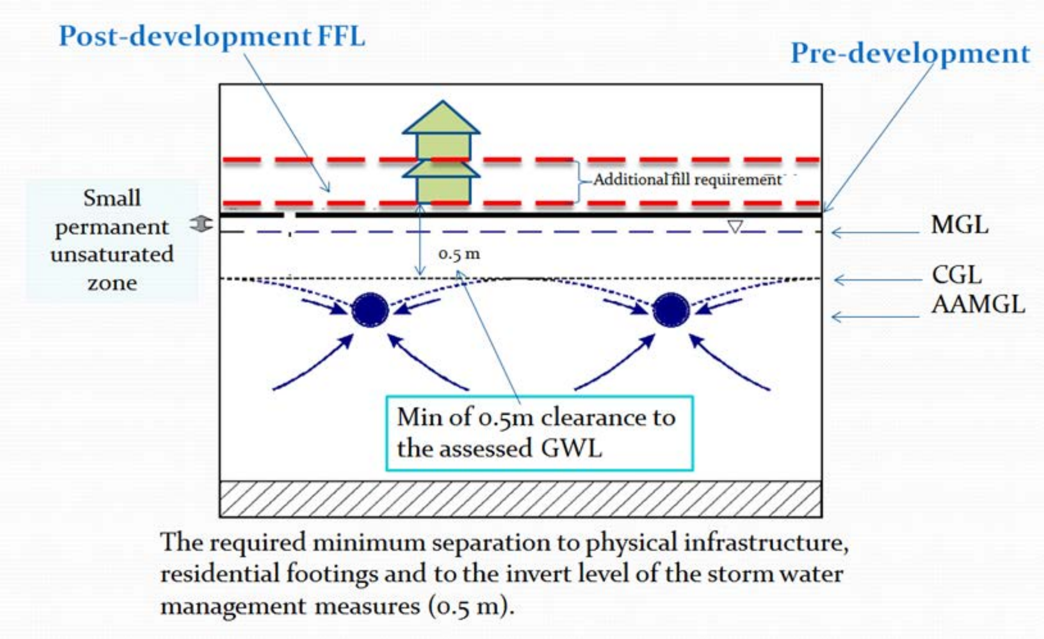


Figure 5:5 – With Sub soil (Use AAMGL or above as assessed Groundwater level) Treatment is at the end of the pipe system

Option 3 – With Sub soil (Use AAMGL or above as assessed Groundwater Level) Treatment is at source.

The option 3 is considered as the most cost effective and well-engineered solution that city invented so far in controlling the groundwater rise as well as treating the highly-polluted groundwater. It has been proposed through joint collaboration between developers, the City of Gosnells, Commonwealth Scientific and Industrial Research Organisation (CSIRO), Department of Water (DoW) and Swan River Trust (SRT) to conduct an in-situ trail of Neutralised Used Acid (NUA) blended soil around subsoil drains. NUA is mineral sand by-product showing considerable nutrient retention properties. Intercepted groundwater will be treated through the use of amended fill brought into the site to remediate the intercepted nutrient enriched groundwater.

The NUA is an industrial by product containing 50% gypsum and 50% iron manganese oxide hydroxide will be blended with an appropriate fill at a maximum ratio of 1:20. Subsoil drains that are placed at Assessed Groundwater Level (AGL) will be improved through a NUA treatment layer surrounding the subsoil drain

With compare to the other two options that has been discussed above, the fill requirement for subdivision to control the groundwater rise with option 3 is very minimal. This option is considered as best management practice for controlling the both groundwater level rise as well as the quality. Figure 5:6 below shows how the soil amendments would help to treat the subsoil flows at source.

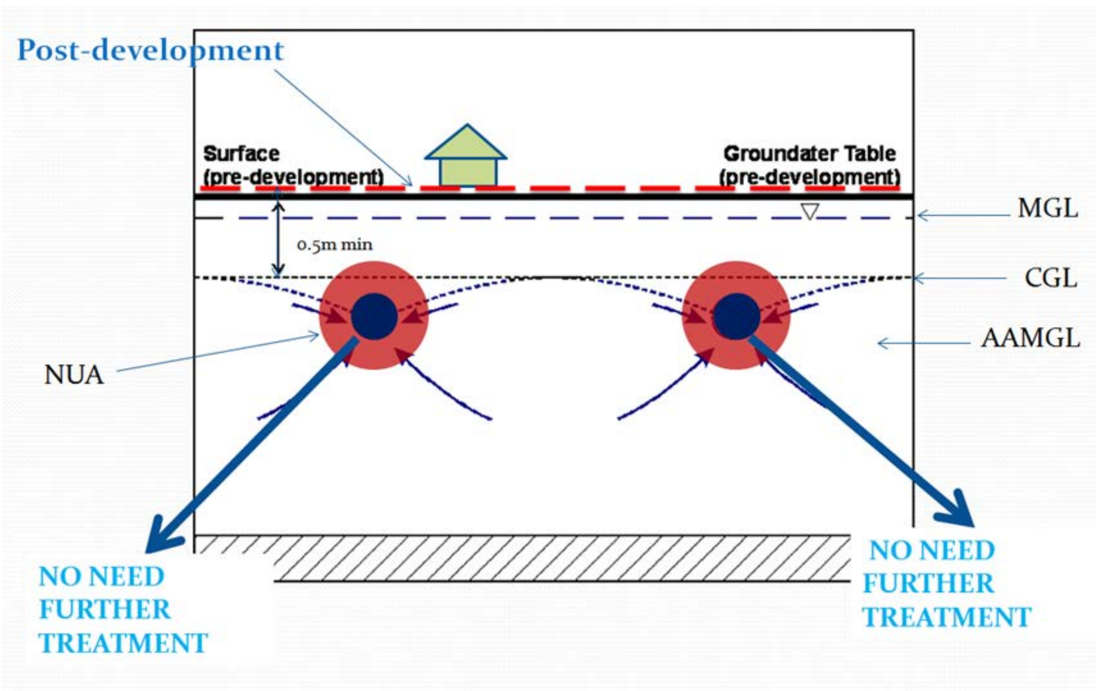


Figure 5:6 – With Sub soil (Use AAMGL or above as assessed Groundwater Level) Treatment is at source

Option 4 – With Sub soil (Use AAMGL or above as assessed Groundwater Level) No Treatment is required.

This option is straight forward and can be used where the intercepted groundwater quality is accepted to direct discharge in to the receiving water body.

5.2. Recommendation for stormwater management in infill land development – development of a stormwater drainage design calculator for lot retention and detention

This section discuss how the author has achieved best storwater management practices within the City of Gosnells local government area with the help of the knowledge gain through 8 years of this thesis study and lesson learnt from last 8 years working as a development Engineer. Unlike most of the other municipalities soils in the study area, (City of Gosnells area) range from deep sands over to peaty sands and sandy clays through to gravelly sandy clay, granite and laterite. This range of soils in the study area, is in sharp contrast to the fairly uniform 'deep sands', which characterize soil conditions for the bulk of other Perth municipalities along the seaboard and the sandy plain. Common practice in the Perth region is for roof runoff to be diverted to soak wells which then pass the stored flow, by percolation, into the local sands and ultimately, into the unconfined aquifers (water table).

The prime focus of residential street drainage infrastructure - in such circumstances - is therefore to cater, almost entirely, for runoff generated within road carriageways and connected paved areas (for example, allotment driveways) only. The City of Gosnells has attracted increased business and industrial activity in recent years and associated with it, an increased population. The resulting needs – greater commercial and industrial precincts and estates, as well as new residential sub-divisions and infill development, featuring medium density allotments (see Figure 5:7) – has put considerable stress on the existing street drainage network causing 'overload' to occur in many areas.

As a first step towards solving the problem of overload of (street) stormwater pipelines in design storm events (ARI, up to 5 years), the City of Gosnells initiated a survey and assessment of its drainage network and produced a set of plans separating those (pipelines) operating 'beyond capacity' and those operating 'within capacity'. An example of one of these plans is presented in Figure 5:8. The next step in the task was to seek advice on re-development of the entire drainage network to match the expected additional flows. This is an expensive practice (with estimated cost of $120 million). Therefore, the best management is to explore an alternative stormwater management strategy involving on-site retention and detention practices (stormwater 'source control'), whereby flow rates of stormwater delivered to the network would be reduced to match the flows that could be carried by it without augmentation.

To make it easy for the users (land developers and owners) and city council officers to assess any stormwater management application in infilled land development areas, a spreadsheet based stormwater calculator is introduced by City of Gosnells. Data obtain from on-site testing (as shown in Chapter 4) was used as the basic information for the development of this calculator.

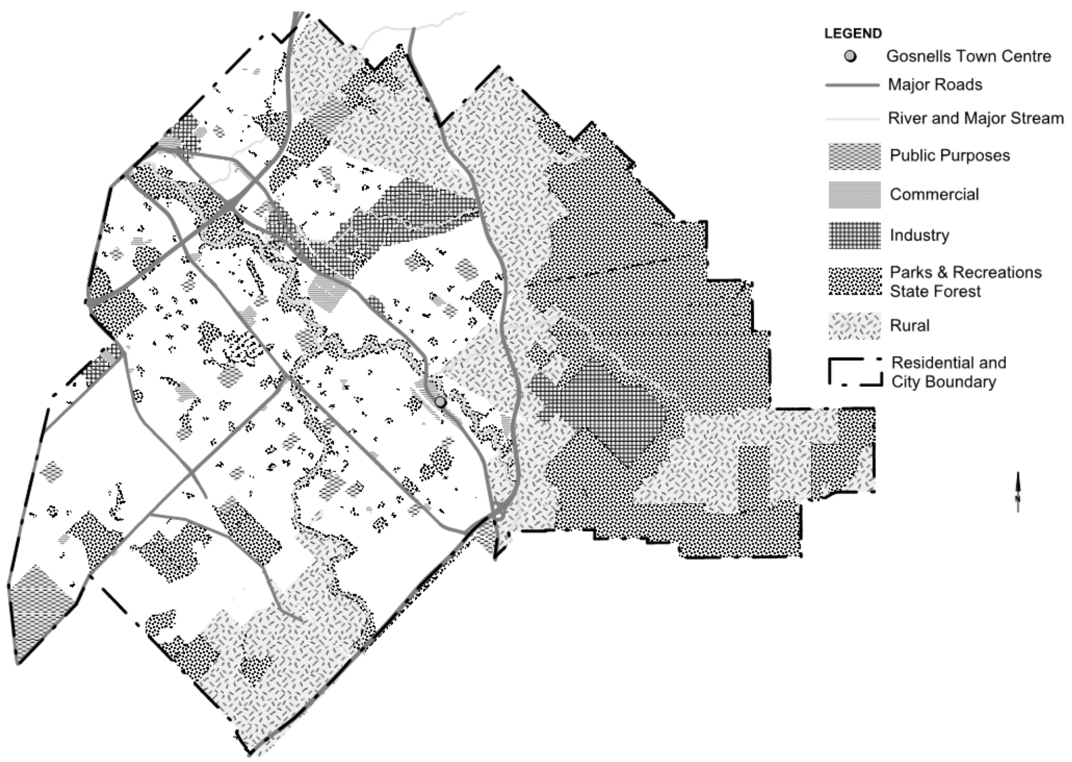


Figure 5:7 – Major features of the City of Gosnells, Western Australia.

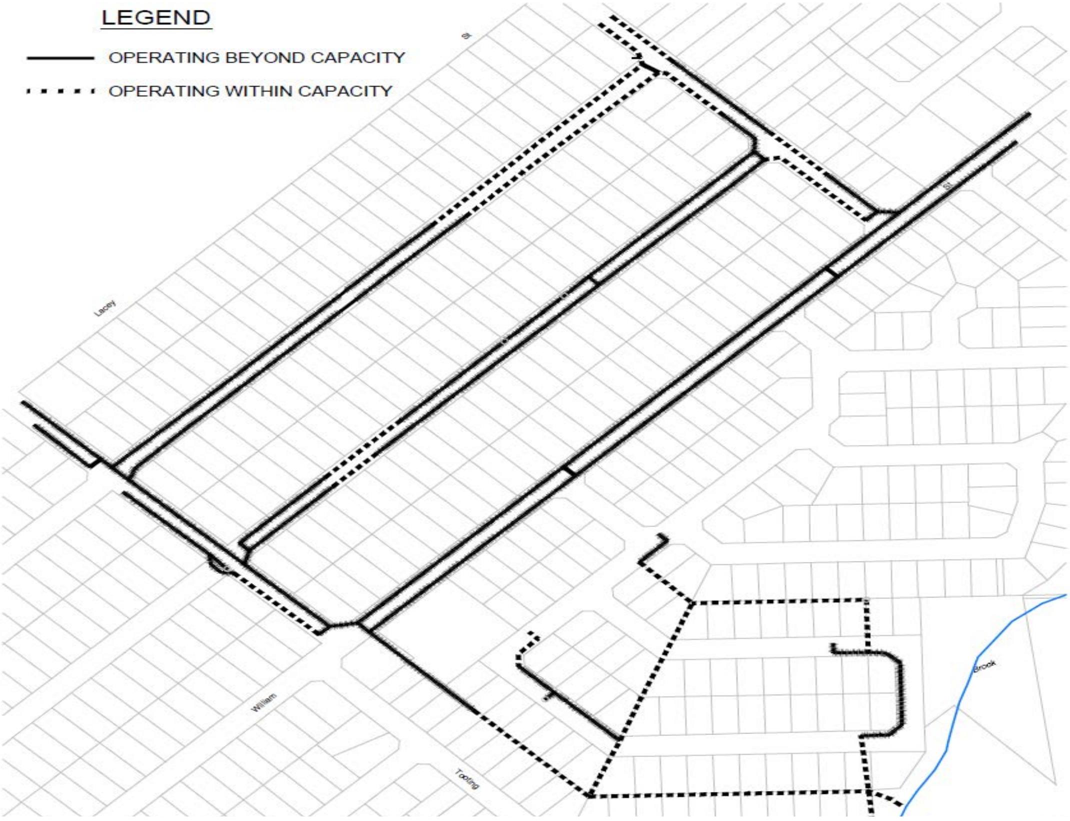


Figure 5:8 – City of Gosnells sub-catchment B13 / Beckenham showing pipelines operating ‘beyond capacity’ and ‘within capacity’.

5.2.1. Some preliminary decisions

The strategy for stormwater management in Gosnells was based on the following decisions/practices

1. Street drainage networks, generally, are near or beyond ‘capacity’; additional development on allotments greater than 350 m2 must therefore be designed – generally - to fully retain “100-years” (ARI) storms with no outflow to (fronting) street drainage systems, when possible. The retained storm runoff is stored temporarily in soakwells which is common practice in Perth sandy soils.

2. This requirement is addressed in certain areas of the City, in particular, those areas characterized by clay and silty soils which have low percolation capability. In these areas, a small outflow is permitted, equivalent to a hypothetical maximum permissible pre-development flow from the lot area, calculated by using a 1 in 5-year ARI and storm duration with a given allotment’s ‘time of concentration’, typically 20 minutes or less. The runoff

coefficient adopted for calculating this flow is C = 0.143 and allows for some historical development of the site, as compared to "virgin" bushland.

3. All properties smaller than 350 m2 are allowed to discharge a small outflow to the street drainage system. This outflow is set at equivalent to a maximum permissible pre-development flow from the lot area with 5-year ARI and storm duration with a given allotment's 'time of concentration', typically 15 minutes. The runoff coefficient adopted for calculating this flow is C = 0.143.

4. Additional assumptions/practices –

   - All roof areas and connected paved areas are connected to in-ground soakwells;
   - Pervious and unconnected paved areas do not contribute stormwater to soakwells;
   - "Design runoff volume" (ARI, Y = 100 years) is determined using rainfall intensities drawn from the full range of storm durations – 6 mins to 72 hours. This produces the greatest runoff volume which must be temporarily stored and therefore, the greatest number of in-ground retention devices; the optimum storm duration given by this process is called "critical storm duration".

This interpretation of 'critical storm duration', based on the full range of storm durations instead of on values derived from catchment-wide analyses which is normal best practice, is justified by the particular circumstances presented in Gosnells, namely, 'at capacity' drainage networks and the acceptance of a small flow from each site with a maximum permissible pre-development, 5-years ARI, into the formal drainage path. It also enables standardization of the design procedure to be incorporated into the Spreadsheet.

5.2.2. Implementation – Site Components

The City of Gosnells provides a Typical Residential Layout for developers to use with the Spreadsheet in preparing a development application. This is illustrated in Figure 5:9.

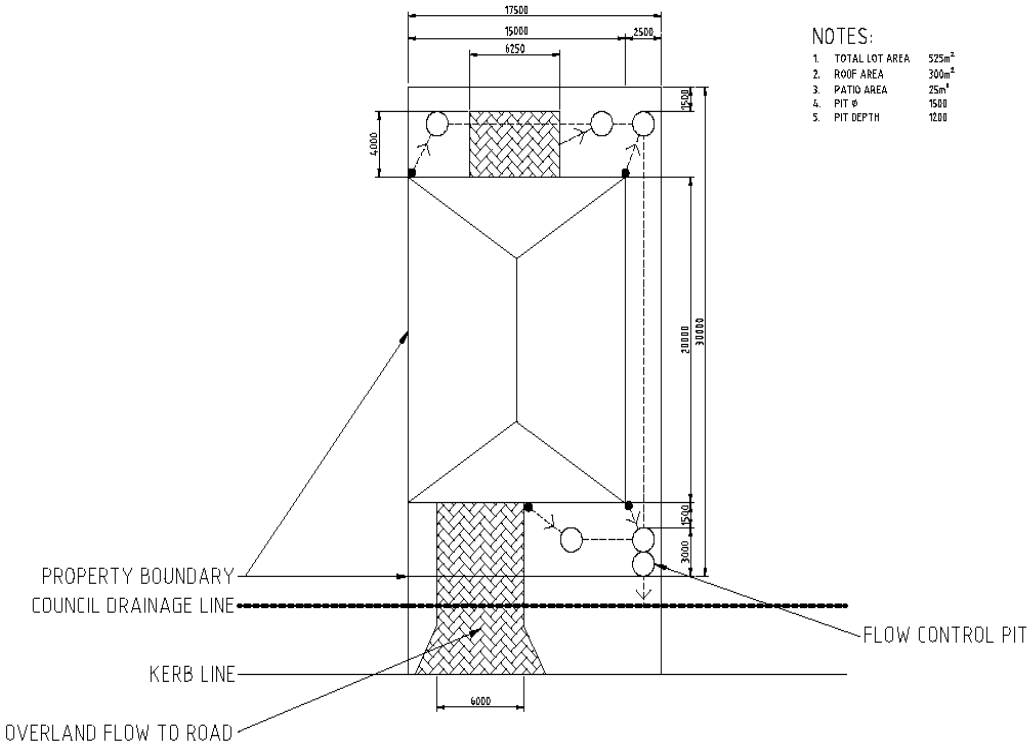


Figure 5:9 – Typical residential layout showing arrangement of soakwells and other features (exemplary model for development application)

Also, the standard drawings are provided to developers which includes typical construction details of soakwells and concrete (in-ground) tanks as required by the City for inclusion in development applications. These drawings remove any uncertainty or misunderstanding about the City’s intentions and requirements for stormwater management in new developments. The details are illustrated in Figure 5:10 and Figure 5:11 respectively. Furthermore, drawings outline the critical key elements of on-site stormwater management that should be considered as a minimum. Further, explanatory notes are provided by the City, to clarify the approach and to explain why this method is required. The theory behind the spreadsheet development will be outlined in the Section 5.2.3.

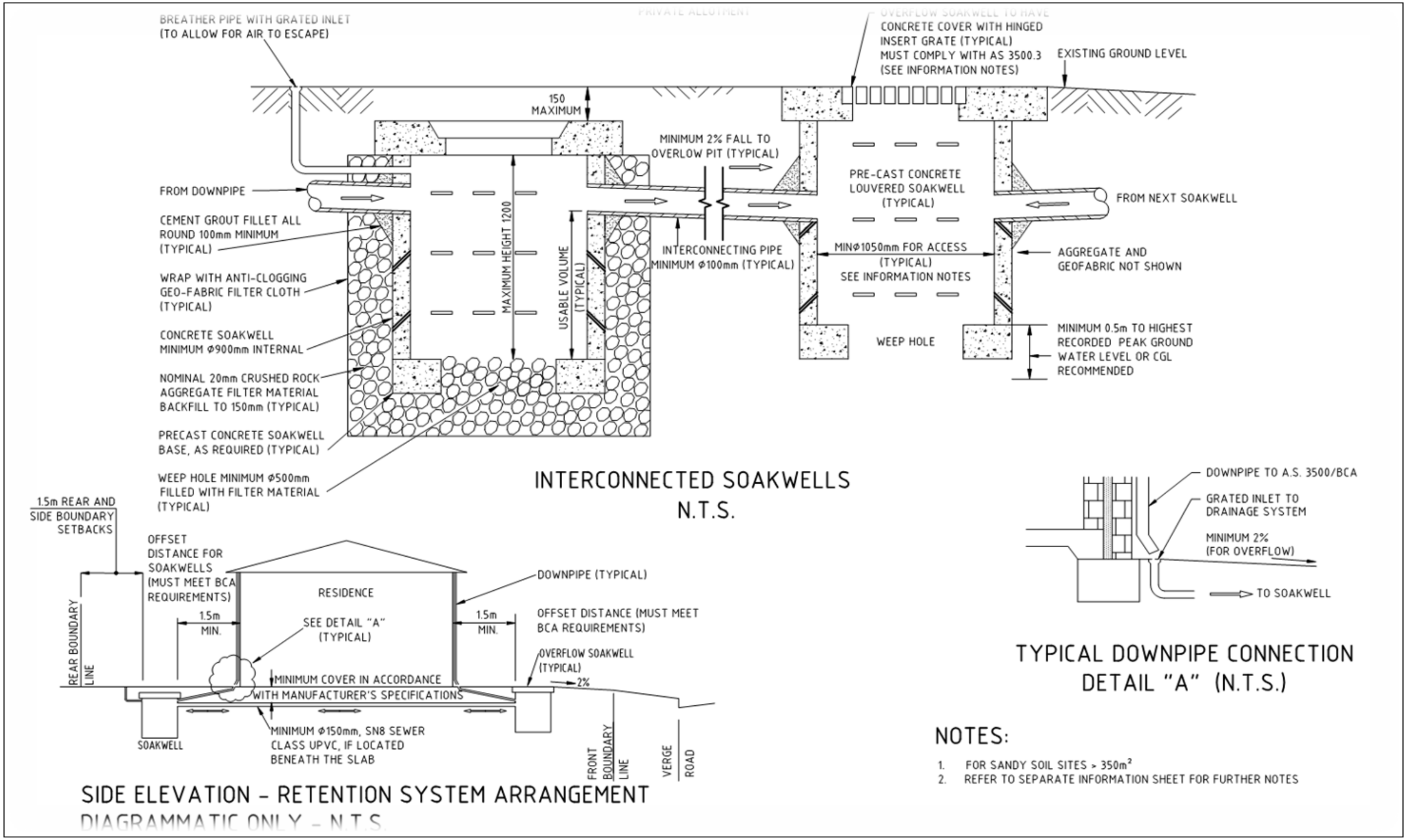


Figure 5:10 – Details of inter-connected soakwells and house/soakwells arrangement in high soil permeability sites

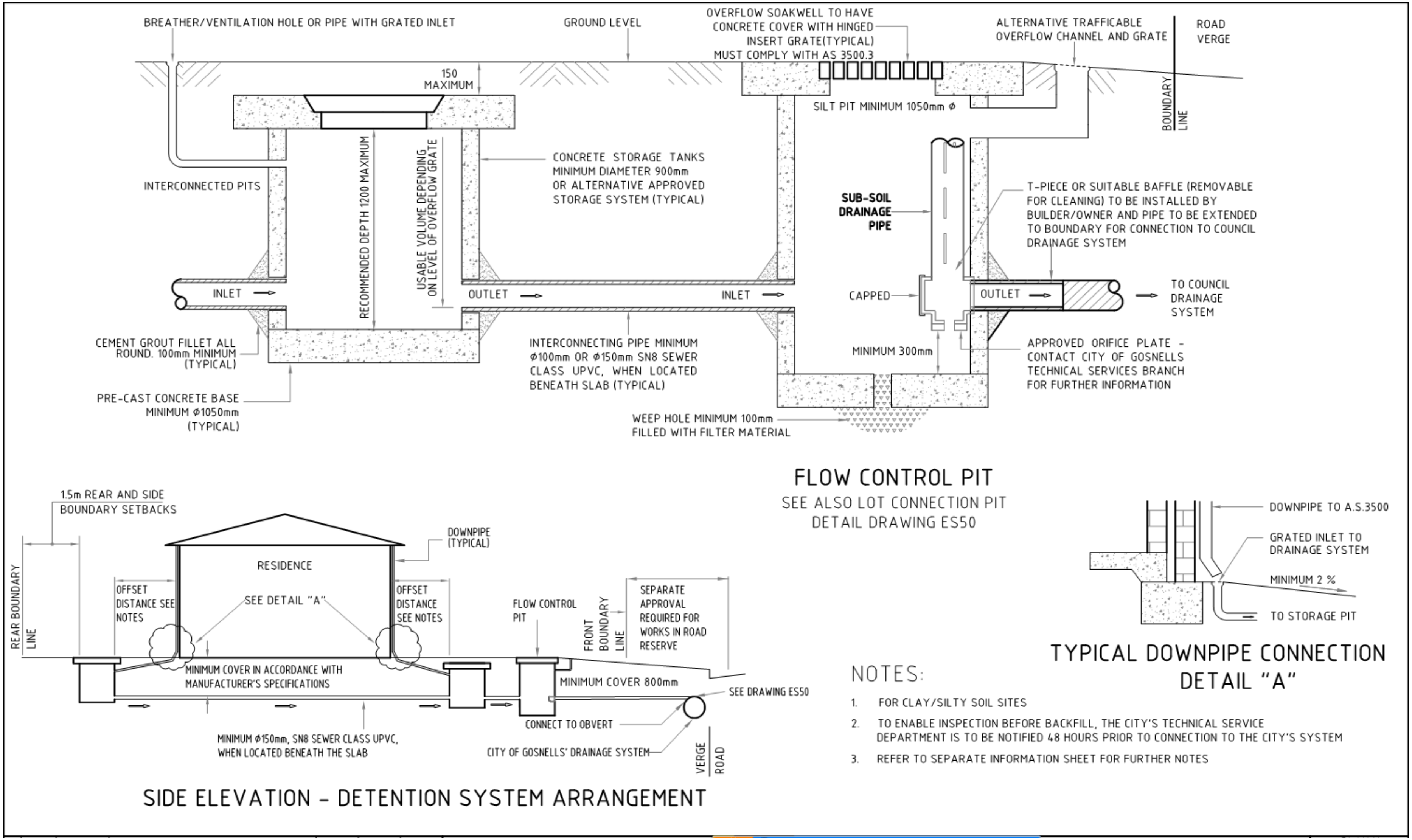


Figure 5:11 – Details of inter-connected circular concrete tanks and flow control pit in low-permeability site

5.2.3. Spreadsheet: Basic Theory

On-site Retention - Soakwells

The theory upon which the Spreadsheet calculations are based for specifying soakwells at a given site is set out as –

“Procedure 2A: ‘Leaky’ well with cleansed water inflow typically from a roof” in “WSUD: basic procedures for ‘source control’ of stormwater – a Handbook for Australian practice” (Argue, 2004/2009). The derivation leads to the formulation –

$$D = \sqrt{\frac{\not{\text{V}}}{\frac{\pi}{4}\left(H + 120k_h\,.\tau.U\right)}} \quad \text{(m)} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (5:1)$$

[This formula includes the assumption, $D \approx H$]

Where $\not{\text{V}}$ = volume of (roof) runoff in storm of critical duration (m^3)

D = diameter of soakwell (m)

H = height of soakwell (m)

k_h = soil hydraulic conductivity (m/s)

τ = time base of the design storm runoff hydrograph (mins)

U = Moderation Factor: 0.5 (sand); 1.0 (sandy clay); 2.0 (clay).

[Moderation Factor, U, is a multiplier which reflects the difference between permeability results obtained in borehole (site) field tests and the observed permeability associated with installed retention devices such as soakwells, gravel-filled trenches, etc.]

Application of this formula leads, typically, to devices of great and impractical size (diameter) in the first instance. It is therefore necessary to ‘compartmentalise’ the roof – dividing it into a number of equally-contributing sections. This process is carried out in the software supporting the City's spreadsheet: the in-ground devices have a minimum diameter of 900 mm and maximum depth of 1.80 m.

Another important factor required in design is the emptying time.

In situations where stored runoff must be passed in its entirety [Case 1(a), above] into the parent soil of the residential site, then it is important to ensure that the device is empty at the time of arrival of a succeeding significant storm.

This issue involves two information sub-sets: first, the means (formula) to calculate how long it takes for the device to empty, and second, a practice criterion (relating storm successions and ARI) against which to compare the time of emptying.

- Emptying time, T in seconds (Argue, 2004/2009):

soakwells : $T = -\frac{4.6D}{4k_h}\log_{10}\left[\frac{\frac{D}{4}}{H+\frac{D}{4}}\right]$, *s*……………………………………… (5:2)

- Criterion relating emptying time, T, and ARI: See Table 5:2.

Table 5:2-Interim Relationship between emptying time and ARI (Argue, 2004/2009)

Average Recurrance. Interval (ARI), Y-years	1-year or less	2-years	5-years	10-years	20-years	50-years	100-years
Emptying time, **T** in days	0.5	1.0	1.5	2.0	2.5	3.0	3.5

On-Site Detention - Concrete Tanks (circular) and Flow Control Pit

The onsite detection infrastructure, recommended for allotments in clay and silty sand sites, operates entirely as a (roof) runoff temporary detention system with discharge to the street drainage network via a submerged orifice (see Figure 5:11).

The orifice ensures that outflow to the street will only take place when 'head' (pressure) in the receiving system falls below that of the water stored on site, and even then, at a quite small flow rate initially. In time, as the peak flow in the street drainage network passes and capacity for conveyance into that system increases, flows through the (submerged) orifice plates of individual allotments will increase, leading ultimately, to complete emptying.

The Spreadsheet provides a calculated "allotment outflow rate" determined as the maximum 5-year ARI flow from the site in its pre-development state (see Section 5.2.1, above). However, this rate will only occur with the orifice operating under "free fall" conditions encountered in the latter stages of a storm event.

The orifice formula used in the Spreadsheet is (Equation 3)

$$A_0 = \frac{Q_{des}}{B.C_d.\sqrt{2.g.h}} \quad m^2 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots..(5:3)$$

Where C_d = Orifice discharge coefficient (0.6)

B = Blockage factor (0.5)

H = Depth of water above the centroid of the orifice (m)

A_0 = Orifice area (m^2)

Q_{des} = Design discharge (m^3/s)

Given the manner in which the on-site (roof) runoff storage system operates and its inter-relationship with the particular circumstances occurring in the street drainage network during a flood - as explained above - it is not possible to assign a time of emptying to any individual site or group of allotments in the network. However, it is predicted that the slope of natural surface within the developed region of the municipality - ranging from 3.0% down to a minimum of 0.1% - is sufficient to guarantee that all stormwater temporarily retained during a 'design' storm event (100-years ARI) will be completely cleared from allotment sites within the 3.5 days specified in Table 5:2. This matter is, of course, complicated by 'tailwater' considerations in the receiving pipelines that convey stormwater down-slope from the City.

Using the spreadsheet

The Spreadsheet is set up for easy and speedy use by builders, plumbers, developers and their consultants, ensuring a competent outcome acceptable to the City.
It involves four steps:

STEP 1: Insert total lot area, roof area and total paved area draining to on-site concrete soakwells and pits;

STEP 2: Select soil type (sand, clayey sand or sandy clay) from the drop down menu;

Three default values of Moderation Factor, U (see Section 4.1), are incorporated into the calculations for soils nominated as "sand" or "clayey sand" or "sandy clay". However, these values can be over-ridden and a value for U inserted from a regression relationship (U *versus* Hydraulic Conductivity) where information on field soil permeability measured at a site is known.

STEP 3: Select size (diameter and height) of proposed soakwells or pits from drop down menu;

STEP 4: Select 'yes' or 'no' to the question: "permission to connect to council drainage?"
The intent of this step is to prevent allotments of (relatively) large size discharging storm runoff into the street drainage system. Special consideration, derived from the answer to the Step 4 question, is given to sites where this requirement causes issues, for example, at a site slightly larger than 350 m^2 located in heavy clay.

The Spreadsheet produces three Outcomes –

OUTCOME 1: Number of soakwells or pits needed on the property;
Planning needs the layout design for soakwells or pits on the site to ensure that there is sufficient clearance between all soakwells and between the soakwells and footings/boundaries.

OUTCOME 2: Volume in m^3, required to be retained/detained within the soakwells or pits;

OUTCOME 3: Diameter of orifice connected to the outlet pipe to council drainage - see Figure 5.11.

The Spreadsheet that is designed for use in the Gosnells region can be viewed on the City of Gosnells' website (www.gosnells.wa.gov.au).

5.2.4. Discussion and Conclusion

The spreadsheet was developed for use by builders, plumbers, developers and consultants active in the process of 'growth' development within the City of Gosnells as well as re-developing presently occupied sites through initiatives such as the Local Housing Strategy, which has resulted in increased densities.

First, it provides a clear and cost-effective engineering practice to the City for achieving its development and re-development goals, despite the presence of a largely 'at capacity' stormwater infrastructure. Appropriate use of the infiltration capabilities of the municipality's sandy soils makes this possible in a large part of the City; the concepts of retention and extended detention, correctly applied, account for the remaining areas with less permeable soils; and,

Second, it provides a tool for use and submission in the approval process, ensuring that practices acceptable to the City, are followed with minimum design effort on the part of proponents of development/re-development projects and minimum staff 'time' required to carry out assessment;

The initiative taken by the City of Gosnells in developing its cost-effective stormwater management strategy, in the circumstances of a substantially 'at capacity' infrastructure and faced with a demand for urban growth, has and is likely to continually attract the attention of state agencies and other municipal agencies, not only in Perth but, also, across the nation.

In the case of Perth City, Australia itself, urban development has extended along the coastline north to Yanchep and south to Rockingham, a distance of nearly 100 km, while penetration of the city eastwards towards the Darling Range has been minimal. There are two reasons for this: residents of Perth are particularly attracted to a coastal life-style and a hesitation for development to extend eastwards beyond the limits of the sandy plain; this is driven by some uncertainty about building practices required in the less permeable soils encountered towards the foothills and the presence of an elevated water table. Indeed, it is common for residential sub-divisions and industrial estates in the eastern suburbs of Perth to introduce a layer of sand – up to one-metre-thick – as a base for new developments to overcome these joint problems. A shortage of sand required for this practice to continue, is causing serious concern in Perth and alternative approaches, such as that offered by the City of Gosnells' is likely to attract some interest.

Further afield – across the nation – the problem of 'at capacity' stormwater infrastructure with anticipated further urban growth, is a not uncommon scenario. The City of Gosnells' approach, using the benefits to be gained by on-site retention of ARI "100-years" storm runoff, followed by 'slow-release' (extended detention) of the temporarily stored stormwater over a period of around 3.5 days, could provide a solution for municipalities, unable to fund expensive infrastructure upgrades and located in regions with clay soil or high water tables.

CHAPTER 6

6 ASSESSMENT OF THE RELATIONSHIPS AMONG PHYSICAL PROPERTIES OF SOIL AND PERMEABILITY FOR STORMWATER MANAGEMENT

6.1. Identify the relationship between the particle size distribution and soil permeability

It has long been identified that hydraulic conductivity is related to the particle-size distribution in a natural soil or a granular porous media (Freeze and Cherry 1979). In surface water and groundwater hydrology, the knowledge of saturated hydraulic conductivity of soil is necessary for modelling the water flow in the soil, both in the saturated and unsaturated zone and transportation of water-soluble pollutants in the soil. Furthermore, it is of paramount importance in relation to some geotechnical problems, including the determination of seepage and infiltration losses, settlement computations and stability analyses (Boadu 2000).

Stormwater infrastructure has historically evolved and in most old-growth areas is operating at or beyond capacity. The cost of broad scale conventional upgrades ahead of residential densification has been deemed unviable. To overcome this constraint, an alternative, more cost-effective approach has to be adopted based on Water Sensitive Urban Design 'source control' principles and onsite stormwater infiltration, i.e. stormwater runoff from developing lots to be managed within the property to mimic or improve pre-development conditions. These approaches present best practice methods to operationally and sustainably manage urban infill. The valuable concept of stormwater management at source is becoming more popular in most of the country.

With all the above facts, hydro-geologists always look for reliable techniques to determine the hydraulic conductivity of the aquifers with which they are concerned, for better stormwater and groundwater development, management and conservation. In order to have a more generalized solution, local authorities and other relevant organizations have implemented many research projects to identify the basic soil properties that influence the soil permeability when considering developing stormwater management at "source control".

In this study, the particle size distribution is being used as a key factor to estimate the soil permeability. The results of this assessment will help the local councils, developers and subdivision engineers to get a better understanding of the behavior of soils and the influence of particle size distribution on soil permeability. Moreover, the case study result will contribute in implementing an affordable and sustainable infiltration based stormwater management system in the identified land development areas. (Kannangara, 2011).

6.1.1. Methodology

The main intention of this chapter is to identify the correlation of a soil permeability and particle size distribution and provide a valuable input to the implementation of onsite infiltration based on best stormwater management practices in urban areas. This research developed an inventory of the basic geotechnical properties of several development areas using field tests and laboratory tests. In the laboratory, specific tests were chosen to provide insight on soil properties surrounding permeability, soil texture and soil structure. About 89 undisturbed soil samples were collected by using a drilling machine and core sampler. The sampling locations were selected to represent nine main soil types which are available in the study area. In this analysis, the falling head permeability test and sieve analysis were the only laboratory tests conducted.

Previous studies were conducted on the same sampling locations where the hydraulic conductivity was obtained on site at 1m depth by using the Guelph Permeameter kit. The main objectives achieved were developing the relationship between soil types and associated infiltration rate, identifying the suitable areas for infiltration based onsite storm water management and exploring further developments. Using the handbook titled ‘Soil Groups of Western Australia” as a guide, the soils were sorted into 9 different soils, named A to I, based on the soil texture. Permeability results were classified into 4 different permeability groups; slow, moderate, rapid and very rapid (Kannangara, 2011).

6.1.2. Results and Discussion

Categorizing using Unified Soil Classification system

When the percentage passing (%) is plotted against the particle size (mm), it clearly showed that the particle size distribution patterns are almost the same even though the samples belong to two different soil types. The Figure 6:1 shows a similar graph drawn for 22 soil samples of soil type B and similarly the other soil types are graphically represented in order to classify them in to unified soil classification system. It can be seen in 7 out of the 9 sieve analysis graphs, emerging patterns are formed for these soil samples except for the soil types H and I where all the curves are slightly dispersed.

As shown in Figure 6:2, most of the soil curves of soil group G follow the same trend, except for a few that were mostly composed of gravel. Soil group B, C, D and F have almost perfect patterns.

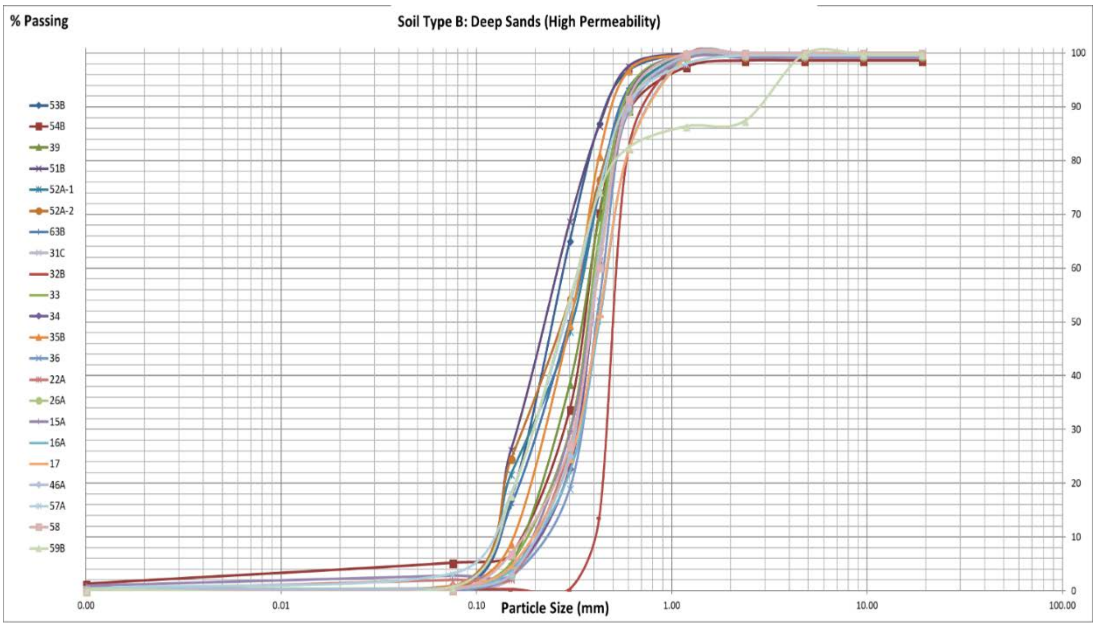


Figure 6:1 – Particle size distribution of soil type B (22 samples)

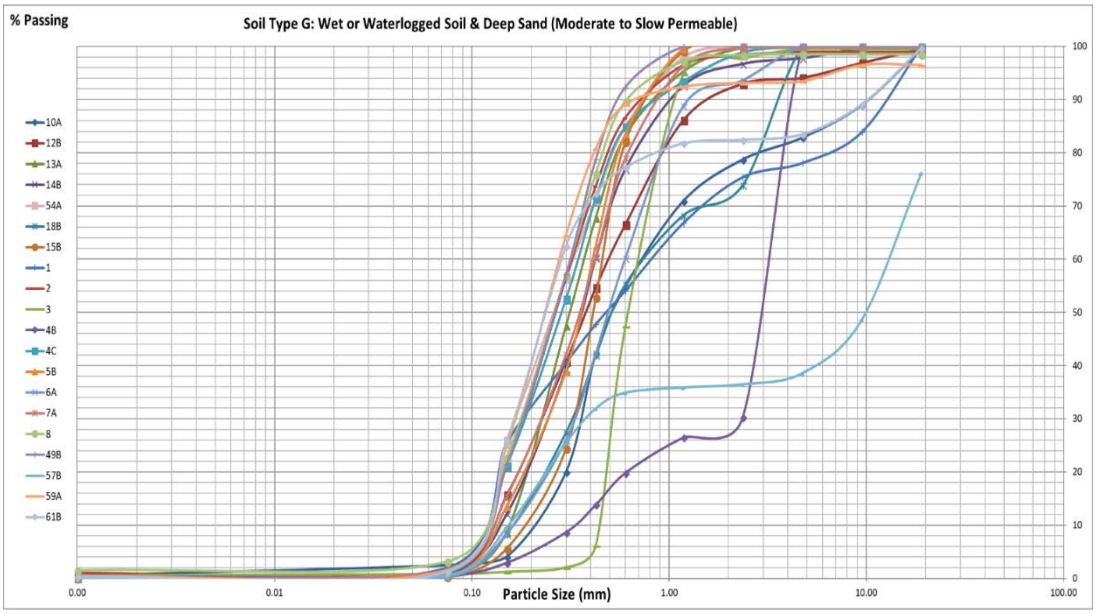


Figure 6:2 – Particle size distribution of soil type G (21 samples)

From these graphs, the unified soil classification system is used to find the soil grading. It has been determined that most of the soil samples are poorly graded, as well as for most of the types of soil. Resulting in the majority of the 89 soil samples being classified coarse-sand soils. Summary of the classification and their relationship to the average permeability has been given in Table 6:1. Moreover, the finer grading of the soil has been found and 18 of them were required to undergo the plasticity tests in order to get more accurate grading as specified.

Table 6:1 - Unified soil classification with respect to average soil permeability

Soil type	Total No. of samples	Unified Soil Classification			Average Permeability (m/day)		
		SP	SW	No. of samples (Unclassified)	SP	SW	Total Average
A	6	1	2	3	0.00	1.16	2.03
B	22	9	13	0	6.19	9.93	8.40
C	6	4	0	2	0.45		0.34
D	12	9	2	1	1.42	3.77	1.69
E	6	1	5	0	0.01	0.00	0.00
F	4	1	1	2	0.51	1.04	0.77
G	21	12	2	7	0.37	0.46	0.60
H	8	1	5	2	0.00	0.45	0.29
I	5	3	1	1	1.26	20.05	4.79

Note- SP- Poorly graded sand, SW- Well Graded Sand

According to the above classification, 41 samples are poorly graded sand and 31 samples are well graded sand. As shown in Figure 6:3, the results clearly show that the average permeability of well graded sand is much higher than that of poorly graded sand. In addition, these results pointed out that the number of finer particles (particle size less than 75µm) present in a soil sample plays an important role with respect to their soil permeability and the requirement for deeper analysis. As a result, the percentage availability of fine particles in soil samples has been taken into account for further analysis with respect to soil permeability.

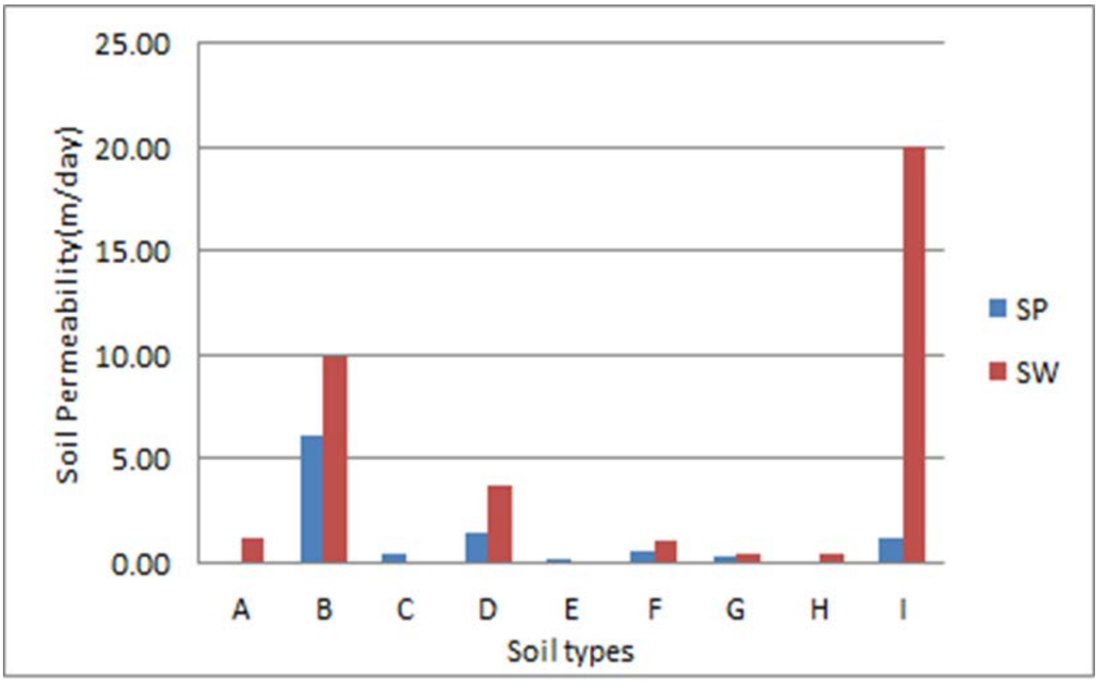


Figure 6:3- Permeability variation of well graded sand and poorly graded sand

Variation of soil permeability with silt and clay

For the selected 90 soil samples, the percentages availability of aggregates were calculated based on the Sieve Analysis percentage passing. The most interesting finding in this particular case is when comparing the soil permeability of soils from the same soil type. As shown in Table 6:2, soil type A clearly shows different behavior based on the percentage availability of aggregates. This analysis was conducted in order to identify the possible parameters that affect the soil permeability and also understand the possible reasons why the soil did behave in this particular way.

Table 6:2- Different properties of Soil Group A

Permeability (m/day)		0.002	5.60
Percentage of Aggregates (%)	Silt & Clay	5.59	0.90
	Sand	70.74	98.27
	Gravel	23.67	0.83

It is clear that these two soil samples belong to same soil type. However, it can be noticed that the percentage of aggregates availability is different which might be one of the possible reason affecting the soil's permeability. One sample has 5% of fine grained soils and 24% of gravel which might be enough to contribute and differ in terms of permeability. Three graphs were plotted with percentage availability of silt and clay, sand and gravel against the hydraulic conductivity in order to get better illustration and better understanding.

Among these three graphs, the one which needs most attention is the Permeability vs. Silt and Clay or fine-grained particles, because the latter promotes the decrease in permeability Figure 6:4 However, the lower the silt and clay percentage, the higher the permeability. As Lay (2009) pointed out, "soils containing less than 5% fine grained soils should have a good permeability". It confirms that hydraulic conductivity decreases with an increasing plasticity index. The plasticity index is a measure of the plasticity of a soil. Soils with a high plasticity index tend to be clay, those with a lower plasticity index tend to be silt, and those with a plasticity index of 0 (non-plastic) tend to have little or no silt or clay. Sand and gravel are coarse grained soils that usually promote permeability.

The final results indicated that the permeability value varies in a range from 0 to 20 m/day while the percentage of silt and clay from 0 to 10%. Moreover, this analysis clearly showed that soil permeability can be varied in a particular range of same silt and clay percentage. This might help in understanding the behavior of soil permeability considering the other factors such as density, void ratio and porosity.

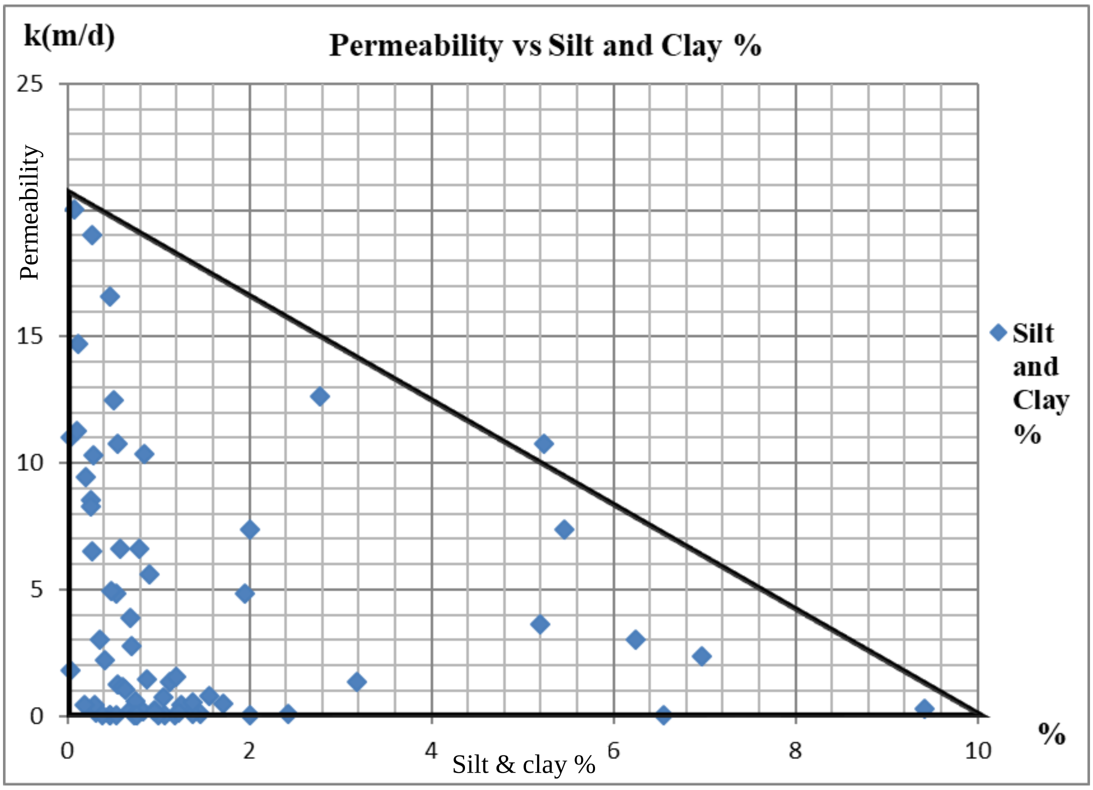


Figure 6:4– Permeability vs. Silt and Clay % (all the samples)

6.2. Investigation into the relationship between particle density, Water absorption percentage and the saturated hydraulic conductivities

An analysis was conducted to investigate a relationship between the particle density and the water absorption capacity of the soil with its own saturated hydraulic conductivity. As explained in Figure 6.4, the properties of fine grained soil such as silt and clay considerably influence the water movement through the soil sample. It is clear that the particle size distribution of a soil sample can be greatly influenced on its own permeability. Considering the factors influencing on soil permeability, they are mainly classified in to three main categories namely environmental factors, human intervention and characterizing variabilities. The environmental factors such as physical soil properties (soil composition, texture, structure, pore spaces, bulk density, horizon development and moisture state), topography and the presence vegetation greatly influence and also these properties are interrelated.

As a result of this complexity, the researchers would have to look at different windows in order to identify the best and mostly influencing factors on soil permeability. Within this chapter, it is trying to understand how particle density of a soil sample could be affected on its own permeability. The particle density of a soil sample is the saturated surface-dry mass per unit volume of particles, the volume including both the permeable and impermeable voids inherent in the particles.

The ratio, expressed as a percentage, of the mass of water held in the permeable voids of the particles brought to the saturated surface-dry condition following soaking under water for 24h, to the oven dry of the material is called as water absorption capacity of a soil sample. This property of a particular soil sample is dependent on the particle size distribution and on the other hand on the soil texture. Soil texture is the relative proportions of sand, silt, or clay in a soil. The soil textural class is a grouping of soils based upon these relative proportions. Soils with the finest texture are called clay soils, while soils with the coarsest texture are called sands. However, a soil that has a relatively even mixture of sand, silt, and clay and exhibits the properties from each separate is called a loam. There are different types of loams, based upon which soil separately is most abundantly present. If the percentages of clay, silt, and sand in a soil are known (primarily through laboratory analysis), the textural triangle could be used to determine the texture class of the soil. Soil texture and soil structure are both unique properties of the soil that will have a profound effect on the behaviour of soils, such as water holding capacity, nutrient retention and supply, drainage, and nutrient leaching. As described above, this analysis is mainly focused on finding a relationship between particle density and the water absorption capacity compare to its own permeability capacity.

Based on AS 1141.5 – 2000 standard and as per the detailed test procedure discussed in Section 3.7.3 selected six samples were subjected to the test. The samples were selected by representing different soil types as well as the low and high range of permeability values met within the study area. The calculated particle density on dry and SSD basis, apparent particle density and water absorption percentage values were used to find a relationship against the saturated hydraulic conductivities measured at the laboratories for the same soil samples.

6.2.1. Results and Discussion

Table 6:3- Calculation particle density and Water absorption

Measurements	Notation	Sample No					
		73	69B	A3	31C	46A	20A
Mass of Saturated Surface Dry test portion (g):	m_2	245.99	229.88	228.2	216.41	245.51	227.26
Mass of flask filled with water and test portion (g):	m_3	1390.47	1385.31	1390.28	1383.09	1400.47	1380.22
Dry mass of test portion (g):	m_1	225.36	219.29	226.94	215.38	243.97	211.5
Mass of the flask filled with water (g):	m_4	1248.91	1248.91	1248.91	1248.91	1248.91	1248.91
Test water temperature (^oC):	^oC	22	22	22	22	22	23
Density of water at test temperature (g/cm^3):	ρ_w	0.99777	0.99777	0.99777	0.99777	0.99777	0.997538
Particle density on a dry basis (t/m^3):	$\frac{m_1 \times \rho_w}{m_4 + m_2 - m_3}$	**2.15**	**2.34**	**2.61**	**2.61**	**2.59**	**2.20**
Particle density on a SSD basis (t/m^3):	$\frac{m_2 \times \rho_w}{m_4 + m_2 - m_3}$	**2.35**	**2.45**	**2.62**	**2.63**	**2.61**	**2.36**
Apparent particle density (t/m^3):	$\frac{m_1 \times \rho_w}{m_4 + m_1 - m_3}$	**2.68**	**2.64**	**2.65**	**2.65**	**2.63**	**2.63**
Water absorption (%):	$\frac{(m_2 - m_1) \times 100}{m_1}$	**9.15**	**4.83**	**0.56**	**0.48**	**0.63**	**7.45**
Method of determining SSD condition:	[x] [ ]						
Saturated Hydraulic Conductivity	m/day	**0.02**	**0.08**	**2.36**	**11.04**	**16.58**	**4.28**

	°C	g/cm^3	°C	g/cm^3	°C	g/cm^3	°C	g/cm^3
Density of water at different temperatures (g/cm3):	11	0.999605	16	0.998943	21	0.997992	26	0.996783
	12	0.999498	17	0.998774	22	0.99777	27	0.996512
	13	0.999377	18	0.998595	23	0.997538	28	0.996232
	14	0.999244	19	0.998405	24	0.997296	29	0.995944
	15	0.999099	20	0.998203	25	0.997044	30	0.995646

The above Table 6:3 shows the measurements taken and the test results calculated based on the empirical equations given as per the Section 3.7.3.

The three graphs below show that how the apparent particle density, water absorption capacity of a soil sample relates to its own saturated hydraulic conductivity and also its percentage of silt and clay. The third graph is directly extracted from the above graph given in Figure 6:4 to represent the samples that were subjected to the particle size density test.

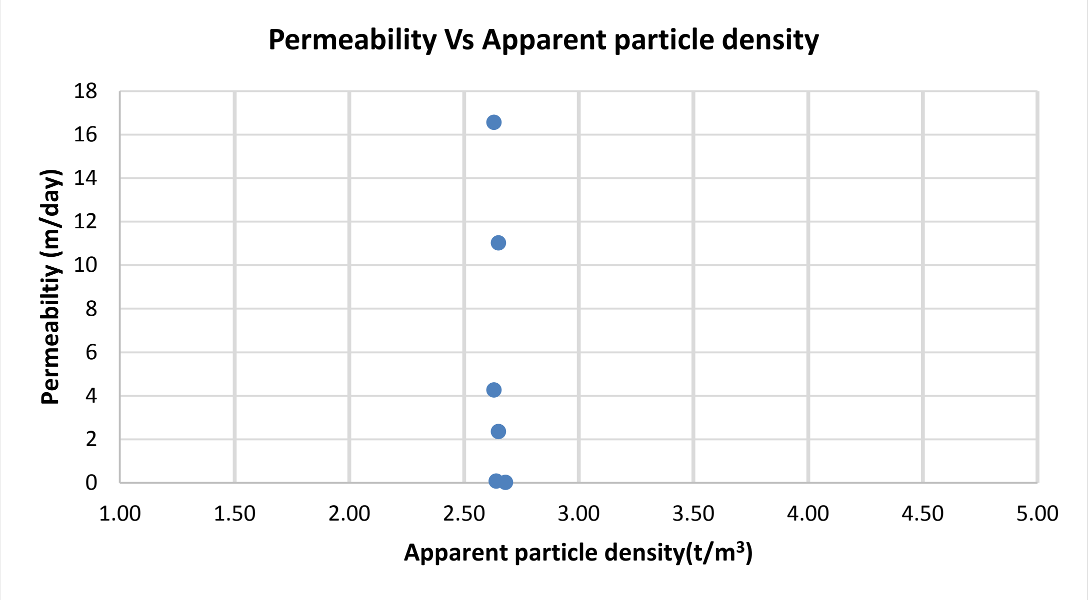


Figure 6:5 – Permeability Vs Apparent Particle Density (for 6 samples)

It is clear that the apparent particle density of a soil sample is constant and infiltration capacity is totally independent of its particle density.

Apparent particle density = 2.65 t/m^3

However, the water absorption capacity of a sample gives direct relationship to its permeably capacity and also to the percentage of silt and clay existence.

These results indicated that the permeability value varies in a range from 0 to 20 m/day while the percentage of silt and clay varies from 0 to 10% and also percentage of water absorption capacity varies 0 to 10%. Moreover, this analysis clearly showed that soil permeability can be expressed in term of water absorption capacity of a soil sample.

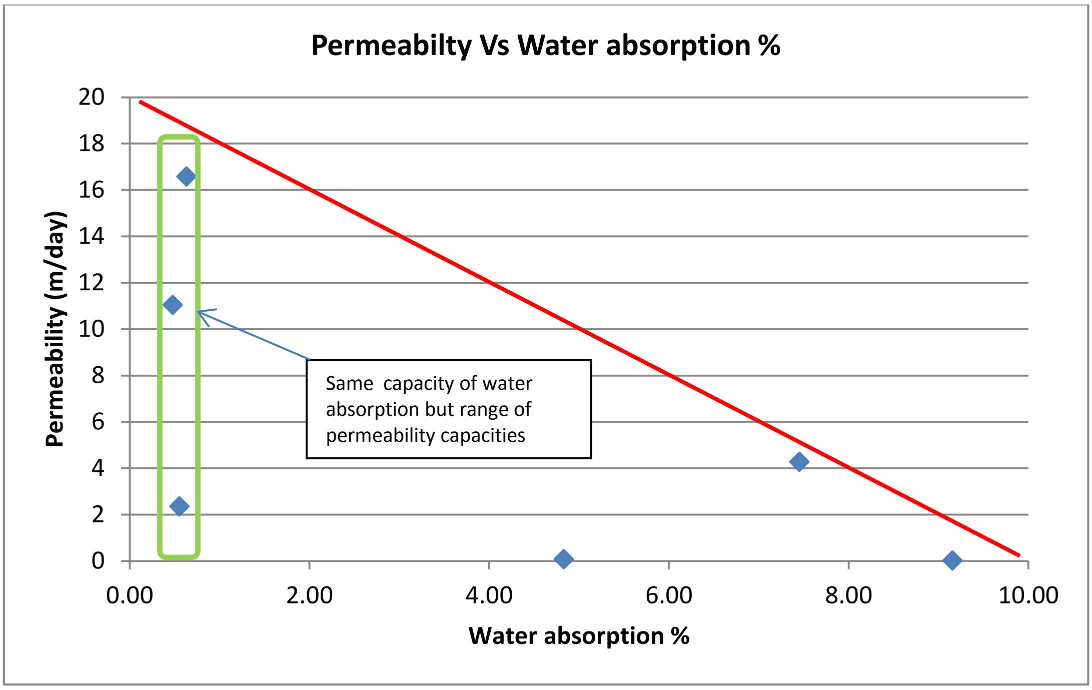


Figure 6:6 – Permeability Vs Water Absorption (for 6 samples)

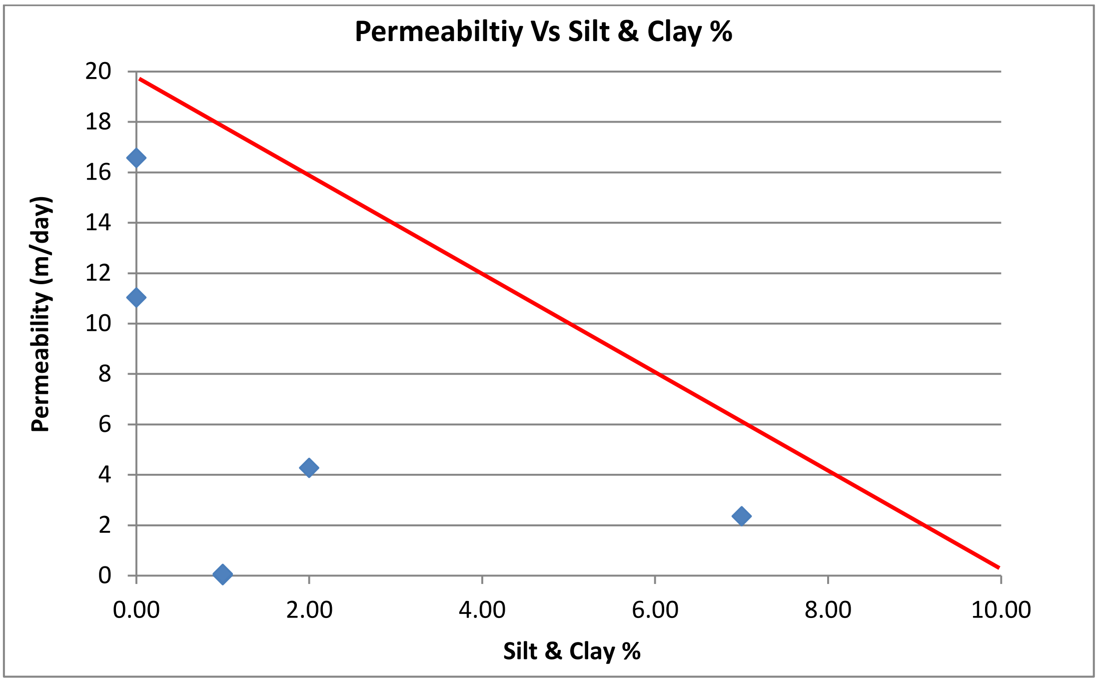


Figure 6:7 – Permeability vs. Silt and Clay % (for 6 samples)

And also, it is clear that the permeability can vary in a range while having the same capacity of water absorption which shows the very similar relationship against the percentage of silt and clay exist in the sample. Again, this analysis confirms that the permeability of a soil sample depends on two or more variables.

6.3. Investigation of the relationship between physical properties and saturated hydraulic conductivities by using empirical formulas.

Different techniques have been proposed to determine saturated hydraulic conductivity values, including field methods (Guelph Permeameter, pumping test of wells, auger hole test and tracer test), laboratory methods and calculations from empirical formulae Todd and Mays (2005). The most accurate method of estimation of saturated hydraulic conductivity is in the field environment by the field methods. However, this method is limited by the lack of specific knowledge of aquifer geometry and hydraulic boundaries Uma et al. (1989). Other limitations are the cost of field operations and associated well constructions. On the other hand, the laboratory tests can create challenging problems in the sense of obtaining representative samples and very often, long testing times. As an alternative, estimating saturated hydraulic conductivity from empirical formulae based on grain-size distribution characteristics, with some of geo-technical soil properties, have been developed and used to overcome these problems.

In hydromechanics, it would be more appropriate to describe the sizes of pores rather than those of the grains size. However, the pore size distribution is very difficult to determine in a soil sample and the best approximation of hydraulic conductivities are mostly based on the grain size distribution as a substitute Cirpka (2003). This method is straight forward, but it was found that this correlation is not easily established Pinder and Celia (2006). However, the void ratio and the porosity of a soil sample can be calculated easily by experimental or from empirical relationship Vukovic and Soro (1992) and those have been considered for formulating empirical equations in addition to particle size distribution to represent the hydraulic conductivity. Several researchers have studied this relationship and several formulae have resulted based on experimental analysis. Kozeny (1927) proposed a formula which was then modified by Carman (1937, 1956) to become the Kozeny-Carman equation. Other attempts were made by Hazen (1892), Shepherd (1989), Alyamani and Sen (1993), Terzaghi and Peck (1964). The application of these formulae depends on the type of soil for which hydraulic conductivity is to be estimated. Vukovic and Soro (1992) noted that the application of different empirical formulae to the same porous medium material can yield different values of hydraulic conductivity, which may differ by a factor of 10 or even 20. Therefore, the main objectives of this analysis is to evaluate the applicability and reliability of some of the commonly used empirical formulae for the determination of hydraulic conductivity of undisturbed soil samples and to identify the most effective soil parameters which govern the value of the permeability.

Most commonly used Empirical Formulae

The following empirical formulas have been commonly used in hydromechanics and they have been used for the analysis.

Hazen

$$K = C \times d_{10}^{2} \qquad (6:1)$$

$$K = \frac{g}{v} \times 6 \times 10^{-4}\left[1 + 10(n - 0.26)\right]d_{10}^{2} \qquad (6:2)$$

Kozeny-Carman

$$K = \frac{g}{v} \times 8.3 \times 10^{-3}\left[\frac{n^{3}}{(1-n)^{2}}\right]d_{10}^{2} \qquad (6:3)$$

$$n = 0.255\left(1 + 0.83^{Cu}\right) \qquad (6:4)$$

Where
K = hydraulic conductivity

g = acceleration due to gravity

v = kinematic viscosity

C = constant

n = porosity

Cu= uniformity coefficient

d_{10} = effective grain diameter

The kinematic viscosity (v) is related to dynamic viscosity (μ) and the fluid (water) density (ρ)

To identify the main physical properties that greatly influence the hydraulic conductivity of a soil, specific laboratory tests were chosen to provide insight on soil properties such as permeability, soil texture and soil structure. Ninety undisturbed soil samples were collected by using a drilling machine and a core sampler. The sampling locations were selected to represent nine main soils types which were available in the study area. The falling head permeability test, the sieve analysis testing and particle size density were conducted for collected samples to calculate soil properties such as density, porosity, void ratio, effective size and soil classification.

The sieve analysis tests were conducted to calculate the D_{60}, D_{30}, D_{10} the effective grain size diameter, grading, uniformity coefficient and the coefficient of gradation. Using these parameters, it was recorded that all the soil samples were coarsed-grained soils and that the majority (more than 95%) of samples were sands and a few were gravels. The soils were classified using the USCS standards and it was found that most of them were poorly graded soils (Kannangara 2012).

6.3.1. Results and Discussion

Acceptability and the reliability of established formulae for Permeability and Porosity variation

With reference to the experimental results, it is identified that there is a relationship between hydraulic conductivity and the effective grain size D_{10}. Several empirical formulas in the literature are used to compare the experimental hydraulic conductivities. However, the use of these formulas did not perfectly match out to be what was expected. As it is clearly shown in Figure 6:8, the hydraulic conductivity values have been over-estimated by the empirical formulas by 5 to 10 times even in the smaller values of the effective grain sizes and these values could not be achieved in the field. The other main concern is that the overestimated hydraulic conductivity values are very much higher than the available design guidelines for infiltration based engineering structures.

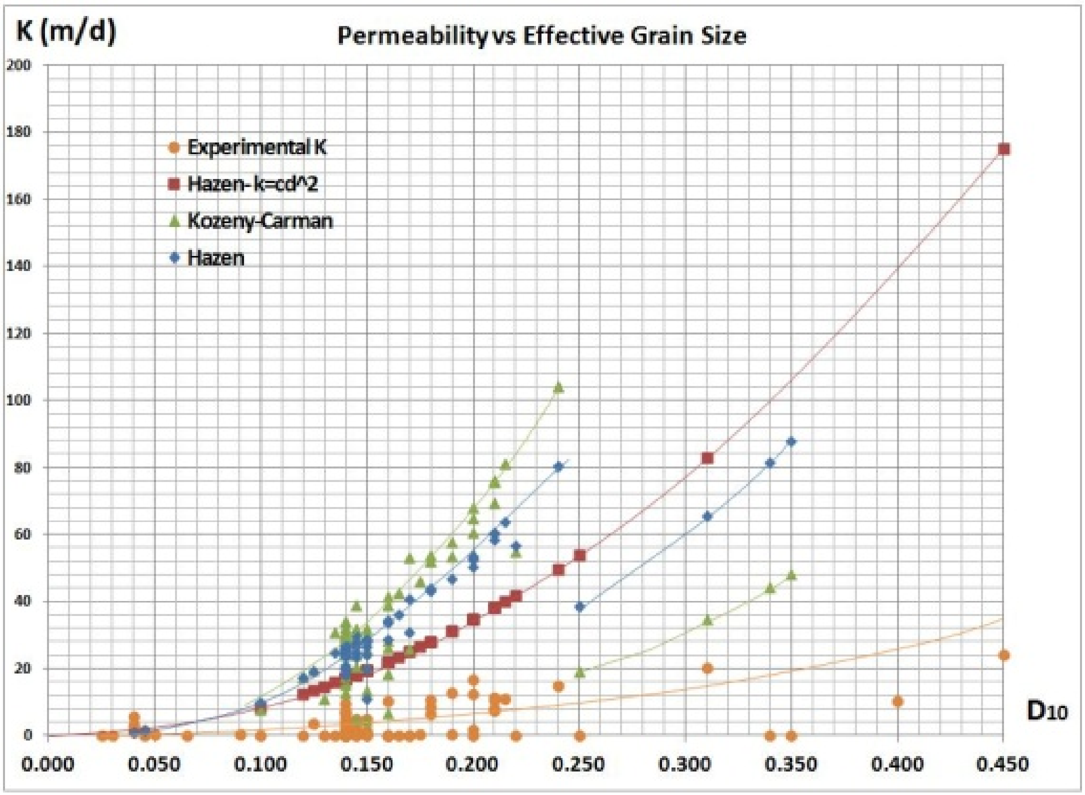


Figure 6:8 – Experimental & Empirical Permeability Vs effective grain size

The Hazen formula has considered only the effective grain size diameter and also the constant C may take values from 1 to 1000 depending on other parameters such as temperature. The other two empirical formulas which have considered both effective grain size and the porosity show a sudden drop at effective grain size of 0.25 and at greater values. The cause of this sudden drop due to the under estimation of the porosity values by the given empirical formula (4) and the behaviour between experimental and the empirical porosity has been further analysed below.

The Figure 6:9 shows the relationship between the porosity values and the effective grain size D_{10} calculated from the experimental data and by using the empirical formula. It is clear that almost all experimental porosity values are higher than that of the calculated values from the empirical formulae. It means that the real value has been under estimated by the given empirical formulae and this value directly influences the representative permeability. However, both porosity values indicate very similar value to each other for the range of effective grain size greater than 0.1mm and less than 0.25mm. This relationship does not exist for the effective grain sizes less than 0.1mm and greater than 0.25mm.

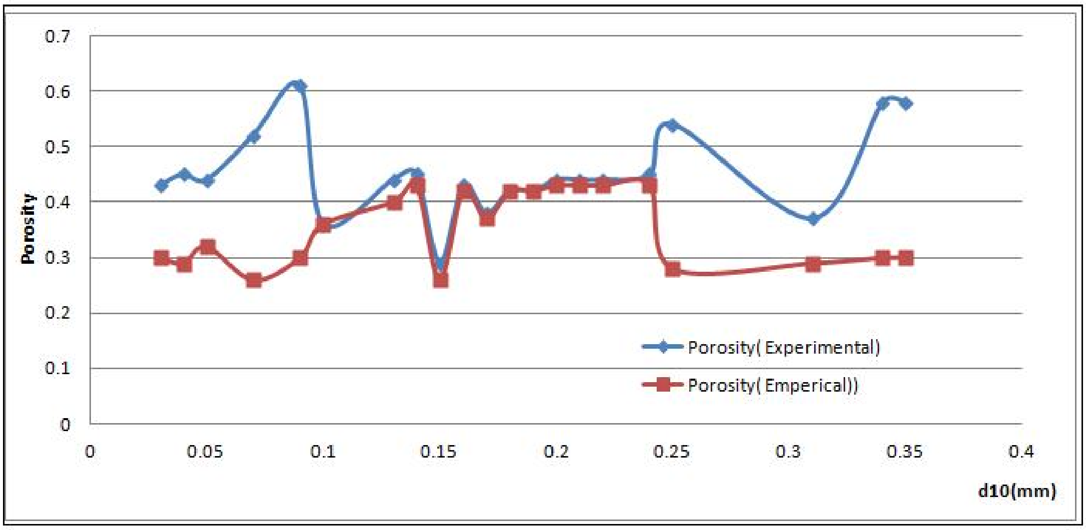


Figure 6:9 – Experimental & Empirical porosity Vs effective grain size

6.4. Identify the relationship between the particle size distribution, Dry density, moisture content relation-modified compaction and soil permeability of engineered landfill

A similar relationship has been identified under the analysis done for capturing the infiltration capacities in infill development sites. The use of clean sand fills over the existing soil with or without removing the reactive soil material is a common practice in many land developments in Australia. The clean sand fill is required mainly for two requirements;

- Foundation requirement for achieving S class classified soil as minimum foundation requirement for residential footings.
- Drainage requirement for achieving better separation from assessed groundwater levels to physical infrastructure, residential footing and to the invert level of the infiltration based stormwater management measures.

With all the above facts, it is clear that if the subdivision requires imported fill, then most of the stormwater management infrastructures are going to be installed within the imported fill layer rather than the existing soil profile. Then the hydro-geologists should always pay attention not only for identifying the properties of the existing soil of the proposed development, but also the properties of the imported fill as it again affects the performance of the selected stormwater management measures and also the foundation requirement.

This section of the thesis has been included to this research study as a result of a discussion held with the Department of Water (DoW) while seeking expert's opinion at the early stage of the research. As per discussion, it was realized that there is lack of information and research conducted on imported fill materials. Land development and Engineering industry is now looking for testing to determine the hydraulic conductivity of the imported fill towards better stormwater and groundwater development, management and conservation.

As a result, the research scope has been extended to identify the basic soil properties of imported fill material that influence its soil permeability as a useful tool for developing stormwater management at "source control". The particle size distribution is used as a key factor to analysis its own soil permeability.

And also, the dry density, moisture content relation and modified compaction tests were conducted to identify the relationship between the permeability and the different compaction level of the imported material. The properties of fine grained soil such as silt and clay considerably influence the water movement through the soil sample. It is well understood that the dry density of the soil sample cannot be varied much as compared to different soil type. This analysis would help to prove how the moisture content in a soil sample could be affected on its permeability with the different settlement or the compaction due to various factors such as environmental, human's intervention and characterizing variabilities.

The completion of this analysis would help to get a better understanding of the imported soils' behaviour and how and up to what the particle size distribution extend and the dry density of the imported material is going to influence its soil permeability. Moreover, the ultimate results would definitely be contributing in implementing an affordable and sustainable infiltration based stormwater management system in the residential land development areas where the imported fill is used over the existing soil.

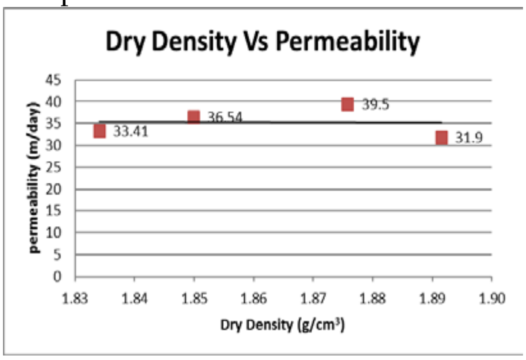
Determining the correlation of a soil permeability and particle size distribution, dry density and moisture content of the imported fill material is very important to provide a valuable input to the implementation of onsite infiltration based on best stormwater management practices in urban areas. The data collected in this study and analysis help to develop an inventory of basic geotechnical properties of several sand mining sites and infill development areas. The samples were collected from five different sand mining site which are located in Perth. In the laboratory, specific tests were chosen to provide insight on soil properties in surrounding permeability, soil texture and soil structure.

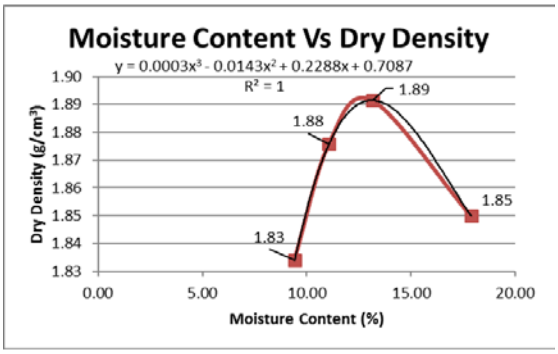
The Sieve analysis test, the falling head permeability test, dry density and moisture content tests were conducted to find the particle size distribution and their permeability variation in different compactions levels. The sampling locations were selected to represent the most of the residential development site where clean sand fill is used part of construction over the existing soil. This analysis would help to see how the moisture content in a soil sample could effect its permeability with the different settlement or the compaction due to various factors.

Variation of soil permeability with Dry density/moisture content and modified compaction

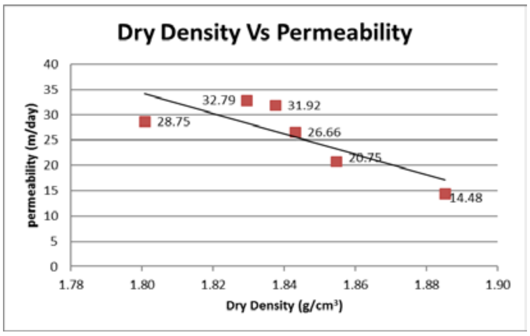
The below given set of graphs are showing how the dry density of soil samples relates to the permeability and the moisture content. Almost all the samples reached their maximum average dry density of 1.89 g/cm^3 at 12-15% of moisture content. And also, it can be clearly identified that the samples have reached their minimum permeability at the maximum dry density.

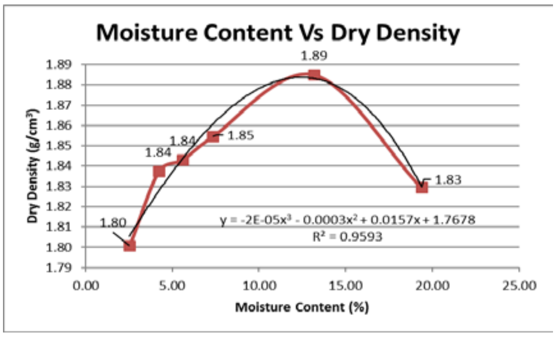
Sample no 1



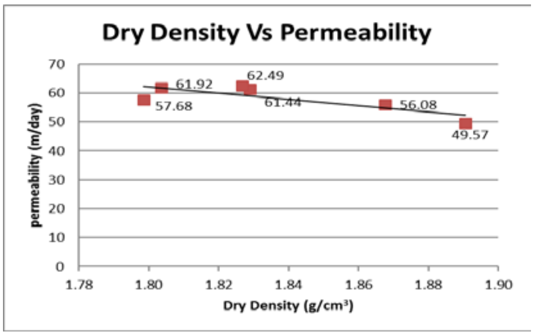


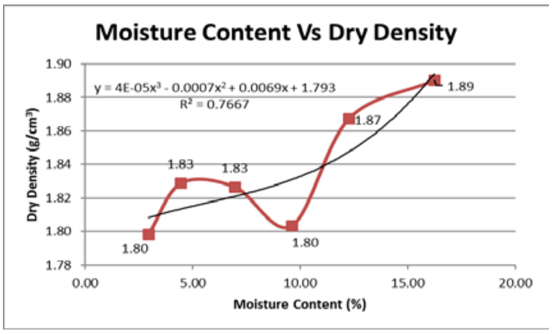
Sample no 2



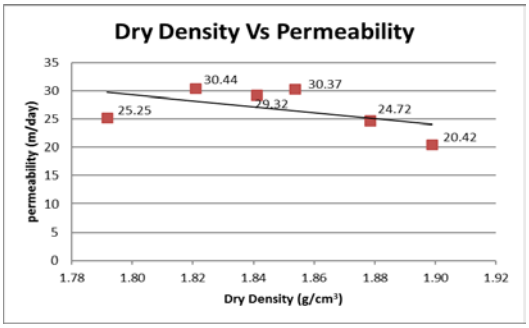


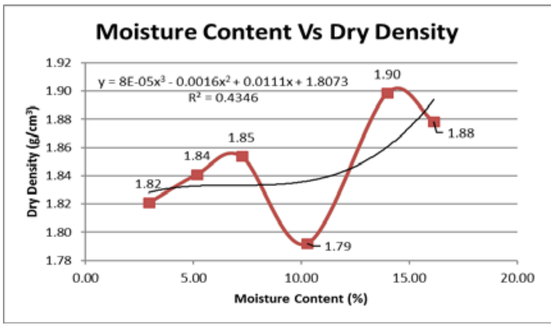
Sample no 3



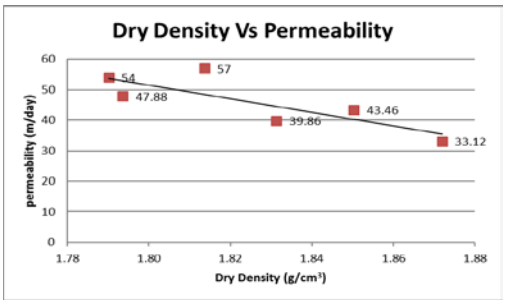


Sample no 4





Sample no 5



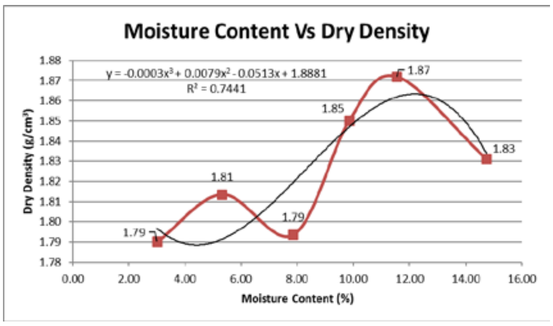


Figure 6:10 – Variation of soil permeability with Dry density/moisture content

Categorizing using Unified Soil Classification system

Analysis of particle size distribution shows that when the percentage passing (%) is plotted against the particle size (mm), the particle size distribution patterns are almost the same even though the samples belong to different geological locations. Figure 6:11 shows a similar graph drawn for four different soil samples that were collected from different sand mining sites. It can be clearly seen that the sieve analysis graphs and emerging patterns are formed.

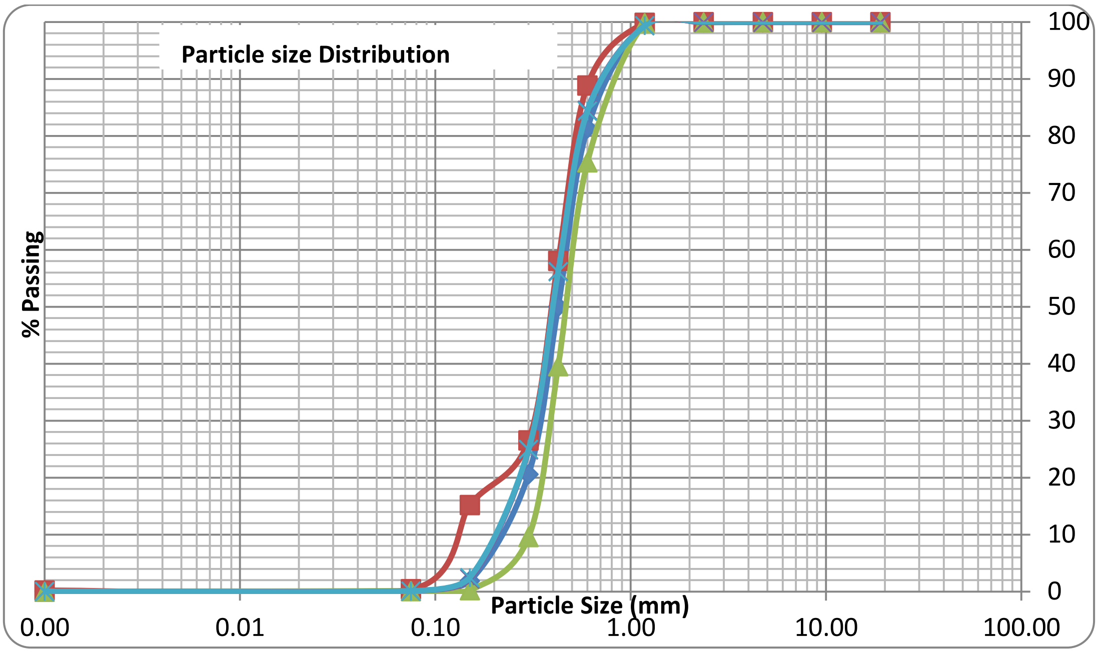


Figure 6:11 – Particle size distribution

From these graphs, the unified soil classification system helps to find the soil grading. It has been determined that the soil samples are poorly graded. And also, the resulting in the four soil samples being classified coarse-sand soils. Summary of the classification and their relationship to the average permeability is given in Table 6:4.

Table 6:4-Unified soil classification for clean sand fill material

Sample No	Unified soil classification	Average Permeability (m/day)
1	Poorly graded coarse sand	35.34
2	Poorly graded coarse sand	25.89
3	Poorly graded coarse sand	58.20
4	Poorly graded coarse sand	26.75

Note- SP- Poorly graded sand, SW- Well Graded Sand

According to the above classification, all four samples were poorly graded course sand. In addition, these results pointed out that the number of finer particles (particle size less than 75μm) present in a soil sample plays an important role with respect to their soil permeability and the requirement for further analysis. As a result, the percentage availability of fine particles in soil samples is use as a trigger to determine it capacity with respect to soil permeability.

Variation of soil permeability with the silt and clay percentage

The above mentioned four soil samples were subjected to the Sieve Analysis test and the percentage passing through each and every sieve were calculated. Table 6:5 and the Figure 6:12 present the results of the analysis, confirming that the hydraulic conductivity decreases with the increasing silt and clay content of a soil sample and that the amount of sand and gravel in a soil sample increases the permeability.

Table 6:5 – Permeability Vs Percentage of Aggregates

Imported Sand Fill - Sample No		1	2	3	4
Permeability at Maximum compaction (m/day)		31.9	14.48	49.57	20.42
Average Permeability (m/day)		35.34	25.89	58.20	26.75
Maximum Permeability recorded (m/day)		39.5	32.79	62.49	30.44
Percentage of Aggregates (%)	Silt & Clay	0.12	0.42	0.11	0.12
	Sand	99.82	99.55	99.83	99.84
	Gravel	0.06	0.03	0.06	0.04

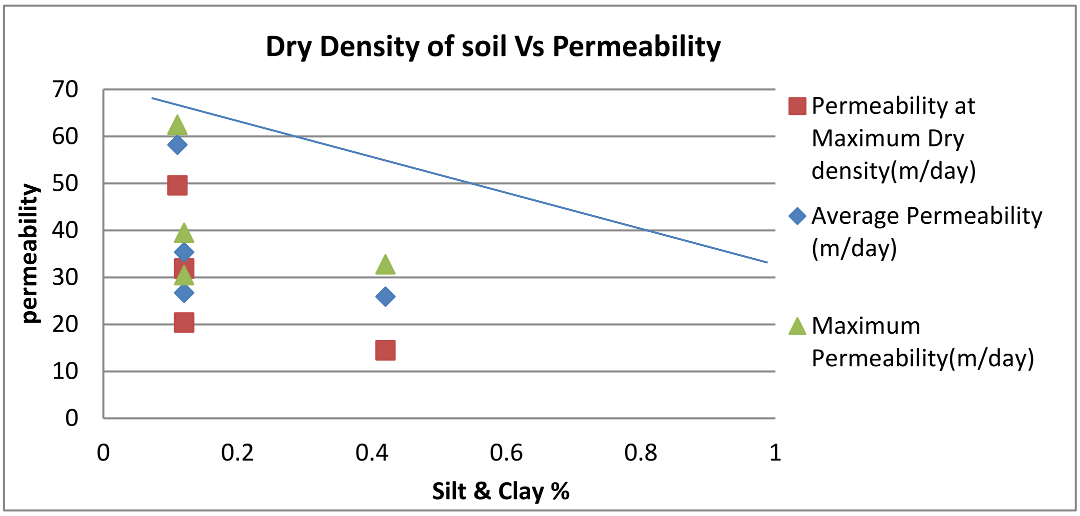


Figure 6:12 – Permeability Vs Silt & Clay percentage

All four imported fill sand samples contained a very little amount of silt and clay as a percentage compare to the soil samples collected from the existing ground at 1m and 1.5m depth. Even though it shows a very small difference between the highest and the lowest percentage of silt and clay (0.31%), this small difference greatly influence on their own permeability capacities. Therefore, this analysis has confirmed again that the soil permeability of a soil sample depends on the percentage availability of aggregates especially with the percentage of Silt and Clay. It further shows that the permeability of imported sand fill depends on the particle size distribution and the level of compaction.

This information will be very helpful for land developers and land owners in selecting their land fill materials. Also, authorities such as city councils to assess the stormwater management performances capebilities based on the properties of the fill materials of the land development.

6.4.1. Conclusions

As discussed above, almost all the samples reached their maximum average dry density of 1.89 g/cm^3 at 12-15% of moisture content. The permeability capacity drops with increased density. It was also identified that the samples reached their minimum permeability at the maximum dry density. The unified soil classification shows that all four samples were poorly graded course sand. The results also show that the number of finer particles (particle size less than 75µm) present in a soil sample plays an important role with soil permeability and the requirement for further analysis

6.5. Determining of a maximum allowable permissible permeability rates for Australian standard filling materials

This finding is one of the main important outcomes of this research as it fills a large knowledge gap that existed for a long time in the area of hydraulic designs in residential land development projects. No further evidence is required to explain the importance of the maximum allowable permissible permeability of a imported fill in residential development at developed stage as this valuable finding is already in practice even before this thesis is published.

This important finding is derived based on the important relationships developed between the saturated permeability and the percentage of silt and clay under the Section 6.1 and Section 6.4.

The following assumptions have been made during a below calculation.

- Blockage factor = 2
- As per the Australian standard AS 3798-2007 the standard fill material should contain of 5% or less fine material.

The theoretical curves for both insitu soils and the imported soils were given in the Figure 6:4 and Figure 6:12. The combination of Figure 6.4 and 6.12 is shown in the Figure 6:13. The area bounded by the theoretical curve, y axis and the x axis represent all the possible permeability capacities with respect to the content of the fines in the soil sample and the compaction level of it. As shown in Figure 6:13, the permeability of the insitu soils layers is more critical than the permeability through imported fill layers. So the maximum allowable permissible permeability capacity of the standard fill material which contains maximum of 5% silt and clay with the blockage factor of 2 is calculated as 5m/day.

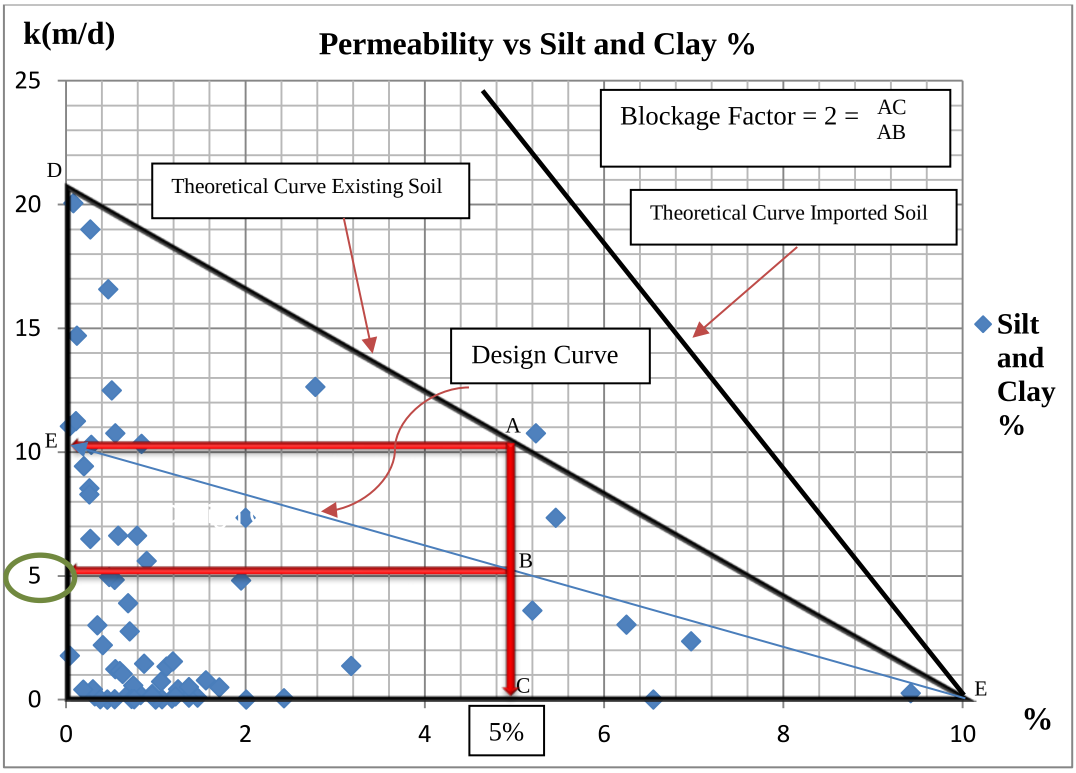


Figure 6:13 – Calculation of the maximum allowable permeability value

The maximum allowable permissible permeability capacity of the standard fill material (contains maximum of 5% silt and clay with the blockage factor of 2) is 5m/day.

6.6. Conclusions

- As per the unified soil classification system, it has been determined that most of the soil samples are poorly graded, as well as for most of the types of soil. Resulting in the majority of the 89 soil samples being classified coarse-sand soils. Moreover, the finer grading of the soil has been found and 18 of them were required to undergo the plasticity tests in order to get more accurate grading as specified.

- It is clear that the apparent particle density of a soil sample is constant and infiltration capacity is totally independent of its particle density.

- It is clear that the permeability can vary in a range while having the same capacity of water absorption which shows the very similar relationship against the percentage of silt and clay exist in the sample. Again, this analysis confirms that the permeability of a soil sample depends on two or more variables.

- Almost all the samples reached their maximum average dry density of 1.89 g/cm^3 at 12-15% of moisture content. The permeability capacity drops with increased density. It was also identified that the samples reached their minimum permeability at the maximum dry density. The unified soil classification shows that all four samples were poorly graded course sand. The results also show that the number of finer particles (particle size less than 75µm) present in a soil sample plays an important role with soil permeability and the requirement for further analysis

- The maximum allowable permissible permeability capacity of the standard fill material (contains maximum of 5% silt and clay with the blockage factor of 2) is 5m/day.

CHAPTER 7

7 DEVELOP A DECISION-SUPPORT MATRIX FOR SELECTING THE BEST STORMWATER MANAGEMENT STRATEGY IN URBAN LAND DEVELOPMENT

7.1. Introduction

The available stormwater management options used in land development are assessed further with a target to provide a user-friendly guidance tool to decision makers in selecting of the best stormwater management strategies depending on the development objective and site characteristics. In the overall assessment process. Focus cannot be on to achieving only one objective, and it is very important to follow a multidisciplinary approach. Implementation of the best stormwater management system is not just an engineering process, but also planning, landscape design, architecture, open space management and asset management processes. When applying strategy, care therefore needs to be taken that as many disciplines as possible provide input into the selection process to ensure that a balanced outcome is achieved. Each and every stormwater management strategy requires meeting at least a minimum requirement of governing factors. Early chapters show that the soil infiltration plays a major role within each and every stormwater management strategies and only the range of infiltration values would be allowed designers to achieve their objectives successfully. For example, if the infiltration is very high, designers cannot achieve their water quality objective through infiltration and another stormwater quality management strategy needs to be considered before the stormwater reaches to the receiving water body. The clayey soils which have very low permeability is not suitable for any type of infiltration based management options. As it clearly explained in available stormwater guidelines and results obtained throughout this study, the importance of identifying the range of permeability categories is one of the selection criteria. As a major part of this study, ranges of permeability categories have been defined as shown in Table 7:1.

Table 7:1- Hydraulic conductivity categories

Colour Code	Hydraulic Conductivity Range (m/day)	Category
	1.56 <	Very High
	0.48 < 1.56	High
	0.12 < 0.48	Moderate
	< 0.12	Low

7.2. Decision-Support Matrix for Strategy Selection

The selection of the best stormwater management strategy requires consideration of multiple factors, such as soils permeability, site scale catchment management objectives, target pollutants, social values, and capital and operating costs to achieve a balance between quantity and quality management objectives and to create a sustainable outcome. Considering all these factors and the potential benefits and limitations of available stormwater management strategies, a "Decision-Support Matrix for Strategy Selection" has been prepared. Table 7:2 summarizes the content of the developed decision-support matrix.

This matrix produces key guidance to the designers in selecting sustainable best stormwater management strategies or finding of best combination of these measures to suit local circumstances

In this matrix, the stormwater management options (best management practices – BMP) have been divided into 5 categories; infiltration systems, conveyance systems, detention systems, stormwater storage and reuse, and pollutant control. Practical examples and methods has been listed under each category. Twenty (20) widely using stormwater best management practices are included in this matrix. Each BMP is then subjected to three major site specifics selection criteria; infiltration capacity, lot size (scale) and objective function of the system. Infiltration capacity is subdivided into four categories from very high to low permeability/infiltration capacity. Scale is divided into four sub-groups; lot scale, street scale, precinct scale and regional scale. Three objective functions are considered as, stormwater quantity management, stormwater quality management and water conservation. Based on these parameters, the matrix helps to finalize and decide the best suitable stormwater management option (best management practice) for a particular land development. There may be several options that are suitable for the considered land development. Therefore, the user can select the best option considering other governing factors such as the installation and maintenance cost, accessibility of the site etc.

The developed Decision-Support Matrix for Strategy selection would be highly useful for land developers as well as authorities, decision makers and policy makers to come up with sustainable stormwater management options in their land development proposals.

Table 7:2- Decision-Support Matrix for Strategy Selection

No	BMP		CLASSIFICATION OF SOIL BASED ON INFILTRATION CAPACITY				SCALE				OBJECTIVE FUNCTION		
			1.56 <	0.48 < 1.56	0.12 < 0.48	< 0.12	Lot	Street	Precinct	Regional	Water Quantity	Water Quality	Water Conservation
			1	2	3	4							
	Infiltration Systems - I												
1	Soakwells	I1	√	√	~		√	√			R	√	~
2	Pervious Pavement	I2	√	√	~		√	√			R	√	~
3	Infiltration Trenches	I3	√	√	~		√	√	√		R	√	~
4	Infiltration Basins	I4	√	√	~				√	~	R	√	~
	Conveyance Systems - C												
5	Swales and Buffer Strips	C1	√	√	√	√	√	√	√	√	C R D	√	~
6	Bioretention Systems (Swales, Basin)	C2	√	√	√	√		√	√		C R D	√	~
7	Rain Gardens	C3	√	√	√	√	√	√			C R D	√	
8	Sand filters	C4	√	√	√	√		√	√		C R D	√	~
9	Retention trenches	C5	√	√	√	√		√			C R	√	
10	Living Streams C6	C6			√	√			√	√	C R D	√	~
	Detention Systems - D												
11	Onsite detention system	D1				√	√	√	√	√	D		
12	Dry/Ephemeral Detention Areas	D2	√	√	√				√	~	D	√	
13	Ponds and Lakes	D3			√	√			√	√	D	~	
14	Wet basin	D4			√	√			√	√	D	~	
15	Constructed Wetlands	D5	√	√	√	√			√	~	D	√	
	Stormwater Storage and Use - S												
16	Rainwater Storage Systems	S1	√	√	√	√	√				R		√
17	Managed Aquifer Recharge	S2	√	√	√	√	√		√	√	R		√
	Pollutant Control - P												
18	Litter and Sediment Management	P1	√	√	√	√	√	√	√			√	
19	Hydrocarbon Management	P2	√	√	√	√	√	√				√	
20	Sediment Basin	P3	√	√	√	√			√		R	~	

key √ BMP is applicable , ~ **BPM is applicable to some extent, R = Retention, D = Detention and C= Conveyance**

Other than to the strategies mention in the table above there are few strategies that are readily available without any were given below (BMP – C7). They are mostly direct uses.

- Building code of Australia – All tap fitting should be water efficient
- Water Reducing and water saving technology

The Domestic Water Study determined the annual water usage to be 128kL per person annually. The Perth Residential Water Study which was intended to update the previous study determined the annual water usage to be 106kL/yr. This is very close to the State Water Plan's consumption target of 100kL/yr. The reduction in water consumption is attributed to increased education concerning the current issue of water shortages and the implementation of water saving technology inside and outside of the home.

Potential reductions in scheme water usage through the implementation of water wise technology are outlined in the Perth Residential Water Use Study 2008/2009 and the Domestic Water Study 1998/2001. If the percentage of those dwellings in the metropolitan area using conventional water use practices implemented water wise technology, then the average water use per person/year would potentially reduce water consumption to 84kL/person/yr, which would be below the State Water Plan consumption target of 100kL/person/yr. If only the enforceable water saving measure were introduced (taps, toilet, bath and shower) then water consumption would equate to 93KL/person/yr. which is still below target. It is considered that all new dwellings within the ODP area will incorporate a substantial amount of water saving technology which will be enforced through the Building Code, and be applied voluntarily to reduce water usage. With continued education and development of awareness programs by the government, new dwellings in the ODP area will be able to achieve the State Water Plans consumption target.

7.3. Matrix for quick reference guide

The Table 7:3 is designed for easy reference of the detailed information about the selected stormwater drainage strategy, design guidelines and scale of application. This will help designer to go through a quick literature review for better understanding the strategy before the strategy applies to the conceptual design or the hydraulic modelling.

Table 7:3- Matrix for quick reference guide

No	STRATEGY		CLASSIFICATION OF SOIL BASED ON INFILTRATION CAPACITY				SCALE				OBJECTIVE FUNCTION		
			1.56 <	0.47 < 1.56	0.12 < 0.47	< 0.12	Lot	Street	Precinct	Regional	Water Quantity	Water Quality	Water Conservation
			Very High	High	Moderate	Slow							
	Infiltration Systems - I	Section - 7.1											
1	Soakwells - I1	Section - 7.1.1	Section - 7.1.1.1	Section - 7.1.1.1	Section - 7.1.1.1	Section - 7.1.1.1	Section - 7.1.1.2	Section - 7.1.1.2	Section - 7.1.1.2	Section - 7.1.1.2	Section - 7.1.1.1	Section - 7.1.1.1	Section - 7.1.1.1
2	Pervious Pavement - I2	Section - 7.1.2	Section - 7.1.2.1	Section - 7.1.2.1	Section - 7.1.2.1	Section - 7.1.2.1	Section - 7.1.2.2	Section - 7.1.2.2	Section - 7.1.2.2	Section - 7.1.2.2	Section - 7.1.2.1	Section - 7.1.2.1	Section - 7.1.2.1
3	Infiltration Trenches - I3	Section - 7.1.3	Section - 7.1.3.1	Section - 7.1.3.1	Section - 7.1.3.1	Section - 7.1.3.1	Section - 7.1.3.2	Section - 7.1.3.2	Section - 7.1.3.2	Section - 7.1.3.2	Section - 7.1.3.1	Section - 7.1.3.1	Section - 7.1.3.1
4	Infiltration Basins - I4	Section - 7.1.4	Section - 7.1.4.1	Section - 7.1.4.1	Section - 7.1.4.1	Section - 7.1.4.1	Section - 7.1.4.2	Section - 7.1.4.2	Section - 7.1.4.2	Section - 7.1.4.2	Section - 7.1.4.1	Section - 7.1.4.1	Section - 7.1.4.1
	Conveyance Systems C	Section - 7.2											
5	Swales and Buffer Strips - C1	Section - 7.2.1	Section - 7.2.1.1	Section - 7.2.1.1	Section - 7.2.1.1	Section - 7.2.1.1	Section - 7.2.1.2	Section - 7.2.1.2	Section - 7.2.1.2	Section - 7.2.1.2	Section - 7.2.1.1	Section - 7.2.1.1	Section - 7.2.1.1
6	Bioretention Systems (Swales, Basin) - C2	Section - 7.2.2	Section - 7.2.2.1	Section - 7.2.2.1	Section - 7.2.2.1	Section - 7.2.2.1	Section - 7.2.2.2	Section - 7.2.2.2	Section - 7.2.2.2	Section - 7.2.2.2	Section - 7.2.2.1	Section - 7.2.2.1	Section - 7.2.2.1
7	Rain Gardens - C3	Section - 7.2.3	Section - 7.2.3.1	Section - 7.2.3.1	Section - 7.2.3.1	Section - 7.2.3.1	Section - 7.2.3.2	Section - 7.2.3.2	Section - 7.2.3.2	Section - 7.2.3.2	Section - 7.2.3.1	Section - 7.2.3.1	Section - 7.2.3.1
8	Sand filters - C4	Section - 7.2.4	Section - 7.2.4.1	Section - 7.2.4.1	Section - 7.2.4.1	Section - 7.2.4.1	Section - 7.2.4.2	Section - 7.2.4.2	Section - 7.2.4.2	Section - 7.2.4.2	Section - 7.2.4.1	Section - 7.2.4.1	Section - 7.2.4.1
9	Retention trenches - C5	Section - 7.2.5	Section - 7.2.5.1	Section - 7.2.5.1	Section - 7.2.5.1	Section - 7.2.5.1	Section - 7.2.5.2	Section - 7.2.5.2	Section - 7.2.5.2	Section - 7.2.5.2	Section - 7.2.5.1	Section - 7.2.5.1	Section - 7.2.5.1
10	Living Streams - C6	Section - 7.2.6	Section - 7.2.6.1	Section - 7.2.6.1	Section - 7.2.6.1	Section - 7.2.6.1	Section - 7.2.6.2	Section - 7.2.6.2	Section - 7.2.6.2	Section - 7.2.6.2	Section - 7.2.6.1	Section - 7.2.6.1	Section - 7.2.6.1
	Detention Systems D	Section - 7.3											
11	Onsite Detention system												
12	Dry/Ephemeral Detention Areas - D1	Section - 7.3.1	Section - 7.3.1.1	Section - 7.3.1.1	Section - 7.3.1.1	Section - 7.3.1.1	Section - 7.3.1.2	Section - 7.3.1.2	Section - 7.3.1.2	Section - 7.3.1.2	Section - 7.3.1.1	Section - 7.3.1.1	Section - 7.3.1.1
13	Ponds and Lakes - D2	Section - 7.3.2	Section - 7.3.2.1	Section - 7.3.2.1	Section - 7.3.2.1	Section - 7.3.2.1	Section - 7.3.2.2	Section - 7.3.2.2	Section - 7.3.2.2	Section - 7.3.2.2	Section - 7.3.2.1	Section - 7.3.2.1	Section - 7.3.2.1
14	Wet basin - D3	Section - 7.3.3	Section - 7.3.3.1	Section - 7.3.3.1	Section - 7.3.3.1	Section - 7.3.3.1	Section - 7.3.3.2	Section - 7.3.3.2	Section - 7.3.3.2	Section - 7.3.3.2	Section - 7.3.3.1	Section - 7.3.3.1	Section - 7.3.3.1
15	Constructed Wetlands - D4	Section - 7.3.4	Section - 7.3.4.1	Section - 7.3.4.1	Section - 7.3.4.1	Section - 7.3.4.1	Section - 7.3.4.2	Section - 7.3.4.2	Section - 7.3.4.2	Section - 7.3.4.2	Section - 7.3.4.1	Section - 7.3.4.1	Section - 7.3.4.1
	Stormwater Storage and Use - S	Section - 7.4											
16	Rainwater Storage Systems - S1	Section - 7.4.1	Section - 7.4.1.1	Section - 7.4.1.1	Section - 7.4.1.1	Section - 7.4.1.1	Section - 7.4.1.2	Section - 7.4.1.2	Section - 7.4.1.2	Section - 7.4.1.2	Section - 7.4.1.1	Section - 7.4.1.1	Section - 7.4.1.1
17	Managed Aquifer Recharge - S2	Section - 7.4.2	Section - 7.4.2.1	Section - 7.4.2.1	Section - 7.4.2.1	Section - 7.4.2.1	Section - 7.4.2.2	Section - 7.4.2.2	Section - 7.4.2.2	Section - 7.4.2.2	Section - 7.4.2.1	Section - 7.4.2.1	Section - 7.4.2.1
	Pollutant Control P	Section - 7.5											
18	Litter and Sediment Management - P1	Section - 7.5.1	Section - 7.5.1.1	Section - 7.5.1.1	Section - 7.5.1.1	Section - 7.5.1.1	Section - 7.5.1.2	Section - 7.5.1.2	Section - 7.5.1.2	Section - 7.5.1.2	Section - 7.5.1.1	Section - 7.5.1.1	Section - 7.5.1.1
19	Hydrocarbon Management - P2	Section - 7.5.2	Section - 7.5.2.1	Section - 7.5.2.1	Section - 7.5.2.1	Section - 7.5.2.1	Section - 7.5.2.2	Section - 7.5.2.2	Section - 7.5.2.2	Section - 7.5.2.2	Section - 7.5.2.1	Section - 7.5.2.1	Section - 7.5.2.1
20	Sediment Basin - P3	Section - 7.5.3	Section - 7.5.3.1	Section - 7.5.3.1	Section - 7.5.3.1	Section - 7.5.3.1	Section - 7.5.3.2	Section - 7.5.3.2	Section - 7.5.3.2	Section - 7.5.3.2	Section - 7.5.3.1	Section - 7.5.3.1	Section - 7.5.3.1

7.4. Integration of study outcome with the available strategies for urban stormwater management to improve the efficiency

This section covers one of the most important piece of this thesis. As a professional drainage engineer with over 16 years' design and practical experience gained, the author of this study observedit is realised that selecting of best stormwater management strategy by analysing the main objective function, infiltration capacity of the supporting soil, scale of application is still confusing among the professionals who are involved in this industry. It is understood that the reason behind this to occur is mainly due to the lack of knowledge in identifying and comparing the basic difference between the strategies listed above. This chapter is mainly focused on developing skills of picking up the right strategy at right place. As a summary, all the stormwater management strategies that is readily available to achieve WSUD by implementing BMPs which have been discussed below.

7.5. Infiltration Systems - I

Infiltration devices are designed to collect the rain that falls on site and store it temporarily and encourage it to infiltrate slowly into the surrounding soil. All infiltration devices have three main parts basically and these are site drainage system, pre-treatment system and infiltration retention system. The drainage system such as roof gutters, downpipes, paths and driveways these collect the stormwater and deliver it to the infiltration device. The per treatment systems such as silt traps, grassed and vegetated areas and sedimentation tanks are located between the infiltration device and the collecting system. These systems are designed to remove insoluble pollutants such are grass and particular matter from reaching the infiltration device. This helps to protects and maximises the life of infiltration devices (Coombes 2007a). This general layout is show in the Figure 7:1 below.

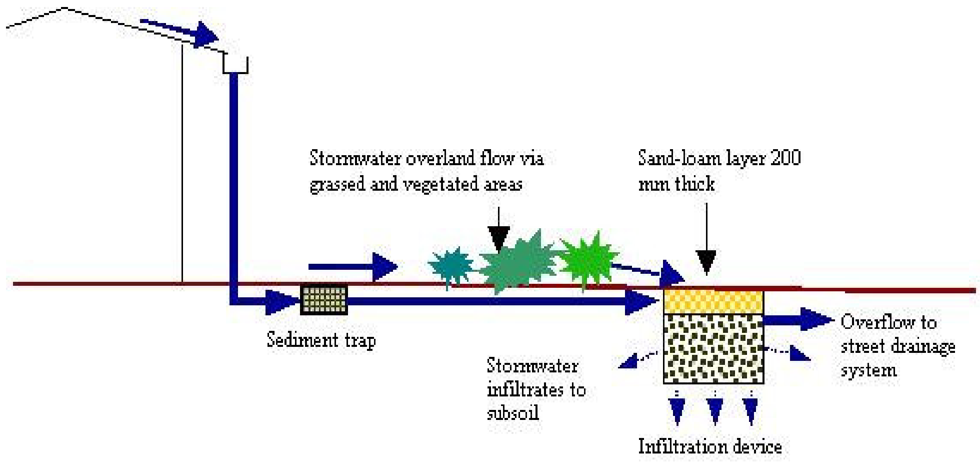


Figure 7:1 -General layout of a Lot drainage

Source: (Coombes 2007a)

The following Key factors should be considered in selecting an infiltration based stormwater management practice.

- Capability to infiltrate stormwater is the soil permeability
- Soil reactivity to frequent wetting
- Presence of groundwater and its environmental values
- Site terrain

Hydraulic conductivity (Permeability)

The hydraulic conductivity places a major role in infiltration based best stormwater management. Field hydraulic conductivity tests must be undertaken to confirm assumptions of soil hydraulic conductivity adopted during the concept design stage. The field saturated hydraulic conductivity (Ks) can be determined using the Guelph Permeameter, falling head augerhole method of Jonasson (1984). The saturated hydraulic conductivity of undisturbed soil sample can be found by using falling head method. As explained in Chapter 4 both Guelph Permeameter and falling head methods were used in this project to measure the permeability at 1m and 1.5m level respectively. The saturated hydraulic conductivity (Ks) is the hydraulic conductivity of a soil when it is fully saturated.

Soil is inherently non-homogeneous and field tests can often misrepresent the areal hydraulic conductivity of a soil into which stormwater is to be infiltrated. Some field experience has suggested that field tests of ‘point’ soil hydraulic conductivity can often underestimate the areal hydraulic conductivity of clay soils and overestimate the value for sandy soils (WSUD Melbourne water 2005). In order to prevent such errors during the testing time, additional samples should be tested and both test results considered in allocating permeability values for housing precincts. More information is provided with examples in the Chapter 4.

Soils with low hydraulic conductivities do not necessarily preclude the use of infiltration systems even though the required infiltration/storage area may become unfeasible. However, these soils are likely to render them more susceptible to clogging and require enhanced pre-treatment. In addition, standing water for a long period of time may promote algal growth that increases the risk of clogging of the infiltration media. Thus, it is recommended that soil saturated hydraulic conductivities exceeding 1×10^{-5}m/s (0.86m/day) are most suited for infiltration. However, Key factors influencing the operation of an infiltration system are the relationship between infiltrations rates, the volume of runoff discharged into the infiltration system, depth to groundwater or bedrock and the available detention storage. Infiltration rate (Q_{inf}) is a product of the infiltration area (A) and the hydraulic conductivity of the in-situ soil (Ks), i.e. $Q_{inf} = A\times Ks$ m^3/s – therefore, different combinations of infiltration area and hydraulic conductivity can produce the same infiltration rate.

According to the Local council design guidelines, emptying time should be 96 hr which can prevent in breading mosquitoes. By considering the above key factors, the permeability value of 0.48 m/day has been taken as minimum permissible permeability in designing an infiltration based stormwater management strategy.

The hydrologic effectiveness of an infiltration system defines the proportion of the mean annual runoff volume that infiltrates. For given catchment area and meteorological condition, the hydrologic effectiveness of an infiltration system is determined by the combined effect of the soil hydraulic conductivity, infiltration area and available detention storage.

Groundwater

Two types of groundwater issues need to be considered when implementing an infiltration system. The first relates to the environmental values of the groundwater (i.e. the receiving water) and it may be necessary to achieve a prescribed water quality level before stormwater can be discharged. The second design factor is to ensure that the base of an infiltration system is always above the groundwater table and consideration of the seasonal variation of groundwater levels is essential if a shallow groundwater table is likely to be encountered. This investigation should include groundwater mounding (i.e. higher levels very close to the infiltration system) that in shallow groundwater areas could cause problems with nearby structures. This separation from the base of the infiltration measures to the AAMGWL is practiced as 0.5 m in the City of Gosnells. The standard separation is 300mm (Stormwater Management Manual Western Australia) which is same as most around the Australia.

Site terrain and soil salinity

A combination of poor soil conditions (e.g. sodic and dispersive soils), steep terrain and shallow saline groundwater can render the use of infiltration systems inappropriate. Dry land salinity is caused by a combination of factors, including leaching of infiltrated water and salt at 'break-of slope' terrain and the tunnel erosion of dispersive soils. Infiltration into steep terrain can result in the stormwater re-emerging onto the surface at some point downstream. The likelihood of this pathway for infiltrated water depends on the soil structure, with duplex soils and shallow soil over rock being situations where re-emergence of infiltrated water to the surface is most likely to occur. This occurrence does not necessarily preclude infiltrating stormwater, unless leaching of soil salt is associated with this process.

7.5.1. Soak wells, Leaky Wells, Dry wells, Soakaway pits - I1

Soak wells also known as leaky well, which have no major different between each other and they are very useful at storm management at source control. They are typically in stored on the road side entry pits at the beginning of a stormwater management system and also they are extensively used in lot scale nowadays (Chalmers & Gray 2004). They consist of a cut opening around the surface with a lid at the ground surface and an open bottom. Stormwater enters the leaky well though the inlet pipe and the top of the device, the holes in the well and the open bottom are covered with geotextile material to cleanse stormwater as it enters the surround ground, as show in the Figure 7:2 below. One of the main advantages of using leaky well is that it is easy to access the chamber and remove the sediments therefore reducing the chances of failure due to clogging (Coombes 2007a).

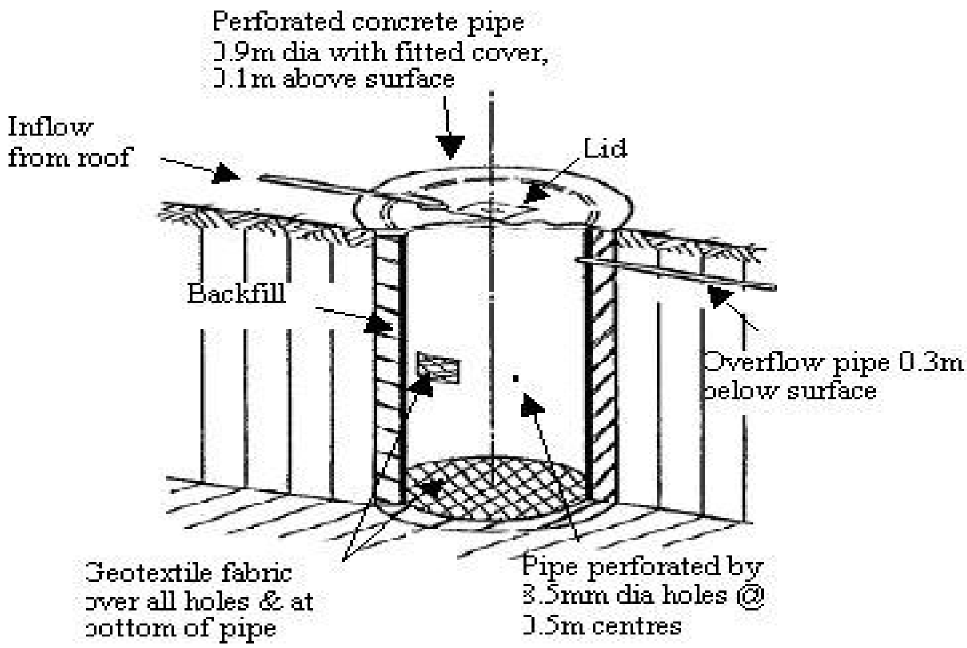


Figure 7:2 -leaky wells, Source: (Coombes 2007a)

Soakaway pits, also known as dry wells, are underground systems used to let stormwater to infiltrate into the ground. The downspout from roofs is connected to an underground pit lined with gravel or coarse materials such as rocks. The layers of gravel help to slow down the rate of infiltrated water but also to clean and purify it naturally. Soakaway pits require relatively high permeable soil and clean water with some pre-filtering to prevent debris from clogging the system, so usually only rainfall from roofs through a downspout should be used for soakaway pits. The water is then slowly filtered down through the gravel and into the surrounding soil providing water to plant roots and recharging groundwater supply (Riversides 2005-2009).

7.5.1.1. Design guidelines

The calculations contained in this section for sizing the storage volume of soakwells and determining emptying time are based on Engineers Australia (2006) and Argue (2004). The calculations should be applied with caution to the sizing of infiltration systems where shallow groundwater is present. This approach does not consider the impacts of shallow groundwater in its calculation, which may reduce infiltration capacity. Detailed modelling of shallow groundwater table situations is recommended. Designers should take into account the maximum groundwater level and hence the minimum infiltration potential, in determining their flood detention design. However, designers should also consider maximum infiltration opportunities to achieve aquifer recharge when the groundwater table is below its maximum level. In design of soakwells the following key factors are considered.

- Decision-Support Matrix for Strategy Selection Strategy selection is provided in Table 7:2 for more details.
- Follow the Table 7:3 for Matrix for quick reference guide.
- Refer Section 5.2 for recommendations for stormwater management in infill land development - design of a stormwater drainage design calculator for lot retention and detention
- At least 0.5 m separation should be allowed from the bottom of the soakwell to the AAMGWL.
- At least 1.5m away from wall and boundary wall.
- Depending on the soil permeability and objective function, the soakwell can be provided with some modifications to the original design. (follow the reference for more detail)
- The design calculation should be undertaken as per the details given in the Engineer Australia 2006 and SMMWA.

7.5.1.2. Scale of application

These systems are used widely in Western Australia as an at-source stormwater management control, typically in small-scale residential and commercial applications, or as road side entry pits at the beginning of a stormwater system. Soakwells can be applied in retrofitting scenarios and existing road side entry pits/gullies can be retrofitted to perform an infiltration function.

7.5.2. Pervious Pavement – I2

Porous pavement offer wide range of stormwater management benefits these include reduction of stormwater discharge from paved areas, increased groundwater recharge and reduced area of land dedicated solely for stormwater management (Chalmers & Gray 2004). Permeable pavement is a variation on traditional pavement design that utilizes pervious paving material underlain by a uniformly graded stone reservoir. The pavement surface may consist of permeable asphalt, permeable concrete, permeable interlocking concrete pavers, concrete grid pavers and plastic grid pavers. Openings in permeable interlocking concrete pavers, concrete grid pavers and plastic grid pavers are typically filled with pea gravel, sand or top soil and grass. Permeable pavements prevent the generation of runoff by allowing precipitation falling on the surface to infiltrate into the stone reservoir and where suitable conditions exist, into the underlying soil. They are most appropriately applied in low to medium traffic areas (e.g., residential roads, low traffic parking lots, driveways, walkways, plazas, playgrounds, boat ramps etc.) that typically receive low levels of contaminants. In addition to the stormwater management benefits, permeable pavements can be more aesthetically attractive than conventional, impermeable pavements.

Asphaltic and concrete paving

Asphaltic and concrete porous paving is laid on a sand/gravel sub base over natural soil. A subsoil drainage pipes are usually in stored if the underlying soil is impermeable. Stormwater pass through asphaltic and concrete to the sub base, where it is stored till infiltration to the surrounding soil. If the soil is impermeable subsoil drainage pipes are used to slowly drain the water into the street drainage systems. As shown in the Figure 7*:3* below (Coombes 2007a).

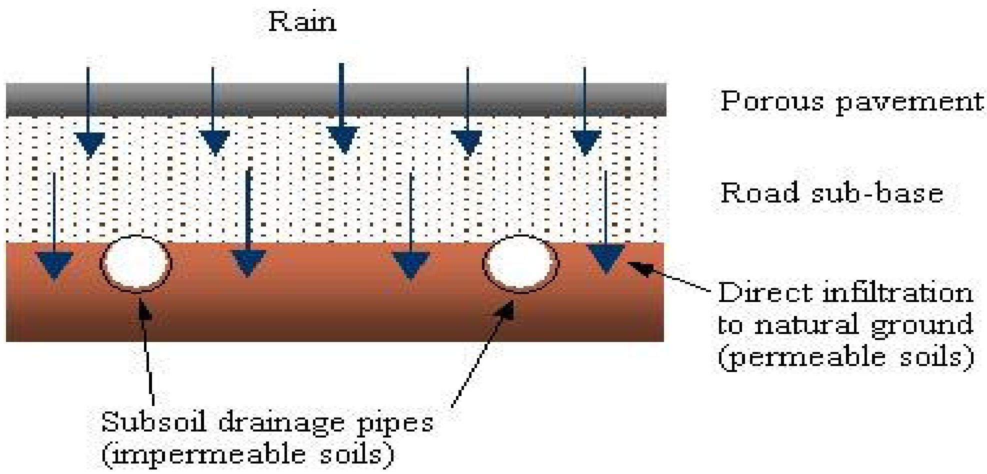


Figure 7:3 -Asphaltic & Concrete porous paving,

Source: (Coombes 2007b)

Grid and modular paving

These are more modern porous paving and are design to reduce on the clogging and are earlier and straightforward to repair. This range includes concrete grids poured in situ, precast concrete grids and concrete, ceramic, fired clay or plastic modular.

They generally have voids which allow the stormwater to pass through to the sand or gravel sub base layer. This lay is usual underline with a geotextile fabric and gravel retention trenches hence creating a very effective stormwater treatment chain. As sown in the Figure 7:4 below.

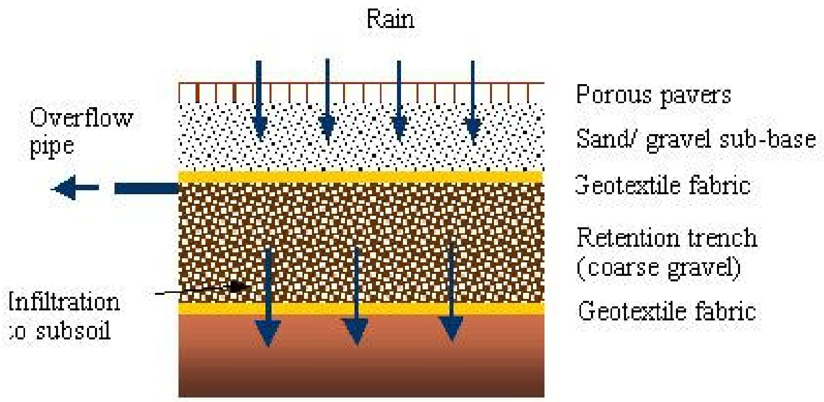


Figure 7:4 -Grid and modular paving,

Source: (Coombes 2007b)

Porous paving is very effective method of increasing the stormwater infiltration but unfortunately there are a number of failures due to poor design. These failures include reducing infiltration capacity, clogging, contamination of aquifer, low structural integrity and no infiltration happening at all due to the slope of the paved area. These limitations maybe overcome by following the following consideration.

7.5.2.1. Design guidelines

The method for design calculation is based on Argue (2004). The equations are applicable where the overall value of the hydraulic conductivity for the product and its underlying sub-structure is known. This method should be applied with caution to the sizing of infiltration systems where shallow groundwater is present. This approach does not consider the impacts of shallow groundwater in its calculation, which may reduce infiltration capacity. Detailed modeling of shallow water table situations is recommended. Designers should take into account the maximum groundwater level and hence the minimum infiltration potential, in determining their flood detention design. However, designers should also consider maximum infiltration opportunities to achieve aquifer recharge when the groundwater table is below its maximum level.

- Decision-Support Matrix for Strategy Selection Strategy selection is provided in Table 7:2 for more details.
- Follow the Table 7:3 for Matrix for quick reference guide.
- The typical cross-sections of the permeable pavements are given in the Figure 7:5.
- There are some specific considerations for the design of pervious pavement. Some pervious pavement systems have a high failure rate that is attributed to poor design, clogging by fine sediment and excess traffic use (USEPA 1999).
- Pervious pavement systems are not suitable for areas with slopes greater than 5% or high wind erosion rates (USEPA 1999, (Coombes 2007b).
- Soils that feature a rising water table, saline conditions, dispersive clay or low hydraulic conductivity are not suitable for pervious pavement.

- The factors that will maximize the likely success of pervious pavement installation include: low traffic volumes and light vehicle weights, low sediment loads, moderate soil infiltration rates, and regular and appropriate maintenance of the surface;
- Pervious paving must be carefully designed in areas with high water table levels, windblown or loose sands, clay soils that collapse in contact with water, and soils with a hydraulic conductivity of less than 0.36 mm/hour;
- In locations where infiltration will cause shrinking of clays and possible damage to structures, a minimum clearance of 5 m or an impermeable lining should be used;
- Pre-treatment of surface runoff should be considered to minimize clogging of the paving media and protect groundwater quality. Suitable pre-treatment systems could include leaf and roof guards for roof gutters, buffer strips, swales or a small sediment forebay for larger scale developments.
- Where possible, flows that are ‘above design’ flows should be designed to bypass the pervious paving system. This can be achieved in a number of ways, including an overflow pipe or pit which is connected to the downstream drainage system.
- The design calculation should be undertaken as per the details given in the Engineer Australia 2006 and SMMWA.

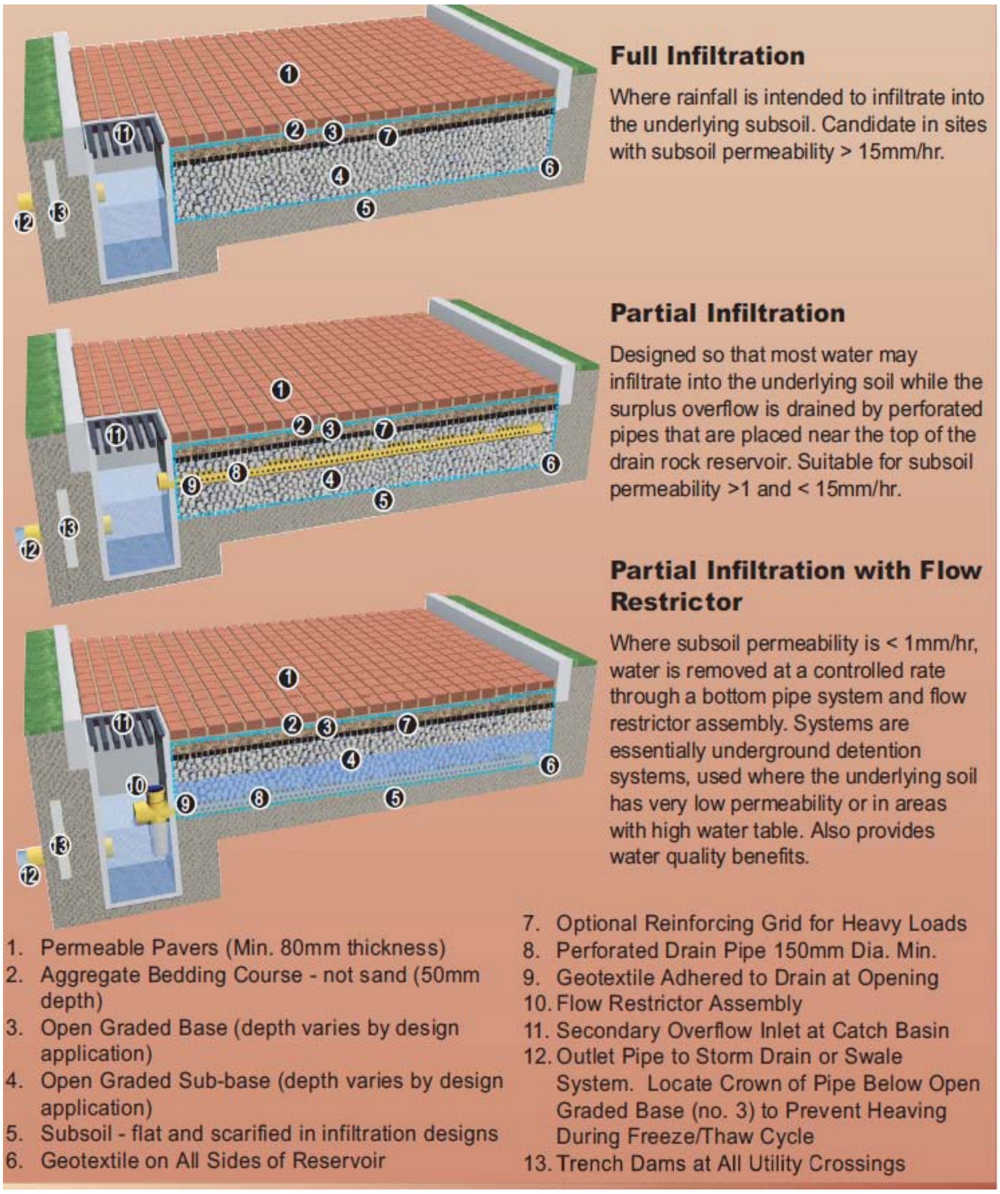


Figure 7:5 -Typical Details -Permeable pavement cross sections

Source : GVRD, 2005

- Clogging with sediment and oil can occur during construction or through long-term use. The construction process, pre-treatment techniques and maintenance requirements should be designed to minimize clogging.
- Pervious pavements have been found to be most practical and cost effective when serving catchment areas between 0.1 and 0.4 hectares. As a guide, the contributing catchment area to a pervious area should not exceed 4 to 1. Where sediment and organic loads are high, the ratio should be reduced to 2 to 1.

7.5.2.2. Scale of application

Pervious paving can be utilized in car parks, streets with low traffic volumes and light traffic weight, and for paving within residential, commercial and institutional developments.

7.5.3. Infiltration Trenches – I3

An infiltration trench is a shallow, excavated trench filled with gravel or rock, through which run-off drains. Stormwater transfers from the trench into the surrounding soil, while sediment and some dissolved pollutants are retained in the trench (see Figure 7:6). The trench is lined with a layer of geotextile fabric, to prevent soil migration into the rock or gravel fill. The top surface of the fill is also covered with a layer of fiber fabric, and then finished with a shallow layer of topsoil.

Figure 7:6 - Infiltration trench filled with appropriate sized gravel

Source: (Coombes 2007b)

Local soil geochemistry and grading determine the infiltration trench's ability to remove particulate and dissolved pollutants. The trenches increase the soil moisture levels, groundwater flow rates.

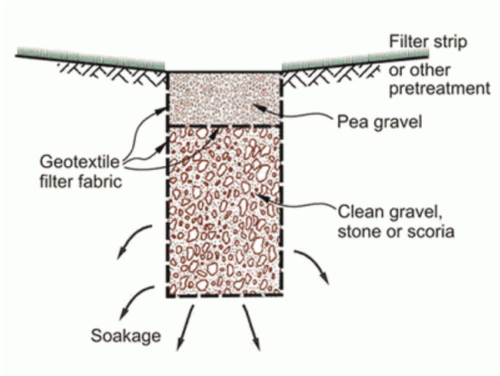


Figure 7:7- Infiltration trenches – Cross sectional details

Source: (Coombes 2007b)

The trench will help retain water in the spaces between the stones, where the water can soak into the ground. As it has already been filtered there should be less pollution entering our water source aquifers (see Figure 7:7).

This will also help detain the excess stormwater from site, to the local stormwater management system, which will help take and ease the load of the systems already working at maximum capacity during bad weather periods. By detaining stormwater, the system will also be able to transport and store stormwater from other sites, that don't deal with stormwater as well as sites that do, then come back and transport the detain stormwater after busy periods of bad weather. Trenches can also be detained for on-site use such as rain gardens, to release excess stormwater, instead of being released on roads or sidewalks.

7.5.3.1. Design guidelines

- Decision-Support Matrix for Strategy Selection Strategy selection is provided in Table 7:2 for more details.
- Follow the Table 7:3 for Matrix for quick reference guide.
- The design calculations are provided in SWMM for Western Australia and the given references.
- Cannot be located on steep slopes, loose or unstable areas.

- Infiltration trenches are suitable too smaller (less than two hectare) catchments.
- In areas with soils with low infiltration rates such as heavy clay soils, a porous drainage pipe can be installed in the bottom of the trench and connected to the stormwater drainage system if required.
- Infiltration trenches are commonly used with overlying pervious pavements as an effective water treatment chain.
- Soil types, surface geological conditions determine the suitability of infiltration systems.
- At least 0.5 m separation should be allowed from the bottom of the trench to the AAMGWL.
- Trenches have the advantage of being able to fit into thin, linear areas, such as road verges and medians. Due to their flexibility in shape, trenches can be located in a relatively unusable portion of the site. However, design will need to consider clearance distances from adjacent building footings or boundaries to protect against cracking of walls and footings.
- Infiltration basins and trenches typically take up a relatively small percentage (2–3%) of the contributing catchment.
- The design calculation should be undertaken as per the details given in the Engineer Australia 2006 and SMMWA.

7.5.3.2. Scale of application

Infiltration trench systems are limited to soils with good infiltrative capacity and should also be sited with adequate buffer distances from existing in ground infrastructure. Infiltration trenches are best suited residential in small scale, commercial and industrial in large scale developments with high percentages of impervious areas.

7.5.4. Infiltration Basins - I4

Infiltration basins are generally grassed depressions along seasonal drainage lines that receive and store stormwater during storm events. The stormwater captured in the infiltration basin is allowed to slowly infiltrate through the soil profile. This reduces runoff rates and volumes downstream and removes sediments and nutrients from the stormwater system. This method of stormwater treatment is most appropriate in areas with highly permeable soils such as sands where the infiltration rates are high or in areas with high evaporation rates (Coombes 2007a). During dry periods, the grassed area that forms the base of the basin can be used for general recreational purposes, creating a valuable community asset (see Figure 7:8).

An infiltration basin is design as a depression with good grass coverage over a layer of coarse gravel surrounded by geotextile fabric. Infiltration basins are fixed with an over flow channel which leads to the street used during major storm events. The general layout of an infiltration basin is shown in the figure shown below (Coombes 2007a).

Infiltration basins also have the benefit of being pleasing to the eye therefore can be used in open public parklands. They can also by planted, the vegetation provides some water quality treatment and the root network assists in preventing the flooring form clogging (Chalmers & Gray 2004).

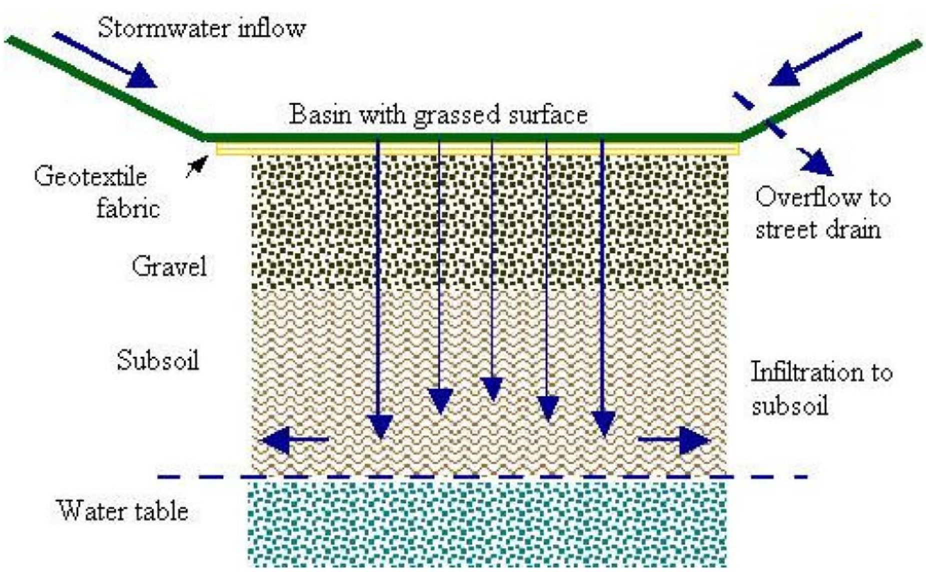


Figure 7:8- Infiltration Basin – Cross sectional details

Source: (Coombes 2007b)

7.5.4.1. Design guidelines

The seasonal nature of local rainfall and variability in groundwater level should also be considered. For example, the groundwater table may only be at its maximum for a short duration, and greater capacity for infiltration may be available throughout most of the year. However, infiltration in areas with rising groundwater tables should be avoided where infiltration may accelerate the development of problems such as water logging and rising salinity (SWMM for Western Australia).

- Decision-Support Matrix for Strategy Selection Strategy selection is provided in Table 7:2 for more details.
- Follow the Table 7:3 for Matrix for quick reference guide.
- Infiltration basins and trenches typically take up a relatively small percentage (2–3%) of the contributing catchment. (WSUD technical manual 2010)
- Additional space may be required for buffers, landscaping, access paths and fencing.
- Infiltration basins are suited medium to large (5 to 50 hectare) catchments (WSUD technical manual 2010)
- May not be appropriate for industrial sites or locations where spills may occur.
- Infiltration basins require a minimum soil infiltration rate of 0.3 m/day.
- If infiltration rates exceed 1.5 m/day, then the runoff should be fully treated prior to infiltration to protect groundwater quality. (WSUD technical manual 2010)
- Not suitable on fill sites or steep slopes. 1:6 batter is recommended for lawn and 1:4 batter for planting
- Risk of groundwater contamination in very coarse soils.
- Difficult to restore functioning of infiltration basins once clogged.
- Basin sized so that the entire water quality volume is infiltrated within 84 hours (WSUD).
- Vegetation establishment on the basin floor may help reduce the clogging rate.

- The design calculation should be undertaken as per the details given in the Engineer Australia 2006 and SMMWA.

7.5.4.2. Scale of application

Infiltration basins are best suited medium large (5 to 50-hectare catchment) residential, commercial and industrial developments with high percentages of impervious areas, including parking lots, high density residential housing and roadways. (WSUD technical manual 2010)

7.6. Conveyance Systems – C

The main objectives of conveyance system are to achieve the objective of water quantity management. It collects all the additional runoff from contributing sub catchments and covey all from upstream to downstream storage areas without affecting any upstream flooding. However, more recent conveyance system designs have been done to achieve both water quality and quantity objectives. The Water quantity objectives can be mainly described under three main three categories as Retention, Detention and Water conservation. Implementing of these systems is very famous at present as they are giving aesthetic view to the environment. The other most important factor of conveyance system is not basically depending on the soil types. (Refer Table 7:2- Decision-Support Matrix for Strategy Selection).

7.6.1. Swales and Buffer Strips - C1

Figure 7:9 – Swales

Source: (Coombes 2007b)

Swales and buffer strips are typically linear, shallow and wide. Swales are vegetated which used to convey stormwater instead of pipes. In order to remove the coarse and medium sediment swales are commonly combined with buffer strips. The buffer strips are vegetated covers which help to reduce the runoff load by flowing in a shallow depth. Buffers can be used as edges to swales, particularly where flows are distributed along the bank of the swales. The system uses overland flow and mild slopes to slowly convey water downstream. Swales also provide a disconnection of impervious areas from hydraulically efficient pipe drainage systems (See Figure 7:9). These results in slower travel times, thus reducing the impact of increased catchment imperviousness on peak flow rates.

Swale vegetation acts to spread and slow velocities, which in turn aids sediment deposition. Swales alone can rarely provide sufficient treatment to meet objectives for all pollutants, but can provide an important pre-treatment function for other Water Sensitive Urban Design (WSUD) measures. They are particularly good at coarse sediment removal and can be incorporated in street designs to enhance the aesthetics of an area.

Swales provide a number of functions including

- Removing coarse to medium sized sediments (and attached pollutants) by filtration through the vegetated surface
- Reducing runoff volumes (by promoting some infiltration to the subsoil)
- Delaying runoff peaks by reducing flow velocities
- Accommodating pedestrian movement across and along them
- Pre-treatment for other WSUD measures.

Buffer zones or strips (also known as filter strips, Figure 7:10) are provide a number of functions including

- Removing sediments by filtration through the vegetation
- Reducing runoff volumes (by promoting some infiltration to the subsoil)
- Delaying runoff peaks by reducing flow velocities
- Removing coarse to medium sized sediments (such as nutrients, free oils/grease and metals).

Figure 7:10 – Buffer Zone or Filter Strips

Gold Coast City Council (2007)

7.6.1.1. Design guidelines

The most important design consideration for a swale drain is the longitudinal slope. It is important to ensure flow velocities along a swale are kept sufficiently low to avoid scouring of vegetation and collected pollutants. Typically, the slope is considered to be most efficient between 1% and 4% to ensure that velocities do not scour the channel or compromise public safety, whilst at the same time limit ponding at low flows. Where the longitudinal slope exceeds 4%, riffles along swales can help to distribute flows evenly across the swale as well as reduce velocities. The riffles maximise the retention time within the swale, further decreasing the velocities and better promoting particulate settling (SWMM for Western Australia). The following key points have to be considered as guidelines in designing of swales and buffer strips.

- Decision-Support Matrix for Strategy Selection Strategy selection is provided in Table 7:2 for more details.
- Follow the Table 7:3 for Matrix for quick reference guide.
- The principal selection criteria for swales should firstly address the function of conveyance and secondly ensure that the system has features that will maximise treatment objectives and habitat and aesthetic values.

- Pre-treatment for swales may include litter traps at point source inlets and buffer strips parallel to the top of the banks to pre-treat sheet flows entering the swale.
- As the selection of vegetation directly impact to the overall performance of the swale, vegetation should be designed to cover the entire width of the swale
- Swales should not be in the line of other services, such as sewers and underground electricity
- Swales can be designed for Greenfield applications or in retrofitting scenarios to replace a proportion of the traditional piped network.

Design of vegetated swales needs to consider three types of storm events as given below

- Frequent storm flows - (typically up to 6 months to 1 year ARI) for water quality treatment
- Minor storm flows - (typically up to 5 year ARI) for conveyance and prevention of nuisance flooding
- Major flood flows - (up to 100 year ARI) to check flow velocities, velocity depth criteria, conveyance within the road reserve and freeboard to the adjoining properties.
- Swale dimensions and contributing catchment area should be selected to ensure 1 year ARI flow velocities for the swale are maintained at less than 0.5 m/s. Swales located within road reserves can be subjected to velocities associated with major flood flows being conveyed along the road corridor. The resultant velocities within the swale should be checked to ensure that the maximum velocity does not exceed 1.8 m/s to prevent scour.
- Public safety should be maintained by providing sufficient conveyance capacity and appropriate flow depth and velocity to satisfy design requirements for adjacent pedestrian and bicycle pathways
- To avoid sediment accumulation on the edge of the impervious area, a flush kerb or drop down should be used. This requires the finished

topsoil surface to be approximately 100 millimetres below the pavement; and Vehicles should be prevented from accessing the swale or buffer strip as this reduces performance.

- The design calculation should be undertaken as per the details given in the Engineer Australia 2006 and SMMWA.

7.6.1.2. Scale of application

Swales are often used in high density residential developments as an alternative to kerb and gutter systems, or as a pre-treatment to other measures. They can also be used in road medians and verges, car park runoff areas and parks and recreation areas to convey runoff. Swales are most applicable at the subdivision scale (i.e. along median strips, or through parks)

Swales are most effective when serving catchment areas up to 2 hectares and typically should not be used in catchments over 4 hectares in area. Larger than this, flow depths and velocities are such that the water quality improvement function of the swale may be compromised. Buffer strips are most applicable at the subdivision scale, with catchment areas less than 2 hectares.

7.6.2. Bio-retention Systems (Swales, Basin) - C2

The two-major different of both Bio-retention swales and (or biofiltration trenches) basin which involve a continuous layer of bio-retention along the length of the swale, or a portion of bio-retention prior to the outlet of the swale whereas bio-retention basins which provide flow control and water quality treatment functions. A bio-retention basin is characterised by the ability to detain/retain runoff in a depression storage (or ponded area) above the bio-retention system. The most common application of bio-retention systems is to recover the runoff using perforated under-drains for discharge or reuse. Bio-retention systems are generally not designed to enable runoff exfiltration from the bio-retention filter media to the insitu soil. Exfiltration is appropriate where soil properties, site terrain, building set back and local groundwater requirements permit.

Bio-retention systems can be designed to either encourage infiltration (where reducing volumes of stormwater runoff is important) or as conveyance systems that do not allow infiltration (where soils are not suitable for infiltration or in close proximity to surrounding structures). See
Figure 7:11.

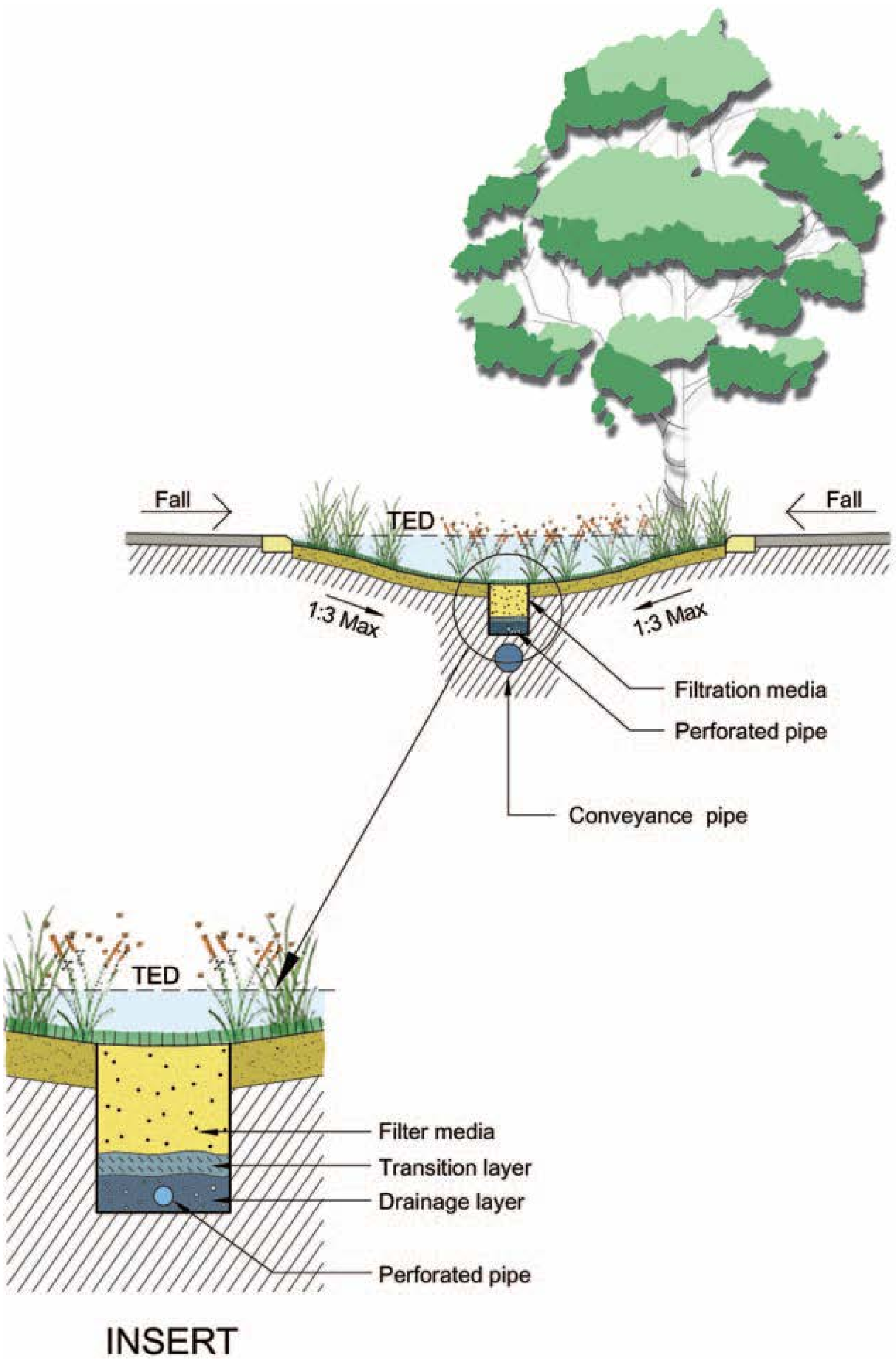


Figure 7:11 – Typical cross-section - Bio-retention system swale
Source: Melbourne Water (2005)

Bio-retention systems can provide both runoff treatment and conveyance functions including:

- The removal of coarse to medium sediments and associated pollutants
- The removal of fine particulates and associated contaminants by infiltration through the underlying filter media layers
- Protection of natural receiving waterways from frequent storm events by delaying runoff peaks, providing retention capacity and a reduction in peak flow velocities
- Swale components can be designed to convey runoff as part of a minor and/or major drainage system
- Potential aesthetic and biodiversity benefits

In many urban situations, the width available for a swale system and the slope will be fixed. Then the length of the swale to convey a minor storm safely will also be fixed. A common way to design these systems is as a series of discrete 'cells' Each cell has an overflow pit that discharges flow to an underground pipe system. Bio-retention systems can then be installed directly upstream of the overflow pits. This also allows an area for ponding over the filtration media Figure 7:11.

Design Guidelines

The following key points have to be considered in designing and selecting of Bio-retention systems (see strategy selection Table 7:2). Details relating to the design of each and every component of Bio-retention systems are provided in SWMM for Western Australia.

Typical pollutant removal rates for bio-retention systems are shown in Table 7:4, Section 4.2 - SWMM for Western Australia) as conservative average pollutant reduction percentages for design purposes derived from efficiencies detailed in Davis et al. (1998), and local Australian sampling data and research by the Cooperative Research Centre for Catchment Hydrology (eWater) based on eastern states conditions using the Model for Urban Stormwater Improvement Conceptualisation (MUSIC) (Cooperative Research Centre for Catchment Hydrology 2003).

Table 7:4- Effectiveness of bio- retention systems

Pollutant	Effectiveness	Mean % Removal
Litter	-	
Coarse sediment	High	90%
Total suspended solids	High	80%
Total Nitrogen	Medium	50%
Total phosphorus	Medium	60%
Heavy metal	High	80%

Note: - Above texts and table directly extracted from stormwater management manual for Western Australia.

In additionally to above facts, the following key points are to be considered in selecting designing bio-retention systems

- Bio-retention systems are generally considered highly effective in removing total suspended solids in typical urban post-development runoff. When sized, designed, constructed and maintained in accordance with commended specifications, bio-retention systems can expect to have 80% removal efficiency for TSS.
- Minimum 2% of total interconnected area (Road) should be provided as bio-retention area
- Saturated hydraulic conductivity of filter media is 180 mm/hr (corresponding to a sandy loam)
- filtration media depth of 600 mm
- filter media particle size (d50) of 0.45 mm
- Bio-retention systems can perform a valuable landscape function. It is important to ensure the planting design addresses runoff quality objectives by incorporating appropriate plant species for treatment of runoff (particularly those with a biologically active root zone)
- Bio-retention systems can provide a relatively maintenance free finish if the design considers the type of inorganic mulch, density and type of vegetative plantings and water requirements during dry periods
- The hydraulic design should prevent scour of the bio-retention surface and provide uniformly distributed flow over the surface area. Flow

velocities should be below 0.5 m/s in a minor flood event and not more than 1.8 m/s for a major flood event to prevent scour

- Where exfiltration of runoff is not desirable from the drainage layer and the saturated hydraulic conductivity of the bio-retention filter media is less than 10 times that of the local soils, it may be necessary to provide an impermeable liner
- Selection of bio-retention filter media should consider the saturated hydraulic conductivity required (preferably 180 millimetres/hour), the depth of extended detention above the filter media and its suitability as a growing medium
- Establish design objectives and targets. Objectives and targets will differ if the system is designed for detention or infiltration but are likely to include an adequate hydraulic residence time to retain sediments and pollutants.
- Meet with local council to discuss the design objectives, any site constraints and whether approval is required from the council or any other authority
- Identify land and asset ownership to ensure that maintenance and management responsibilities are clearly understood
- Consider the design tools available for designing of various components of the bio-retention system (references are provided)
- The design calculation should be undertaken as per the details given in the Engineer Australia 2006 and SMMWA

7.6.2.1. Scale of Application

Bio-retention systems are best suited small (i.e. less than 5 hectare) catchments with high percentages of impervious areas. Bio-retention systems can be appropriate in areas where runoff is insufficient or unreliable, evaporation rates too high, or soils are too pervious to sustain the use of constructed wetlands. The limitations to the use of bio-retention systems include the need for adequate sunlight and pre-treatment for coarse sediments to prevent clogging.

7.6.3. Rain Gardens (Biofilters) and Green roof – C3

In Western Australia, mostly the Biofilters are called as rain gardens. The rain garden is a finer scale product of the bio-retention system which has discussed under the Section 7.6.2. A raingarden be similar to a regular garden with one major difference – it is positioned to receive rainwater from hard surfaces such as a downpipe from a roof, paved areas or roads. Using layers of soil and gravel for filtration and planted with a combination of plants, shrubs and grasses, a raingarden reduces the amount of stormwater that would otherwise wash pollutants into the stormwater system and our rivers and creeks. The target pollutants are coarse sediments, suspended solids, phosphorus, Nitrogen and heavy metals.

Green roofs are also known as roof top garden, living roofs, eco roofs and nature roofs. The benefits of green roofs include control runoff, improving water quality, reducing air pollution, increasing biodiversity and it provide additional living space.

Anyone can create a raingarden. They are a creative, low cost and easy to maintain way in which you can contribute to cleaner, healthier rivers and creeks (Melboune water – residential garden). The rain gardens are normally used to treat the smaller event called first flush. Depending on the type of runoff that treats, there are several types of raingardens available in practice. They are as follows.

- Downpipe diversion raingarden
- Green roof raingarden
- Infiltration raingarden
- Planter box raingarden
- Porous paving raingarden
- Swale raingarden
- Road side raingarden
- Tree pits

All of these types' raingardens are mainly based on two types of principal engineering designs which are called as with liner and without liner. And also, the performance of the raingarden can be improved by providing a submerge zone below the filter media. The rain gardens can be easily fitted to purpose and they will work in a different type of climate, soil and groundwater conditions. The Critical elements in raingarden design are given in the Figure 7:12.

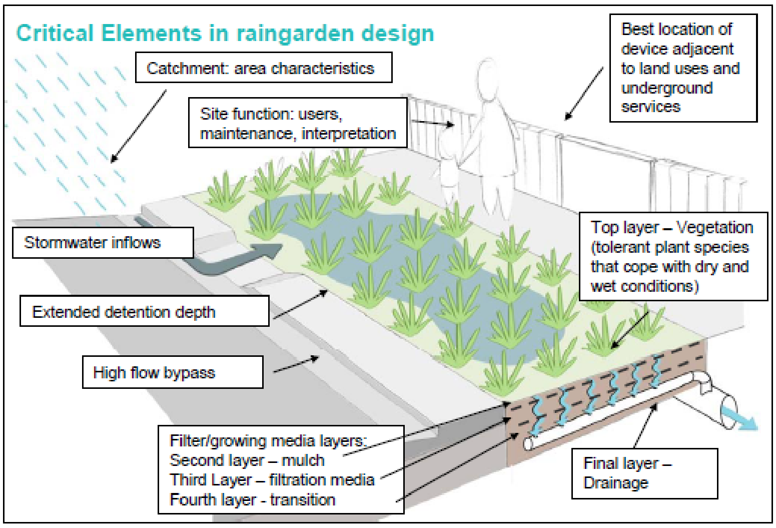
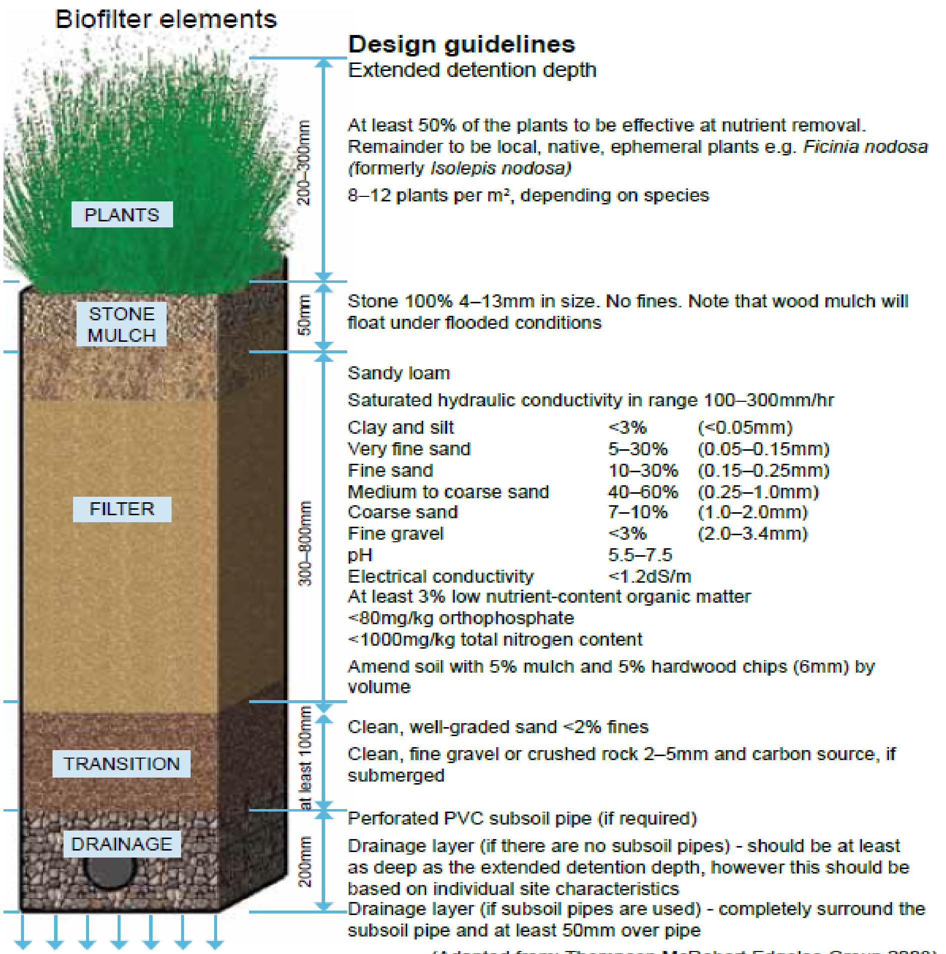


Figure 7:12 – Typical arrangement – Biofilter or Rain garden
Source: Clearwater, 2012

7.6.3.1. Design guidelines

- Identify the location on the development where can be captured (examples. from a downpipe, low point of the road profile, near to the driveway, overflow from a rainwater tank)
- Decision-Support Matrix for Strategy Selection Strategy selection is provided in Table 7:2 for more details.
- Follow the Table 7:3 for Matrix for quick reference guide.
- Make sure the design is integrated with the landscape design for the development.
- Design to infiltrate or connect to the existing drainage system depending on the type of soil and the presence of the groundwater.
- Size the rain garden match 2% of the interconnected impervious catchment for water quality treatment.
- Design the storage volume for 1 year critical average recurrence interval event which would be roughly 300mm deep with 2% of interconnected area.
- Use appropriate vegetation to suit the climate condition.

- Use a submerged zone or irrigation system to promote vegetation health and keep them live during the long dry period of summer.
- The design guidelines given under bio-retention system are still applicable for rain garden. (Figure 7:13)
- The design calculation should be undertaken as per the details given in the Engineer Australia 2006 and SMMWA.



(Adapted from: Thompson McRobert Edgeloe Group 2008)

Figure 7:13 – Typical cross-section – Biofilter or Rain garden
Source - DoW WA

7.6.3.2. Scale of Application

Rain garden or the Biofilter can be easily use as a source control treatment element at upstream catchment. Rain gardens are a measure that may be implemented at a variety of scales, such as subdivision, commercial and industrial sites, roads and lot scales. Rain gardens are mostly a common in most of new subdivisions. They are implemented at the subdivision stage and mostly encouraged individual property owners to maintain by them self.

7.6.4. Sand filters – C4

Sand filters are exactly same as the bio-retention system, biofilters or rain garden. However, the sand filters have no vegetation growing on surface and also the filter media is sand. Sand filters are not integrated with vegetation as the filter media does not have capacity to retain the enough moisture to support plant growth. And also, they are installed mostly underground. In the absence of the biological treatment opportunity in the sand filters gives reduced stormwater treatment performance compared to the rain garden or biofiltration systems.

Sand filters are mostly used in retrofitting situation where limited opportunities are available for treating the stormwater runoff. In absence of vegetation sand filters requires more maintenance as it get clog the filter surface easily. So, it is important to provide some pre-treatment options like screening to remove litter, debris and coarse sediments. The name gross pollutant trap is also another name that used instead of sand filters.

7.6.4.1. Design Guidelines

The sand filler systems are normally consisting of three chambers named an inlet chamber that allows sedimentation and removal of gross pollutant, a sand filter chamber and an over flow bypass chamber. The shape of the sand filter is depending on the design, existing site constraints. The Figure 7:14 shows a typical arrangement of a sand filter system.

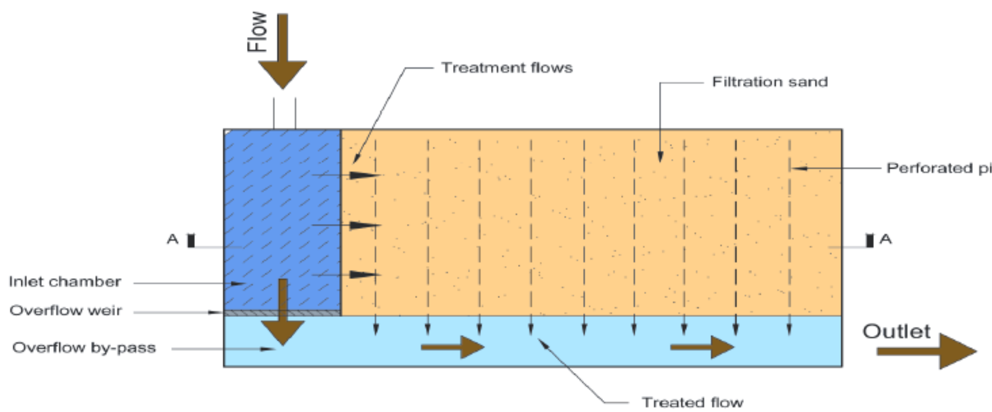


Figure 7:14 –Typical plan view – Sand filter
Source – WSUD Engineering Guidelines

- Identify the location on the development where the total runoff can be captured
- Decision-Support Matrix for Strategy Selection Strategy selection is provided in Table 7:2 for more details.
- Follow the Table 7:3 for Matrix for quick reference guide.
- The sedimentation chamber can be designed to keep the water permanently within the chamber or drain out and dry between two rains.
- Provide sufficient access space for manual or mechanical removal of sediment and accumulated debris.
- Filter media depth is around 400-600mm.
- The filter media should have a hydraulic conductivity between 360mm/hr to 3600 mm/hr. The effective diameter of the filter media 0.7 and 1.0mm
- Provide direct access to whole surface of the sand filter chamber to remove the clog layer of top 20-25mm as finer particles which have accumulated on the surface.
- The design calculation should be undertaken as per the details given in the Engineer Australia 2006 and SMMWA.

7.6.4.2. Scale of Application

Sand filters (dross pollutant traps) are common in urban retrofitting developments. They are commonly use in street and subdivision scale.

7.6.5. Retention Trenches - C5

The retention trenchers are used as temporary underground stormwater storage prior to infiltrate in the ground. The trenchers are normally consisting of structured linear duct lined with geotextile fabric and it is fully filled with coarse aggregate. A pre-treatment chamber is important to provide before stormwater enter in to the tranche. The sediment trap prevents clogging the trench with sediments. The Figure 7:15 shows a typical cross section of a retention trench. Infiltration trenches are very similar in concept to infiltration basin. However, the trenches hold water underground before it infiltrates to the ground where as basin hold water above ground.

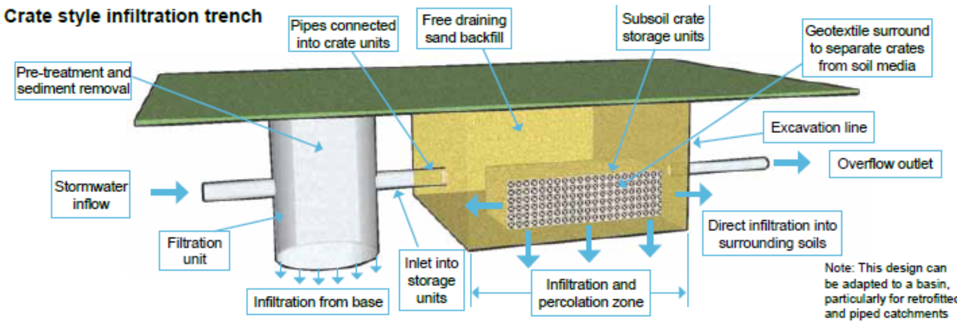


Figure 7:15 –Typical cross-section – retention treach
Source – WSUD Engineering Guidelines

7.6.5.1. Design Guidelines

- Decision-Support Matrix for Strategy Selection Strategy selection is provided in Table 7:2 for more details.
- Follow the Table 7:3 for Matrix for quick reference guide.
- Consider the soil type and infiltration capacity of the soil before start the design process.
- The trenches are useful in where the space restrictions exist. They are common in urban retrofits.
- Retention trenches are best use in small residential, commercial and industrial developments where the catchment area is less than 2 hectares.
- These are commonly used in with overlying pervious pavement as an effective water treatment element.
- The design calculation should be undertaken as per the details given in the Engineer Australia 2006 and SMMWA.

7.6.5.2. Scale of Application

The retention trenches are mostly use in street scale developments especially in retrofitting projects.

7.6.6. Living Streams - C6

A living stream is a constructed or retrofitted stormwater conveyance channel that mimics the characteristics (morphology and vegetation) of natural streams. As well as conveying stormwater, they also treat it using physical and biological processes, and they create diverse habitats for wildlife. They can become complex ecosystems that support a wide range of plants and animals.

The protection of existing waterways and the restoration of degraded waterways or drains are important techniques for improving stormwater management in our urban environments. When undertaking urbanisation of rural land or retrofitting in existing urban areas, this would mean the conversion of existing constructed drains into 'natural' meandering streams. Revegetation and reshaping of drains can restore the many values of a natural or 'living' stream. A living stream achieves multiple outcomes, including creating a healthy ecosystem, improving water quality, conveying floodwaters and creating an attractive landscape feature for the residential community (Water and Rivers Commission, 1998b).

The attention on vegetation growth within the low flow channel has to be in balanced with the typical annual flood flow. The vegetation is important to maximise the channel roughness at low flows, while managing roughness at higher flows. Infiltration, detention and treatment of the stormwater through contact with vegetation are maximised at base flow and during low intensity rainfall events. During high rainfall events, flood protection is maintained by conveyance in the floodway. Healthy vegetation provides wildlife habitat, ecological corridors, erosion control and bio-filtering of pollutants, which is particularly important. The Figure 7:16 shows a typical cross-section of a living stream.

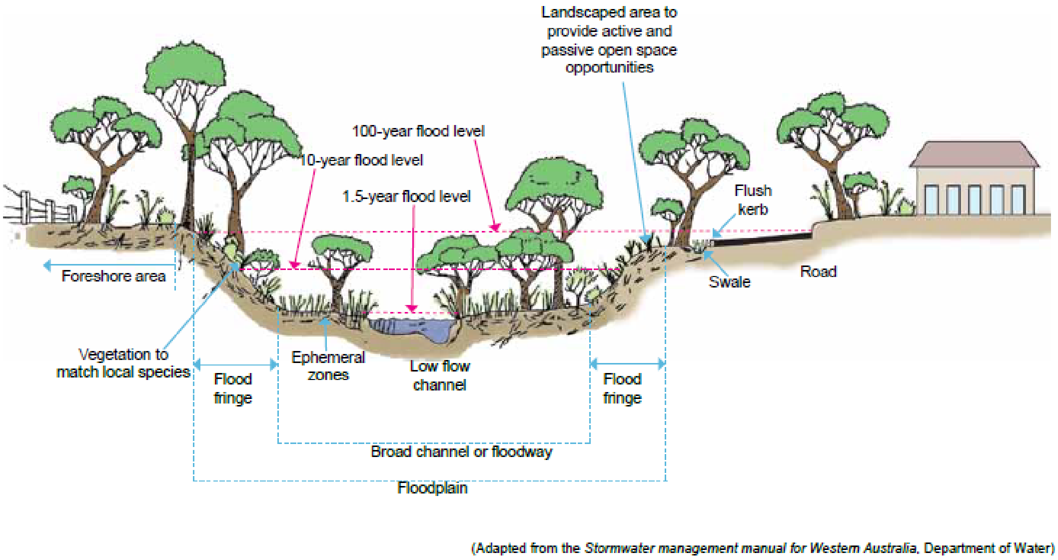


Figure 7:16 –Typical cross section of a living stream
Source – WSUD Engineering Guidelines

7.6.6.1. Design Guidelines

- Decision-Support Matrix for Strategy Selection Strategy selection is provided in Table 7:2 for more details.
- Follow the Table 7:3 for Matrix for quick reference guide.
- The living streams convey large flows safely.
- Make sure the design is integrated with the landscape design.
- The living stream should not intersect the dry season groundwater table.
- Flow velocities should not exceed 1.2m/s.
- Manning's equation can be used to estimate the channel capacity and the velocity.
- Depth to width ratio of a natural open drain (living stream) should fall within the range 1:10 to 1:15 and also the slope should be maintained maximum of 1:4 to facilitate vegetation establishment.
- Full meander wavelength is found to occur between 7 to 15 times the bankfull widths.
- The average distance between the ends of riffles is half the meander wavelength.
- The radius of the sinusoidal curves ranges between 2.3 to 2.7 times the bankfull widths.
- If the slopes are steeper than 1:100, then the engineered beds are to be use with the help of series grade controls such as riffles and meanders. (see Figure 7:17)
- The design calculation should be undertaken as per the details given in the Engineer Australia 2006 and SMMWA

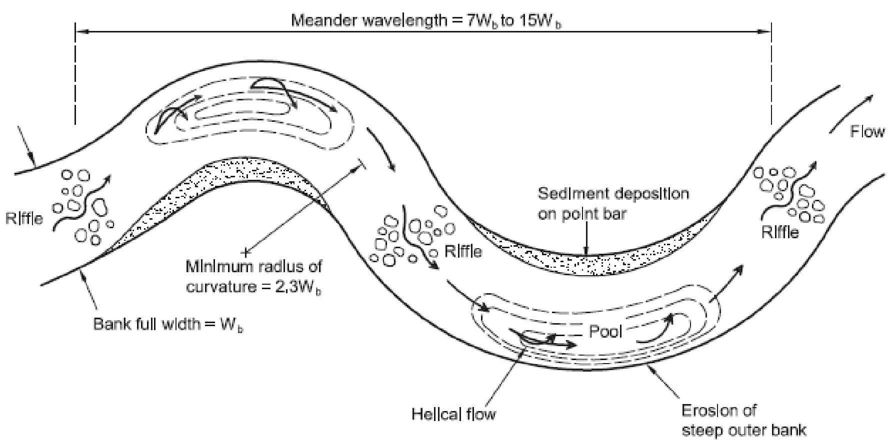


Figure 7:17 –Theoretical meandering stream channel
Source: Water and Rivers Commission/Department of Environment 1999–2003

7.6.6.2. Scale of Application

Living streams are used to retrofit the existing open drains and channels. They are basically covered the drainage requirement of new subdivision and the regional drainage requirement.

7.7. Detention Systems - D

7.7.1. Onsite detention system- D1

Stormwater detention basin or ephemeral areas are used to reduce the peak discharge as a result of large catchment whereas onsite detention systems are used to reduce the peak discharge that coming from the small catchment like a residential lot or a commercial lot to maintain the existing capacity of the downstream drainage system. Most of infill developments where new developments are undergoing within the already developed areas require a stormwater management strategy “at source” when a development is likely to increase runoff to such an extent that the downstream drainage cannot cater for additional runoff. If there is no any other practical way to increase the downstream capacity, then the only solution available is lot detention/retention. A detailed analysis of lot retention and detention requirement has been carried out under the Section 5.2.

7.7.1.1. Design Guidelines

- Decision-Support Matrix for Strategy Selection Strategy selection is provided in Table 7:2 for more details.
- Follow the Table 7:3 for Matrix for quick reference guide.
- The design calculation should be undertaken as per the details given in the Engineer Australia 2006 and SMMWA.
- Refer Section 5.2 for recommendations for stormwater management in infill land development - design of a stormwater drainage design calculator for lot retention and detention.

7.7.1.2. Scale of Application

This strategy can be easily applicable at lot scale and street scale.

7.7.2. Dry/Ephemeral Detention Areas - D2

Dry/ephemeral detention areas (detention basin) are formed by dam walls, by excavating below ground or use of naturally depression area for compensating the additional runoff temporally until it emptied between the rainfall events through controlled outlet at the base of the detention area. In a detention system soil's infiltration capacity is not supporting for emptying the storage volume through the base where as in retention system infiltration does support for emptying the storage volume. The dry/ephemeral detention areas mainly use to reduce the risk of flooding and reduce the downstream erosion by reducing the outflow velocities. Even though, these detention storage areas are greatly focus on quantity management they also help to improve the water quality by removing some particle by settling on the base which is the process called sedimentation.

7.7.2.1. Design Guidelines

- Decision-Support Matrix for Strategy Selection Strategy selection is provided in Table 7:2 for more details.
- Follow the Table 7:3 for Matrix for quick reference guide.
- The design should protect the receiving environment from flooding, erosion and pollution.
- The targeted pollutant removals are litter coarse sediment, suspended solids.
- The design should maintain the pre-development flows up to 1 in 100 year ARI event.
- The lowest point of the detention is should be at least 300mm above the maximum or controlled groundwater level.
- These flood storage areas can be easily integrated with the landscape design done for the public open space (POS).
- Avoid any permanent water logging especially between May and November in the south-west of Western Australia throughout the year in the north as mosquito can breeds.
- The design calculation should be undertaken as per the details given in the Engineer Australia 2006 and SMMWA.

7.7.2.2. Scale of Application

Dry/Ephemeral detention basins are used in large catchments such as regional, district locals and subdivision stage.

7.7.3. Ponds and Lakes - D3

Pond is a permanent water body of shallow a depth condition generally. Shallower water depth is greatly help to support the rooted plants. Not like in the wet basins, plants can be growing across the whole pond. The primary difference between ponds and lakes is the size. There is no huge different between ponds and lakes. The ponds are smaller than lakes. Lakes are much deeper than ponds. Due to this reason, rooted plants are growing in ponds as the sun light can reach the its bottom easily. And lakes have stratified hot and cold temperatures between layers in summer months, while ponds usually have consistent temperature throughout.

7.7.3.1. Design Guidelines

Ponds and lakes designs are mostly follow the same basic design guideline as wet basin.

7.7.3.2. Scale of Application

Ponds and Lakes are mostly sits on reginal scale as natural water bodies. However, they are used in even subdivisional scale as aesthetical water feature within the POS.

7.7.4. Wet basin - D4

Wet basins are permanent water bodies. Keeping the permanent pool water throughout the year is the mechanism that uses to treat stormwater. The permanently sits water helps to remove most of sediments including fine sediments. Wet basins are capable of remove most urban pollutant depending on the how large the permanent water body and catchment that feeds the basin (Galli, J. 1990).

Figure 7:18 –Wet Basin
Source – WSUD Engineering Guidelines

7.7.4.1. Design Guidelines

- Decision-Support Matrix for Strategy Selection Strategy selection is provided in Table 7:2 for more details.
- Follow the Table 7:3 for Matrix for quick reference guide.
- Can be designed to provide peak flow attenuation.
- 80% TSS removal can be expected.
- Depth should not be greater than eight feet as the base of the basin become anoxic. Varying the depth is ideal.
- Provide intermittent benches around the perimeter for safety and promote vegetation. It should be at least ten feet wide and above normal elevations.
- Use minimum pool surface area as 0.25 acres. (See Figure 7:18)
- Maximize the stormwater contact time and retention time; use a length to width ratio at least 3:1.
- Set the invert of the inlet pipe at or below the level of permanent water.
- Set the side slope not steeper than 3:1.
- Set the invert of the outlet pipe at least one foot below the permanent water level.

7.7.4.2. Scale of Application

Wet basins are mostly use in reginal and subdivisional scale.

7.7.5. Constructed Wetlands - D5

Figure 7:19 –Constructed wetland
Source – City of Gosnells

Constructed wetland systems are shallow, extensively vegetated water bodies. They are used for extended detention, fine filtration and biological pollutant uptake processes to remove pollutants from stormwater. Wetlands generally consist of an inlet zone (sedimentation basin), a macrophyte zone, and a high flow bypass channel. The macrophyte zone generally has an extended detention depth of 0.25m to 0.5m, specialist plant species (depending on the desired operation and target pollutant) and a notional detention time of between 48 and 72 hours.

Wetlands can also provide a flow control function by rising during rainfall events and slowly releasing stored flows after the event has finished. To increase flow control benefits, wetlands can be constructed with extra retention or detention capacity. When flows exceed the 'design operational flow' of a wetland, excess water is directed around the wetland (macrophyte zone) via a bypass channel to protect wetland vegetation and to ensure trapped pollutants are not resuspended (Source –WSUD Technical Design Guidelines–Version June 2006). See Figure 7:19.

7.7.5.1. Design Guidelines

- Decision-Support Matrix for Strategy Selection Strategy selection is provided in Table 7:2 for more details.
- Follow the Table 7:3 for Matrix for quick reference guide.

- Constructed wetland can be part of the POS and design should aims to ensure that planting fulfils the intended aesthetic requirement as well as stormwater treatment function.
- The constructed wetland is about 1-2% of the total catchment area.
- In a well design wetland, the mean annual volume of stormwater captured and treated within the wetland should be 80% the mean annual runoff volume generated from the contributing catchments.
- The detention time should preferably be 48-72 hours.
- The inlet zone of the wetland should be designed as sedimentation (detention basin) basin. See Section 7.7.2. The use of inlet zone is to remove the coarse to medium sized sediments (125µm or bigger) and controlling the flows entering to the macrophyte zone.
- The preferred extended detention depth is 0.5m.
- The macrophyte zone should be designed to retain water permanently. Therefore, suitable material should be provided at the base or base should sit on a clay profile.
- Take necessary preventive measures to control the mosquitos breeding.
- The detailed design steps and calculations are given in WSUD Technical Design Guidelines – Version June 2006.

7.7.5.2. Scale of Application

The constructed wetland is used in very large scale developments such as regional, district and local scale. Depending on the existing site constraints and the availability of the land constructed wetland can be used even in subdivision scale developments.

7.8. Stormwater Storage and reuse - (S) (Rainwater harvesting)

Rainwater harvesting is a technique of collection and storage of rainwater in to natural reservoirs or tanks, or the places where infiltrate stormwater into subsurface aquifers before it lost as surface runoff. There are two main strategies called rainwater tank and aquifer recharge are commonly practice.

7.8.1. Rain Water Storage Tank - S1

Figure 7:20 –Rain water storage tank
Source – Evaluating option for WSUD, 2009

Rainwater tanks pick up rainwater from roof and store it for later consumption. Mostly the rainwater tanks are used for watering the garden. When the stored water regularly used even during the rainy days, the maximum benefit of a rainwater tank can be achieved If the rainwater tank is connected through pumping arrangement to the internal appliances such as toilet flushing and washing mashing. An alternative portable water supply is required when the rainwater tank has insufficient water for internal use. This requirement can be easily fixed by toping up the tank either through portable water supply, or may also be through an external switching valve which is triggered automatically when tank volumes fall below a certain level. See Figure 7:20.

Water quality is an important item in all rainwater systems as rainwater has a little health risk when it uses for non-potable purposes such as garden watering, toilets, appropriate hot water supply systems and washing machines. Additional treatment options may be required when rainwater is to be used as a potable supply.

7.8.1.1. Design Guidelines

- Decision-Support Matrix for Strategy Selection Strategy selection is provided in Table 7:2 for more details.
- Follow the Table 7:3 for Matrix for quick reference guide.

- Depending on the availability of the space, the purpose of use and the reuse technique (pumping or gravity) rainwater tank can be designed to go above ground or the underground.
- The rainwater tanks can be use domestic use and also in large scale like commercial, industrial, municipal buildings such as community halls and sport centres.
- Physical, chemical and biological processes can improve the quality of the rainwater storage system. Some of the treatment option are Gutter guards, first flush devices and filter socks.
- Provide mesh screens on inlets, outlets and overflow devices will help to control animals and mosquitoes.
- The capacity of the rainwater storage is depending on the type of water use, roof area or the catchment area and the rainfall event. For domestic use, 1-5 kL tank would be sufficient.
- Refer SMMWA – Structural Controls for detailed design information.

7.8.1.2. Scale of Application

Rainwater tanks are generally applied at the lot level, but can be applied at the street level in larger development projects.

7.8.2. Managed Aquifer Recharge – S2

Figure 7:21 –Managed Aquifer Recharge
(Source: City of Salisbury)

Aquifer storage and recovery, also referred to in some areas as Managed Aquifer Recharge, is a means of enhancing water recharge to underground aquifers though either natural means, pumping or gravity feed (EPA 2005). Water stored in the aquifer can then be pumped from below ground during dry periods for subsequent reuse, thereby providing a low-cost alternative to large surface water storages. The surface runoff infiltrate through soakwells is a form of groundwater recharge. However, soakwells are not considered as managed aquifer recharge.

The quality of the stormwater should meets high standard before it starts recharging. It is important to know that there is no subsequent deterioration of groundwater quality or aquifer properties with the groundwater recharging process. Due to this reason the aquifer recharging system should incorporate a constructed wetland, detention pond, dam or tank, part or all of which act to remove pollutants and provide a temporary storage role prior to aquifer recharge. And also, the type and level of treatment of recycled water prior to injection or infiltration to an aquifer is dependent on the quality of the groundwater and its current use. The typical arrangement of an aquifer recharge process is shown in the Figure 7:21.

7.8.2.1. Design Guidelines

- Decision-Support Matrix for Strategy Selection Strategy selection is provided in Table 7:2 for more details.
- Follow the Table 7:3 Matrix for quick reference guide.
- It is important to have an inventory of the existing environmental values, the groundwater levels and the groundwater quality of the area where new aquifer recharge station is proposed.
- The quality of the stormwater is basic design consideration.
- Base on the available data, it is required to evaluate the pre-treatment requirement.
- Pre-treatment is recommended as it gives an added benefit of removing the sediment from the stormwater as it reduces the risk of clogging the infiltration or the injection system.
- Make sure that there is sufficient permeability and storage within the receiving aquifer
- Refer SMMWA – Structural Controls for detailed design information.

7.8.2.2. Scale of Application

Aquifer recharge can be applicable even at small lot scale but mostly use at regional, district and subdivision stage. It is not possible to apply this strategy at street scale.

7.9. Pollutant Control P

The pollutant control devices are mostly used specially in Western Australia within the new development areas and also retrofitted to existing development areas. Some of these devices are called litter and sediments management systems (gross pollutant traps, trash racks, side entry pit traps, Floating debris, sediment basin, grate and side entrance screens, baffled pits, circular settling tank. etc.) and hydrocarbon management systems (oil-water separates).

7.9.1. Litter and Sediment Management - P1

These devices are used to control litter (particles bigger than 5mm) and sediments (particles bigger than 0.5mm) contains as pollutant within the stormwater runoff. These devices come with different shapes and designs which suits to the existing site condition. See Figure 7:22.

Figure 7:22 –Litter and Sediment trap
Source – SWMM-WA

7.9.1.1. Design Guidelines

The design techniques for litter and sediment traps are same and straight forward. The techniques behind the litter and sediment trap designs are retaining gross pollutant by physical screening or rapid sedimentation.

- Decision-Support Matrix for Strategy Selection Strategy selection is provided in Table 7:2 for more details.
- Follow the Table 7:3 Matrix for quick reference guide.
- Identify the areas that generate high litter or the sediments.
- Identify the flow direction and the best suitable location for collecting the identified litter or the sediments.
- Determine whether the treatment is required at source, in line or at the end of the pipe system.

7.9.1.2. Scale of Application

The typical application scales for litter and sediment traps are the subdivisional or regional scale. A subdivision drainage system would involve smaller traps in side inlet pits and pit systems that filter runoff from a small number of blocks.

7.9.2. Hydrocarbon Management - P2

The common sources of hydrocarbon are vehicle emission, waste water (industrial discharges, wash down of vehicles or floors), service, repairs, stations and other activities that may result in oils, grease, solvent, acids, fuels, coolants and surfactants. The standard method that is used for managing the hydrocarbon is oil water separators. Depending on the technique used within the separator there are three types of separators available named flow density-based separators, Coalescence plate-based and Vortex-based separators.

7.9.2.1. Design Guidelines

- Analysis the source of pollutant and pick up the strategy for management.
- Decision-Support Matrix for Strategy Selection is provided in Table 7:2 for more details.
- Follow Table 7:3 Matrix for quick reference guide.

- The oil water separator is not required for rainfall runoff over the hardstand or the road runoff unless it contains considerable amount of hydrocarbon.
- Runoff from a busier carpark, service station or fuel pump requires an oil water separator before it discharges in to the next treatment unit or receiving water body.
- Easy access for maintenance is important
- Detailed design information is given in SWMM-WA.

7.9.2.2. Scale of Application

Hydrocarbon management strategies are mostly used in lot scale and street scale. They are used in some of the major intersection if the surrounding area is high environmental sensitive. Various types of hydrocarbon traps are available in different scale.

7.9.3. Sedimentation Basin - P3

Sediment basins are used as flow control and water quality treatment devises which usually act as be pre-treatment element of constructed wetland, or bio-retention basin Figure 7:23.

Sedimentation basins are generally most effective in removing coarser sediments larger than 0.125mm. The efficiency of sedimentation basin depend on the basin area and the design outflow rates. Typically, sediment basins are designed to remove 70 to 90 % of sediments larger than 0.125 mm.

The design discharge for a sedimentation basin is typically the maximum flow rate for a 1 or 2-year Average Recurrence Interval event. In a flow event, greater than this design discharge, a secondary spillway directs water to a bypass channel or conveyance system, preventing the resuspension of sediments previously trapped in the basin. Sediment basins should be designed with sufficient sediment storage capacity to ensure acceptable frequencies of desilting.

If the design consider flood storage volumes in addition to outflow rate and targeted coarse and medium sediments, the sedimentation basin can be easily upgraded to a detention basin. (WSUD – technical manual)

Figure 7:23 –Sedimentation basin
Source – City of Gosnells

7.9.3.1. Design Guidelines

- Identify the design constraints and determine the design objective
- Decision-Support Matrix for Strategy Selection Strategy selection is provided in Table 7:2 for more details.
- Follow Table 7:3 Matrix for quick reference guide.
- Select the size of the sediment that target to remove and estimate the design flow after consulting the local government or the relevant authorities.
- Removal of particles < 125 µm is recommended.
- Determine the size and the shape of basin depending on the topographical survey.
- Detail design should include hydraulic structures, outlet chamber, flow control devise and overflow structure.

7.9.3.2. Scale of Application

Sedimentation basins can take various forms (at a range of scales). They can be used as permanent systems integrated into an urban design, or temporary measures to control sediment discharge during construction. They are very common in regional, district and subdivisional scale.

7.10. Conclusions

This chapter mainly covered details about the basic design consideration and the scale of application which may guide the use of a Decision-Support Matrix for Strategy Selection. For easy reference, depending on the main objective of the use of stormwater management strategy, each strategy has been categorised into five main groups such as Infiltration systems, Conveyance System, Detention systems, Stormwater storage and Use and Pollutant Controls. The summarised data will guide user to pick up the best stormwater management strategy depending on the existing site condition such as permeability, scale of application and the main objective of the strategy use.

Considering the factors affecting the selection of best stormwater management practice and the potential benefits and limitations of available stormwater management strategies, a Decision-Support Matrix for Strategy Selection would be highly useful for land developers as well as authorities, decision makers and policy makers to come up with sustainable stormwater management options in their land development proposals.

All the references are given at the end of the thesis for further detailed information which is required for detailed designed stage.

CHAPTER 8

8 DEVELOP A LOCAL WATER MANAGEMENT STRATEGY (LWMS) FOR A LAND DEVELOPMENT

8.1. Introduction

This chapter shows an application of Water Sensitive Urban Design concepts to a land development by developing a Local Water Management Strategy (LWMS) to a land development as a case study. Central Maddington Outline Development Plan (ODP) area is selected as the case study area. The application is prepared in accordance with State Planning Policy 2.9 – Water Resources and the Western Australian Planning Commission's Better Urban Water Management document. The primary function of this LWMS is to address the management and sustainability of the total water cycle associated with the planning and development of a combination of both Infill and Greenfield land development.

The Central Maddington Outline Development Plan (ODP) area covers approximately 150ha of land. The area equates to approximately 30% of residential land in Maddington and 15% of total Maddington suburban area, which also accommodates industrial and rural activities. The natural feature of the Canning River defines the northern extent of the ODP boundary with Kelvin Road defining the western boundary. The eastern border of the ODP area is partly defined by the Maddington railway line and the residential suburb of Maddington. Other significant features of the ODP include Albany Highway and its abutting commercial area and the Maddington railway line, which seemingly divides the ODP area into two distinct northern and southern precincts. The ODP area also has an assortment of smaller parks and the Maddington Primary school.

The primary purpose of the ODP is to facilitate infill development of the residential area at much higher densities, to encourage a greater proportion of population within convenient walking distance of the nearby Centro Maddington Shopping Centre and the Maddington railway station. The Figure 8:1 shows the Central Maddington ODP.

The preparation of the Central Maddington ODP involved:

1. Amending the City’s Town Planning Scheme No.6 (TPS 6) to change the zoning of ODP area to a ‘Residential Development’ zone.
2. Preparation of the ODP to introduce higher residential density codes and identify the location of new roads and areas of public open space, which is intended to overly a the Residential Development zone.

The Central Maddington ODP provides the framework to guide future subdivision and development. To ensure water issues associated with subdivision and development will be adequately considered, the ODP is accompanied by this Local Water management Strategy (LWMS).

The Central Maddington ODP area is well established low density urban environment. The ODP is intended to facilitate an increase in residential densities, provide additional road connections and areas of public open space. This type of development is typically referred to as "urban infill" and the provision of additional infrastructure and/or upgrades of infrastructure within an established urban environment are commonly referred to as "retrofitting".

The infill nature of this ODP is significant and very different in regard to the drainage issues that is addressed through the local water management as compare to the drainage issues that is normally addressed in Greenfield developments. In many instances, there are considerable constraints to implementing water sensitive urban design (WSUD) infrastructure, with the two most common being availability of land to retrofit the existing situation and the cost associated of doing so. In this regard, preparation of an LWMS for infill requires a flexible and practical approach to implementing WSUD principles which, in some cases, might not be ideal but represents the "best fit" scenario.

The WAPC's Better Urban Water Management document provides a process for achieving better management of urban water, through the application of integrated water cycle management via the planning system of Western Australia. Whilst it does not specifically address some of the complexities with urban infill development, its principles regarding local water management are sound and have been adhered to and/or adapted where necessary in the preparation of this LWMS.

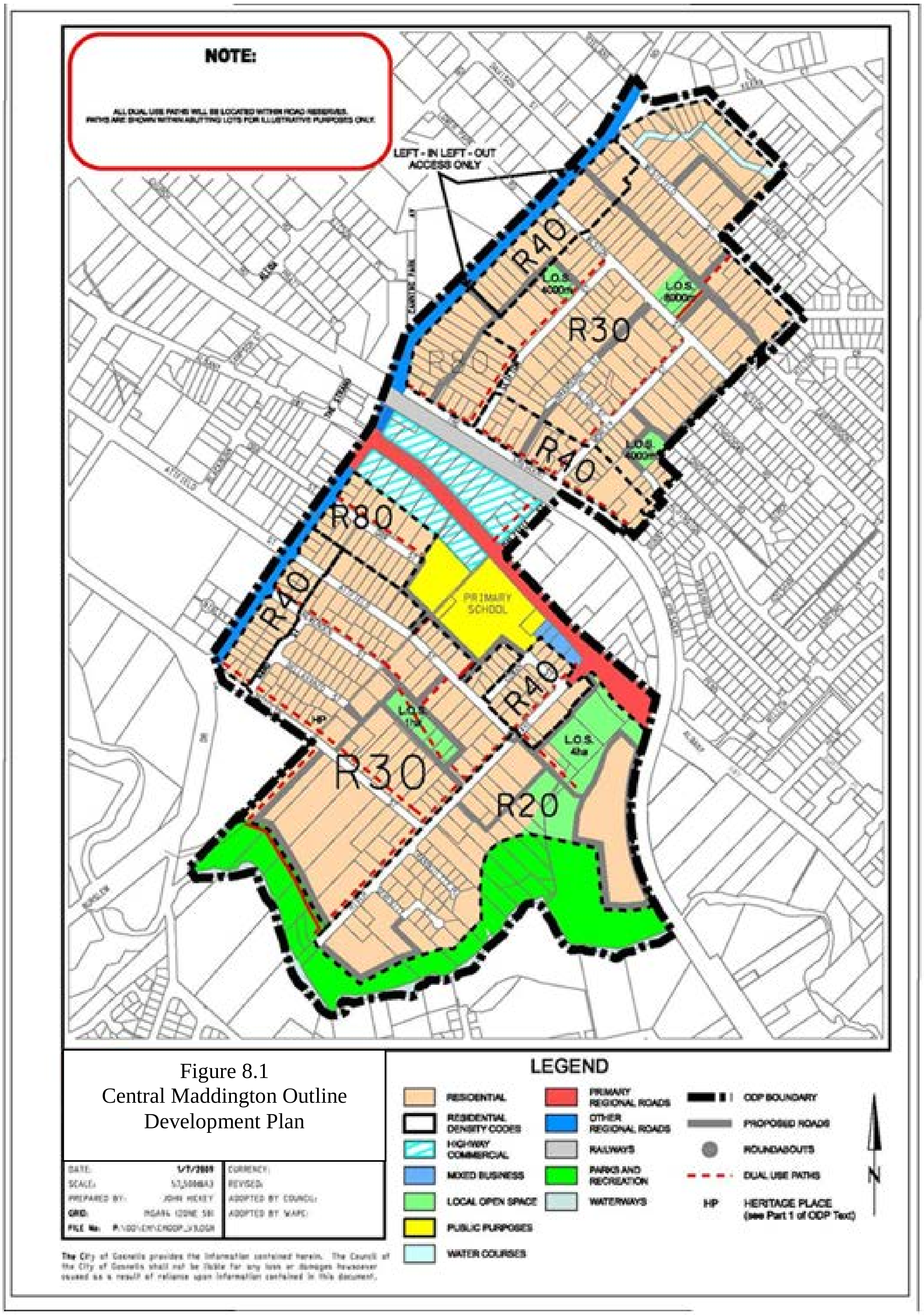


Figure 8:1 – Central Maddington ODP

8.2. Integrated Total Water Cycle Management: Principles and Objectives

The total water cycle is made up of a number of water elements, namely reticulated scheme water, groundwater, stormwater, wastewater, flooding, water quality, wetlands and watercourses. These elements should be viewed as a single interconnected system and considered as an integral part of the planning and development of an area. The key principles of the integrated water cycle management system are outlined in State Planning Policy 2.9 Water Resources (Government of WA 2006). These are:

- Consideration of all water resources including wastewater, in water planning;
- Integration of water and land use planning;
- The sustainable and equitable use of all water sources, having consideration of the needs of all water users, including the community, industry and the environment;
- Integration of human water use and natural water processes; and
- A whole-of-catchment integration of natural resource use and management.

Incorporating the above principles into the planning for the Central Maddington ODP is to be achieved, in part, through the application of water sensitive urban design techniques detailed in the Stormwater Management Manual for WA, 2004-2007.

The general objectives of water sensitive design have been summarized in Better Urban Water Management, (2008) and were adapted from the Stormwater Management Manual (2008). The objectives outlined below are focused toward minimizing the impacts of urbanization on the natural water cycles and addressing issues of water conservation, water quality and water quantity in connection with other social and environmental objectives and principles.

- Protect natural systems – protect and enhance natural water systems and their hydrological regimes in urban developments;

- Integrate stormwater treatment into the landscape – use stormwater in the landscape by incorporating multi-use corridors that maximise the visual and recreational amenity of developments;

- Protect water quality – protect waterways and other water bodies from drainage from urban development and minimise outputs of phosphorous, nitrogen and other pollutants;

- Manage run-off and peak flows – reduce peak flows from urban developments by using local detention measures and minimising impervious areas; and

- Add value while minimising development costs – minimise the drainage infrastructure cost of development.

This LWMS is intended to provide the framework for sustainable management of the total water cycle associated with subdivision and development of the Central Maddington ODP area. It is based on the approach, and the principles and objectives outlined above.

8.3. Proposed Development

The ODP is the planning framework intended to guide subdivision and development of the ODP area. The planning for this area is premised on state and local planning strategic objectives which propose to make more efficient use of established urban land that is in close proximity to public transport and commercial centres. This is expected to achieve a more compact and sustainable form of urban development and assist in meeting the state's proposed future growth and population targets outlined in its regional strategy Direction 2031 and beyond.

The ODP will facilitate low, medium and high density residential development, ranging from R20 to R80. It is estimated that the proposed increase in residential density has the potential to yield a further 2,300 dwellings across approximately 150 hectares. To support the proposed increase in population to the area, the ODP provides new areas of public open space, additional roads, and cycle and pedestrian paths. The ODP is expected to improve the connection and accessibility to the nearby Centro Maddington shopping centre and Maddington railway station.

Residential lots within the ODP area were previously zoned Residential R17.5 under TPS 6, with the ODP primarily proposing to intensify the extent of residential development. With respect to this LWMS, this is significant, in that it represents an increase in stormwater runoff from additional dwelling roofs and paved areas, as well as additional stormwater runoff from proposed new roads. The catchment is made up of predominantly heavy soils, which limits opportunities for infiltration and biological water quality treatment. Whilst this strategy addresses all elements of water cycle management, a key focus is the imperative to manage the quantity and quality of additional stormwater so that existing hydrological processes are maintained, environmental assets are protected and flood risk is mitigated.

Helm Street Main Drain enters the Canning River in the ODP area, although only 1.45% of the drain's catchment lies within the ODP area. This tributary of the Canning River has been identified by the Swan River Trust as a high priority for water quality amelioration. There is potential impact on water quantity and quality in this water course for the ODP area, though, is not considered high.

The implementation of the water management strategies in this report will, to a large extent depends on how the ODP area is developed. With the high level of fragmented landownership, it is expected that the majority of the ODP area will involve landowners submitting planning and building applications for individual properties. Those smaller lots involving proposals for several dwellings with access to an existing road can be dealt with via individual applications, with water management able to be addressed on a lot by lot basis.

Development of properties requiring the construction of new roads will have to be staged to allow time for those roads and associated drainage facilities to be constructed. This is to be achieved through the preparation and approval of an Urban Water Management Plan (UWMP).

The UWMP will provide specific details on the management and location of verge water treatments for the length of a new road, and subsequently allow individual properties along this road to be developed on a lot by lot basis.

The construction of new roads and preparation of UWMPs will be prioritised on the willingness of landowners to subdivide and develop and the extent to which each road will facilitate such development. A number of UWMPs will be required for the various sections of new road proposed on the ODP, and these will need to be prepared and approved prior to approval for subdivision and development. Responsibility for the preparation of an UWMP and associated costs will be a matter that needs to be addressed through the drafting of plans for the operation of a developer contribution arrangement for the ODP area.

Notwithstanding the above, this LWMS details a range of strategies designed to guide the development of the ODP area and the management of the various water components of the urban environment.

8.4. Pre-development Environment and Implications for Local Water Management

8.4.1. Built Form

The ODP area is part of a well-established urban environment which provides opportunities for strategically located residential infill development. It is well serviced by existing retail, commercial and community facilities, and the adjacent Centro Shopping Centre and the Maddington Railway Station.

The ODP area, shown in Figure 8:1 is divided by the railway line, Albany Highway and a number of commercial properties in between. This separation represents two distinct sub-precincts which, for the purposes of this report will be referred to as Central Maddington Precinct North (CMPN) and Central Maddington Precinct South (CMPS), where relevant.

The predominant land use in CMPN, accounting for approximately 70 percent of all lots and 90 percent of the land area, is low density residential development. Relatively large underdeveloped single residential lots characterise the area. Approximately 70 percent of the total numbers of lots exceed 1000m^2 in area with around one third exceeding 2000m^2. The remaining lots less than 1000m^2 the majority in the 700m^2 to 1000m^2 ranges.

Land adjacent to the railway reservation and fronting Albany Highway forms part of a commercial precinct with land area totalling 59ha and lots averaging 3000m^2. Lots in the commercial precinct are occupied by car/caravan sales yards, an office complex and a small amount of retail development, and some of the lots are vacant.

Land uses in CMPS are varied, with low density residential lots accounting for approximately 50 percent of the land area. This land, like CMPN, is characterised by large underdeveloped lots, however there is a greater proportion of lots below 1000m^2 in area compared to CMPS. These lots are generally situated within 150 metres of Olga Road. The residential component of the overall ODP is generally developed with single dwellings and associated outbuildings and is serviced to a large extent by existing infrastructure such as roads, drainage, scheme water and power etc. An aerial photo in Figure 8:2 shows the ODP area and adjacent Centro Maddington shopping centre and Maddington Railway.

Figure 8:2 - An aerial photo showing the ODP area

8.4.2. Existing Drainage Network and Surface water runoff paths

The majority of the ODP area is situated within the Canning/Helm Street catchments of the Swan Canning River systems. Surface runoff flows through natural drainage contours and the Water Corporations Helm Street Main Drain. A part of the Helm Street Drain within the ODP area is a Conservation Category Westland referred to as Stokely Creek. Flows are generally westward and outfall to the Canning River.

The ODP area is also served by an existing piped drainage network intended to cater for a low density urban environment. The existing piped and open drain network can be separated into individual catchments which have been determined based on the topography and direction of flow of the piped network and the open drains they feed into. The catchments are illustrated in Figure 8:3 which show surface drainage channels and the piped network and includes inlets and outlets of the various catchments.

The GP catchment feeds into the Graze Place Drain which delivers flow to Bickley Brook and, thereafter, the Canning River. The RR catchment flows into the Railway Reserve Drain which eventually flows into the Canning River. The C1 and C2 catchments also flow into the Canning River. The RRC catchment represents the only commercially zoned catchment and flows in the Railway Reserve Drain.

Whilst the piped networks play a role in stormwater conveyance and flood avoidance, they present limited opportunities for improving stormwater quality before discharge to the receiving environment.

Implementation of the ODP will see the construction of new dwellings and new local roads within the existing urban form, which will generate additional stormwater runoff from new roof and paved surfaces. As a result, the cumulative effects of discharging additional stormwater into the existing drainage system are likely to exceed system capacity and have an adverse impact on the existing hydrological processes within the ODP area.

One option to address additional stormwater volume is to upgrade the capacity of existing drainage network to cater for increased volumes. However, this is considered a costly exercise and is likely to be cost prohibitive to the developers and does not offer opportunities to address water quality issues.

The preferred option is to manage stormwater runoff from both new dwellings and new roads by ensuring that post development flows do not exceed predevelopment flows, thus maintaining the status quo. This is to be achieved in part, through on-site detention of stormwater for all new dwellings on individual lots, which is usually achieved through the use of conventional soakwells. However, due to poor infiltration qualities of the study area's generally heavy soil it is expected that more unconventional methods will be required. To address stormwater generated from new roads, stormwater is to be detained and treated within new road verges so that predevelopment flow levels will be maintained. Further details are provided in Section 5.2 of this report. The Figure 8:3 shows the various drainage catchments within the ODP area. The pre-development discharge flow rates for the piped drainage system for the various catchments are examined in the relevant strategy section of the report. Catchments and discharge rates are based on existing densities and impervious surfaces.

To ensure issues of water quality are addressed, runoff is to be treated prior to discharge to receiving waters. Apart from the first rainfall after the summer months, which typically collects the accumulation of nutrients, stormwater runoff from subsequent rainfall from individual residential and commercial properties is relatively clean. So, it is assumed that treatment is not required for all newly created dwellings.

The treatment of new road runoff and runoff from other paved areas, which are potentially contaminated with hydrocarbons, phosphates and nitrates, will need some form of treatment to reduce pollutant load. This treatment will occur within new road verges via some means of bio-filtration.

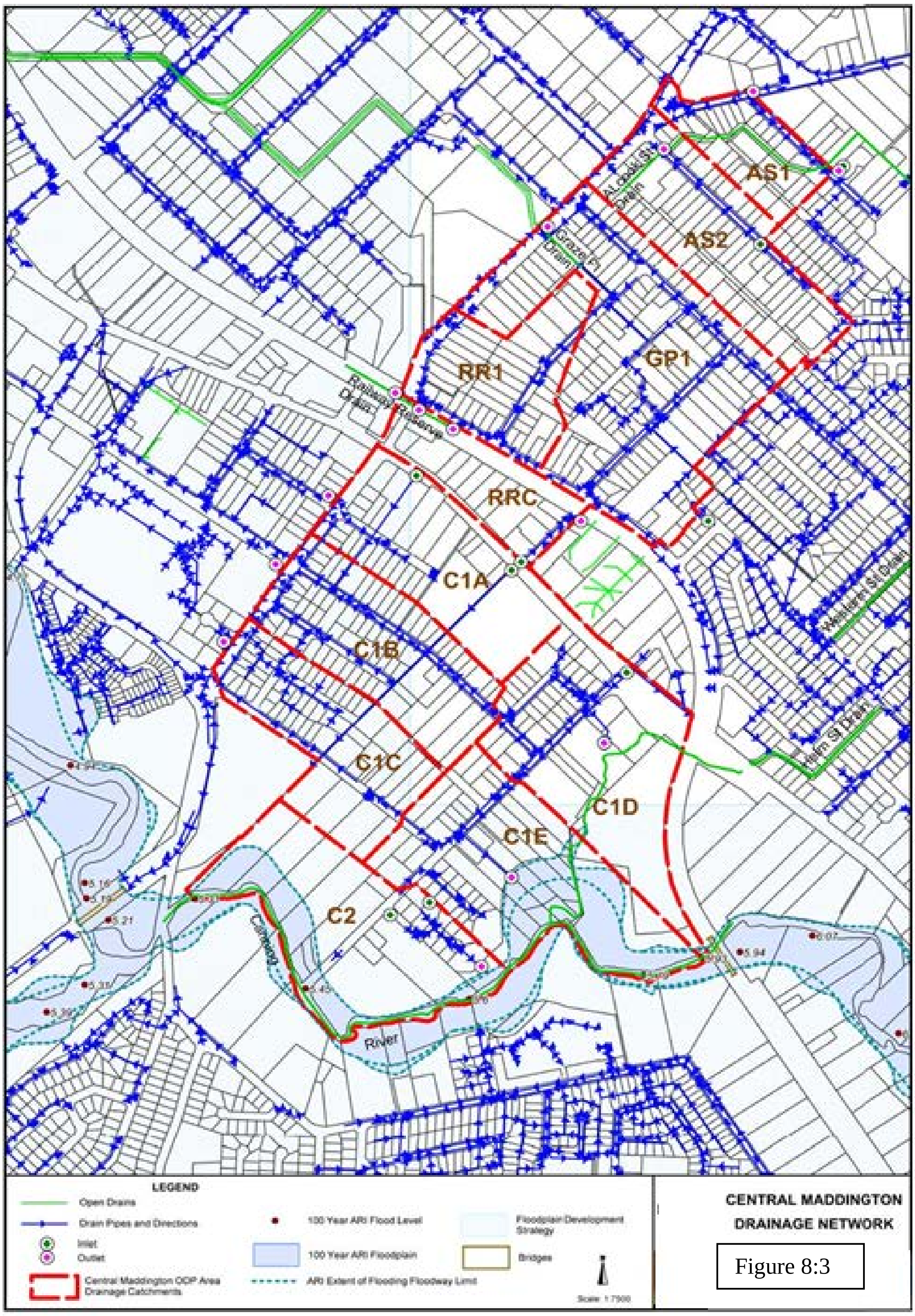


Figure 8:3 - Predevelopment Catchment Plan

Contaminants considered were those known to be associated with stormwater and included hydrocarbons, pesticides, herbicides, metals and organochlorines, to name a few. The Helm Street drain has been identified to contain contaminants such as metals and herbicides but not at considerably high levels compared to other sample sites. The Swan Canning River Water Quality Improvement Programs (SRWQIP) aims to reduce nitrogen and phosphorus input from catchments into the Swan Canning River. With respect to the Helm Street Drain the SRWQIP advises that:

- For nitrogen, the Helm Street drain has unacceptable water quality (annual average TN load of 1.7 tons) and requires a load reduction of more than 45%.

- For phosphorous, the objective for the Helm Street drain (annual average TP load 0.07 tons) is to maintain and improve water quality requiring a load reduction of 10-45%.

As explained above the treatment of the surface runoff is important at the post-development stage. The strategy selection should be targeted at least to maintain the predevelopment water quality or should be improved the quality compared to the predevelopment condition.

8.4.3. Soil Type and Groundwater

The sample sites targeted for in infill are proposed to be redeveloped at higher densities. The catchments associated with the infill areas are highly impervious then careful management of the certain increased of stormwater runoff is critical.

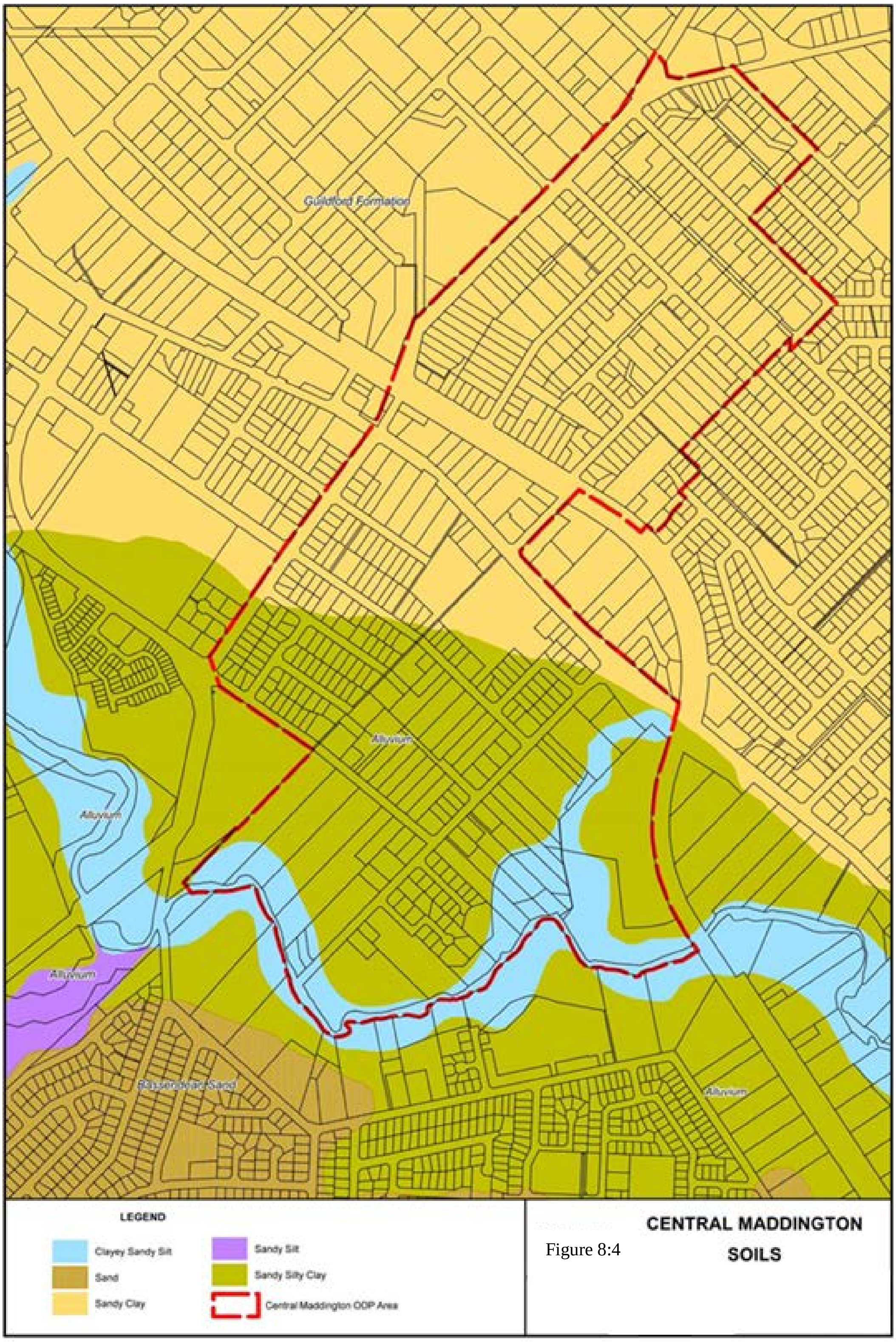


Figure 8:4 – Soil Mapping for the Study Area

The soil mapping for the study area is shown in Figure 8:4.

The permeability distribution map developed for the entire Maddington ODP in Section 4.8 is provided in Figure 4:27. The both onsite and the laboratory test results of the study (As per Table 4:12 and Table 4:24) confirm that soils within the ODP area have poor infiltration qualities and will not be suitable for infiltration in the management of additional stormwater expected from the redevelopment of the area.

The Department of Water's Groundwater Atlas shows a maximum groundwater depth between 6mAHD and 8mAHD and a minimum depth of 6mAHD to 3mAHD. Groundwater levels are on average one metre below the surface and represent the upper level of the superficial (unconfined) aquifer beneath the Swan Coastal Plain (Water & Rivers Commission 1997 in Brown and Root 2001).

As a summary, the full geotechnical investigation shows that:

- Almost 100 % of the Maddington ODP area is comprised of soils with very slow permeability.
- Groundwater levels are, on average approximately 4m.

Due to the poor infiltration characteristics of the soils, groundwater levels are unlikely to rise from direct infiltration from larger rainfall events. Any existing localised flooding is predominantly caused by surface runoff rather than rising groundwater. However, the perched groundwater table could contribute to increased flooding to some extent. Poor infiltration provides a disconnection between groundwater and infiltrated stormwater which means that the potential for groundwater contamination from stormwater runoff is negligible. In this regard, addressing issues of water quality is best targeted towards improving the quality of stormwater.

The hydrological contours of the ODP area are illustrated in Figure 8:5.

The management of stormwater quality is addressed in Section 7 of thesis.

The acid sulphate soil mapping (WAPC Bulletin 64, 2009) for the ODP area identifies a moderate to low disturbance risk rating to a depth of three metres, in accordance with the Western Australian Planning Commissions Bulletin 64 (2009). It is unlikely that earthworks will occur below 3m and therefore an acid sulphate management plan is unlikely to be required during the development of the ODP area. The acid sulphate soil mapping is shown in Figure 8:6.

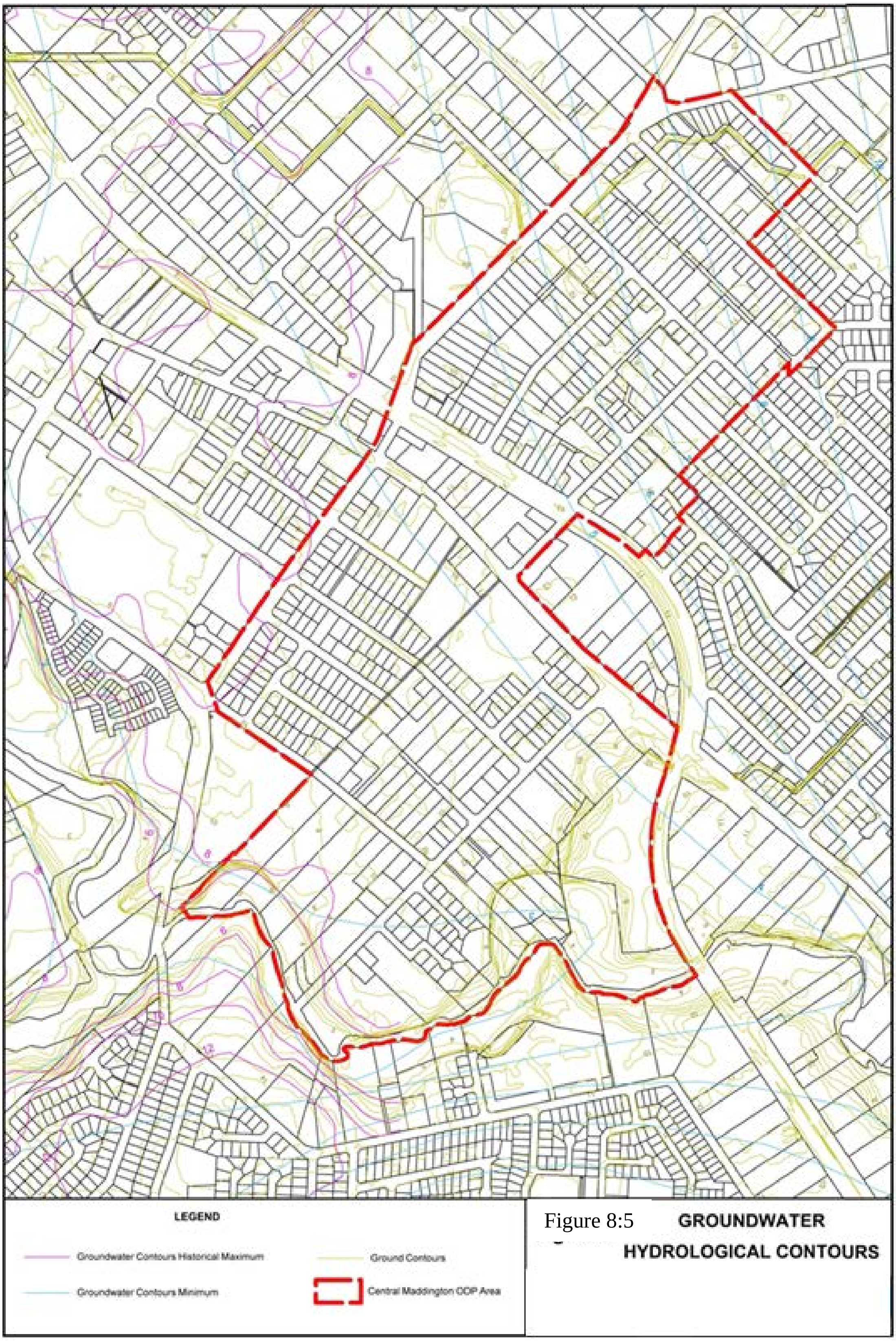


Figure 8:5 – Hydrological contours for study area

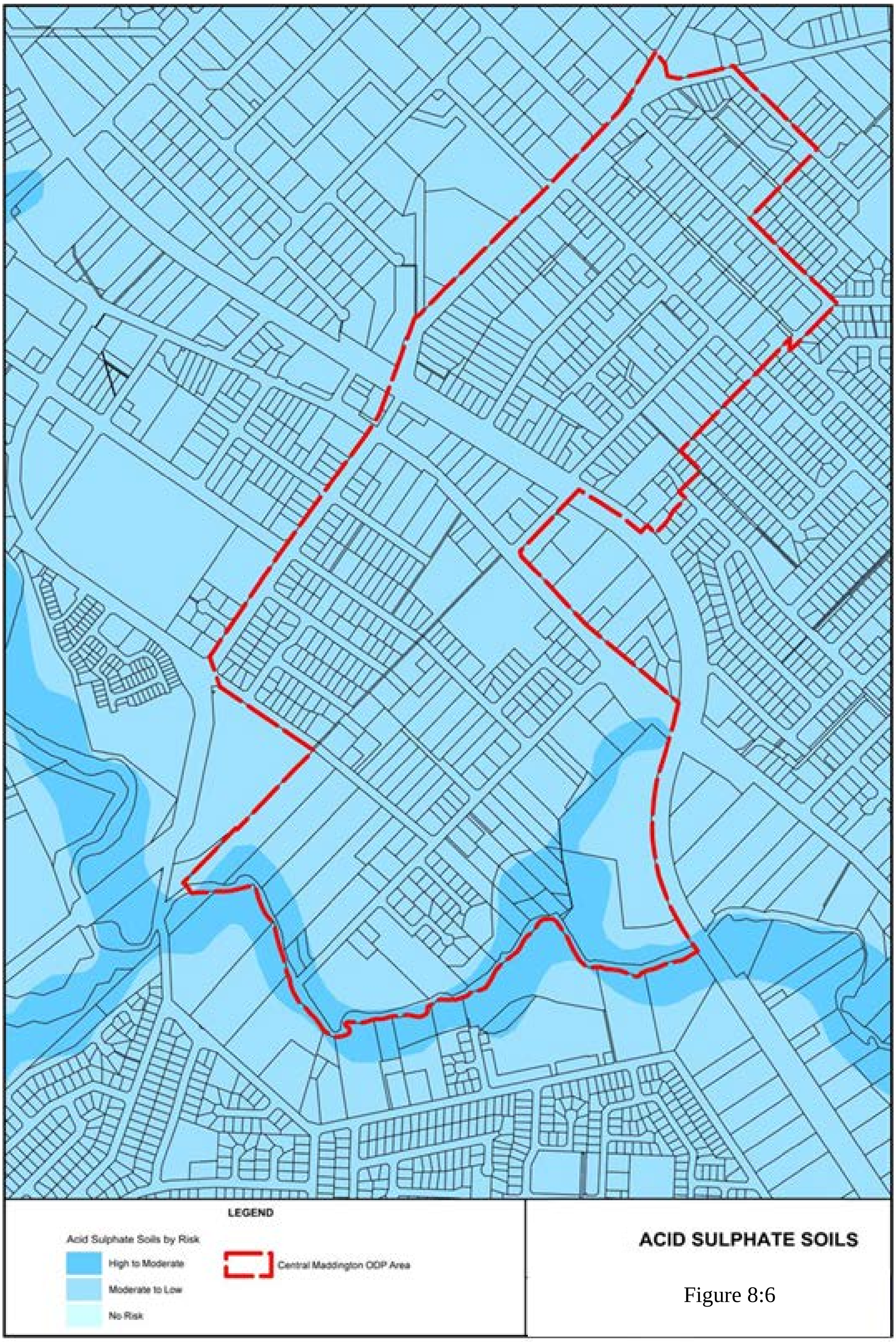


Figure 8:6 – Acid Sulphate Soils

8.4.4. Environmental Attributes

The ODP area is bordered by the Canning River along the southern boundary and is closely linked with the areas of remnant vegetation associated with Bush Forever site 246 (also partly mapped as Conservation Category Wetland (CCW)) and Stokely Creek (that part of the Helm Street drain between Albany Highway and the Canning River, which is also mapped as CCW) that outfall to the Canning River (Figure 8:7).

In the past, parts of the Helm Street drain upstream of Albany Highway have been modified and either 'trained' or piped beyond the ODP area. The portion of drain within the ODP area, close to the river (Stokely Creek wetland) is relatively intact (Brown and Root 2001).

The Canning River foreshore part of the ODP area is reserved for Parks and Recreation under the Metropolitan Region Scheme (MRS). As the zoning suggests, this area is intended for public recreation and not for subdivision and development. Therefore, a sufficient level of protection is afforded to Bush Forever sites along the Canning River and the river environment generally.

With respect to water management, any additional stormwater runoff generated from development of the ODP area, is not to discharge to the Canning River directly, either from new roads or newly developed private property, unless it has been treated to improve water quality. It is also important to maintain pre-development stormwater quantities as additional stormwater discharge to the river has the potential to erode river banks and alter hydrological processes. Structural controls will need to be introduced, where possible, to improve quality of stormwater runoff prior to discharge to the Canning River.

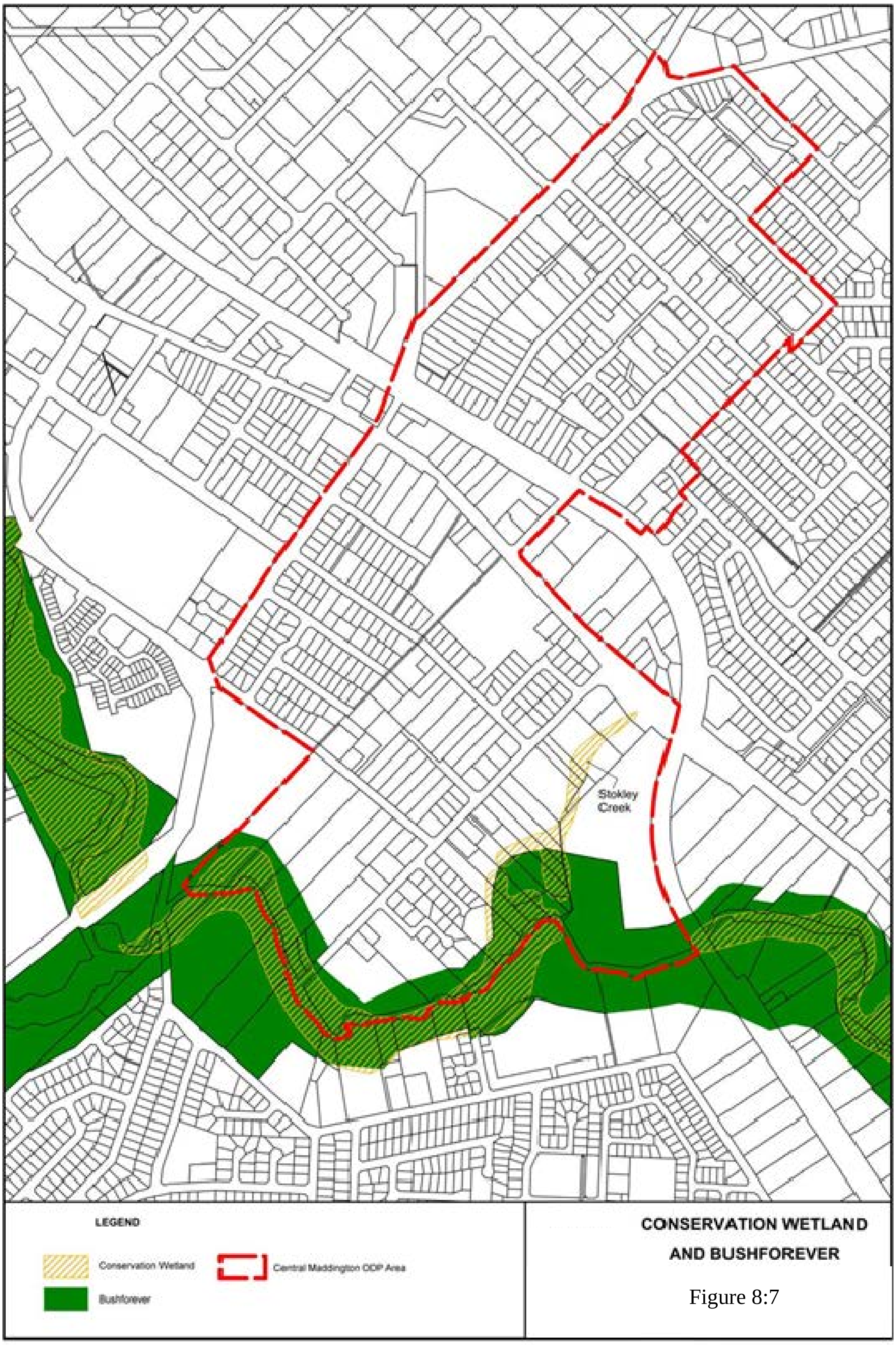


Figure 8:7 – Stokely Creek CCW and Bush Forever Sites 246 along Canning River.

8.5. Design Objective Functions

There are three main objective functions namely Water Conservation and Efficiency, Water Quantity and Water Quality. The design objective functions that are appropriate for the any development are outlined in Better Urban Water Management (WAPC 2008). These objectives and associated urban water management criteria are intended to guide the preparation of Local Water Management Strategies which will facilitate sustainable urban water management for the ODP area (Case study area). These objectives are described in more detail below and the subsequent strategies proposed are detailed further in the Section 8.6.

Water Conservation and Efficiency

Objective	Criteria
Minimize the use of potable water used outside of homes and building	Water consumption benchmark of 100kl/person/year of scheme water.

Water Quantity Management

Objective	Criteria
Post-development annual stormwater discharge volume and peak flow is to be maintained relative to pre-development condition	*Ecological Protection* Critical one-year (ARI) event, the post - development discharge volume and peak flow maintained to pre-development conditions, to maintain environmental flows and/or hydrological cycles *Flood management* Manage the catchment run off for up to the 1 in 100 year ARI event in the development area to match the pre-development conditions

Water Quality Management

Objective	Criteria
Maintain surface water quality at pre-development levels (winter concentrations) and, if possible, improve the quality of water leaving the development area to maintain and restore ecological systems in the sub catchment in which the development is located	*Drainage* All post development stormwater runoff entering the drainage network is to receive treatment prior to discharge to a receiving environment *Pollutant controls* Pollutant outputs of the post development stormwater runoff should not exceed pre-existing catchment conditions and where possible, improve water quality in accordance with the national Water Quality Management Strategy (ANZECC and ARMCANZ 2000).

8.6. Selecting the Best Stormwater Management Strategies

Development of land, particularly where involving more compact forms of housing construction, usually results in an increase in hard or impervious areas when compared to pre-existing site conditions.

Given increasing demand for what is becoming a scarcer resource, there is also a need to ensure new development incorporates measures to minimise water use.

Stormwater runoff from denser forms of development is likely to impose an increased demand on the City's road drainage system, which may not readily accommodate additional stormwater and could add to the risk of flooding. An all-encompassing upgrade to the road drainage system is not viable, given the costs involved, the lack of funds available to do so and likelihood that any passing of such a cost onto developers could potentially make redevelopment unviable. In addition, a major pipe network upgrade would not be desirable for environmental reasons.

On-site infiltration and detention facilities or underground storage systems can provide temporary storage for stormwater runoff within the confines of the development area.

The aim is to restrict the discharge from the site at a rate which the City's existing drainage system is capable of accommodating, mimicking the pre-development conditions or to upgrade the system to accommodate the increased flows.

While such an approach is common practice throughout Perth in Western Australia, the soil conditions and high groundwater table throughout much of the ODP area can limit the effective operation of on-site detention methods. Thus to have a better understanding into the soil conditions across the city, the city of Gosnells

The City undertook this research, in partnership with Curtin University, investigations into soil conditions across the City. The study aims to profile the physical composition of soils and their capability to drain freely and in turn produce guidelines for the most effective means of on-site drainage disposal for different soil types.

As explained throughout, this thesis has developed some clear methodology on identifying the capacity of different soil types and how the permeability capacities impact the management the stormwater in new developments. This research finding reveals that significant variety in soil types between and within different suburbs. Clay soils at depths between 0.5m and 1.5m (and likely deeper) have been regularly encountered in testing undertaken.

As an interim approach, the City will require drainage details to be provided in support of development applications clearly demonstrating how on-site stormwater disposal will be appropriately managed. Based on findings in chapter 04 and in particular the drainage capability data in Table 4:61, Table 4:49, Table 4:24, Table 4:12 and Figure 4:27, it was concluded that soils of the case study ODP area is predominantly clay-based soils. Exceptions will be allowed where an applicant can demonstrate through site-specific geotechnical and soil permeability testing that more favourable drainage conditions prevail on-site and that a drainage system with reduced capacity can be designed and installed accordingly.

In terms of water conservation measures, the City will encourage the use of devices such as water-efficient fittings and appliances, rainwater tanks and grey water recycling systems in new and existing dwellings. Applicants should check the Building Code of Australia and Australian Standards as changes to mandatory requirements may be made from time to time.

As per the discussion made in previous chapter above, this section described how important the "Decision-Support Matrix" (Section 7.2) is in decision making process in order to pick up the right strategy for the right place depending on the existing site constraints. With the help of the Decision-Support Matrix for strategy selection and the Matrix for quick reference guide (Section 7.3), based on the assessed pre-development environment and its implication on local stormwater management at the post-development stage, the best stormwater management strategies were selected for the case study area. They are given below under the three main design objectives functions.

Note: - All the selected BMPs are directly refer to the Table 7:2, Decision-support Matrix for Strategy Selection.

8.6.1. Water Conservation Strategies

The two significant components of water conservation involve stormwater (non-potable) and mains scheme water (potable). Implementation of conservation measures relies upon reducing consumption of potable water by, using it more wisely, and using potable and non-potable water in a more efficient manner.

There are some number ways to conserve potable water sources. Whilst these methods are not always enforceable, their use is likely to increase based on increased awareness of the issue of water scarcity and associated water restrictions for domestic irrigation. The concept of water conservation is premised on water reducing technology and also retaining roof rain water (non-potable) so that it can replace other household water uses that otherwise require scheme water (potable).

The objectives and strategies for potable water conservation for the ODP area are tabled below Table 8:1.

Table 8:1- Water Conservation Strategies

Objective	Criteria	Strategy	BMP
Minimize Total Water Use	Reduce average water consumption to 100kL/year	Reduce water consumption by using water saving technology with • Household tap fixtures • Shower fixtures • Low volume dual flush toilets	C7
Use water more efficiently		Use rainwater storage tanks as a means of storing roof stormwater and use it as an alternative to potable scheme water in the following instances • Garden reticulation • Toilet flushing • Car washing • Washing machine eater Use other stormwater retention/detention methods • Below ground rainwater/stormwater storage units and media filled storage tanks • Rain garden • Roof garden • Stormwater scultures and water features Limit garden irrigation by reducing number of watering days per week	S1 I1 C2 C3 C7

Application of the above strategies to conserve water will help achieve the benchmark water consumption target of 100kL/year, outlined in the State Water Plan. Additional information on water conservation can be found on the Department of Water's website.

The use of stormwater tanks is not enforceable however studies have shown that their use has the potential to save 18 to 55kL per year (this is only an estimate as annual rainfall will vary from year to year). The reduction in scheme water use represents a potential cost saving, and it is considered that due to ever increasing water shortages many people will install rainwater tanks in future development of the ODP area.

Whilst mandatory water saving measures, applied under the BCA, are likely to achieve the State Water Plan consumption target of 100kL/year (as detailed above), the use of rainwater tanks with a potential scheme water saving of 18 to 55kL would represent a further significant reduction in scheme water usage for the ODP area.

8.6.2. Stormwater Quantity Control Measures

Due to the prohibitive cost of retrofitting the existing piped drainage network, the poor infiltration quality of the soil, and the lack of availability of space to accommodate additional drainage facilities, the considered option is for individual properties to accommodate larger rainfall events on-site individual properties, and for new roads to detain larger rainfall events as close to the source as possible within road reserves.

The objectives and strategies for the management of stormwater quantities for the ODP area are tabled below Table 8:2 and address runoff for newly constructed dwellings on private lots and also runoff from newly constructed roads.

Table 8:2- Stormwater Quantity Management Strategies

Objective	Criteria	Strategy	Implementation	BMP
Post-development annual stormwater discharge volume and peak flow is to be maintained relative to pre-development conditions	*Ecological Protection* Critical one-year (ARI) event, the post -development discharge volume and peak flow maintained to pre-development conditions, to maintain environmental flows and/or hydrological cycles	Bio-retention pockets are to be introduced into verges of new roads and engineered to accommodate additional stormwater runoff for a 1-year rainfall event	Proposed new dwelling or lots requiring new road frontage must prepare and submit a UWMP for approval by the city prior to approval for subdivision or development. Stormwater bio-retention systems for new roads designed for a 1 year ARI rainfall event in accordance with calculation (only summary of the pre- and post-development runoff calculations is given with thesis)	C3
	Flood management Manage the catchment run off for up to the 1 in 100 year ARI event in the development area to match the pre-development conditions	Stormwater detention for newly created dwellings or lots to be engineered to accommodate the 1 in 100year rainfall event. New roads are to be engineered to detain post development stormwater volumes for a 100 year ARI rainfall event within the piped drainage system, and release stormwater at pre-development levels into the existing drainage system. All new building pads to be raised 300mm above the 1 in 100 year ARI event expect for dwellings south west of Philip Street and South east of River Avenue which requires the minimum standard of 500mm. Monitoring stations will be set up throughout the ODP area to monitor water quantities to ensure pre-development flows are being maintained.	Proposed new dwellings or lots accessed from an existing road, require a detailed drainage strategy to be submitted and approved by the city prior to approval for development and/or subdivision On-site stormwater systems for new dwellings or lots to be designed in accordance with drainage strategy Stormwater detention system for new roads designed for a 100 year ARI rainfall event (only summary of the pre-and post-development runoff calculations is given with thesis) A surface water monitoring program will be undertaken by a qualified consultant	D1 S1

Pre-and Post-Development Runoff and Lot Detention Storage Calculations

The various catchments on the plan at Figure 8:3 represent drainage catchments. These have been determined by topography and the flow of the piped network and the larger open drains they connect with.

Table below are the pre-existing stormwater discharge levels for individual catchments for the 1 in 5yr ARI rainfall event. To ensure these flows are maintained consideration is to be given to the 1 in 100yr ARI rainfall event, with any additional runoff to be stored on-site within individual lots in the catchment.

This is to be achieved by providing additional capacity within underground storage units and in some cases, may require further storage capacity within rainwater tanks. It is considered that retention of the 100-year event can be achieved with a three-cubic meter underground storage unit, and if additional storage capacity is required, then a two-cubic meter rainwater tank will suffice. A visual concept of this approach is provided in the Drainage Strategy Concept Plan in Figure 8:8. It's important to note that post development flows have factored in the proposed new residential density codes shown on the ODP which will increase the amount of impervious area within the ODP area and generate more runoff than the existing situation.

The information below shows the volume of post-development stormwater generated from each catchment in the ODP. It is the developers' responsibility to ensure that the additional quantities of stormwater can be adequately detained on-site for individual lots during a larger rainfall event.

The volumes of stormwater expected to be generated from proposed new individual lots for the 100-year ARI rainfall event will be detained on-site through the implementation of drainage strategy detailed in the drainage concept plan given in Figure 8:8. This means that storage of stormwater will not be required in parkland proposed on the ODP.

The following calculation provides detail on how the post development stormwater volume is determined for Catchment C1, Sub-catchment C1A (R80). Further to this, stormwater volumes have been tabulated for convenience with all other relevant information specific to each catchment provided underneath next to an asterisk.

Please note that all values and calculations shown below are indicative only and will need to be confirmed by individual drainage strategies submitted for development and or subdivision of individual lots.

Catchment C1

Sub-catchment C1A (R80)

*Area of R80 catchment = 33056*m^2

*Proposed R80 - density = 180*m^2 *average lot size*

Predevelopment coefficient = 0.4 (Clay soils)

*1 in 5-year flow rate = 93.4L/s = 0.0934*m^3/s

Number of existing lots in catchment = 21

Number of existing dwellings = 16

*16 dwellings on 500*m^2 *lots = 8000*m^2 *total lot area*

Post developed area of R80 catchment – pre-existing area of existing dwellings

*33056*m^2 *- 8000*m^2 *= 25056*m^2

Post development coefficient 0.65

1 in 100-year flow rate = 209.4 L/s

Catchment volume allowing for predevelopment flows = 455 m^3

*25053/180 (average lot size) = 139 lots to accommodate 455*m^3 *runoff*

= ***3.27***m^3 ***per lot for a 1 in 100-year event****.*

Similarly, the storage requirement for the other catchments has been calculated and the summary of the calculations are given in below.

Table 8:3- Lot runoff calculation – Catchment C1

Catchment C1								
Sub catchment	Land use	Area m^2	Pre Flow m^3/s 5yr ARI	Post Development Coefficient.	Post Flow L/s 100 yr ARI	Volume m^3	No. of lots	Volume per lot m^3
C1A	R80	33,056	0.0934	0.65	209.4	455	139	3.27
	HC	24,172	0.128	0.8	155	248	0.0185 m^3/m^2	
	PS	45,857	0.129	0.75	234.1	463	0.0215 m^3/m^2	
C1B	R40	15,676	0.0443	0.55	50.7	79	32	2.47
	R30	67,299	0.190	0.5	288	521	149	3.50
C1C	R40	11,857	0.0335	0.55	30.8	41	19	2.16
	R30	72,808	0.206	0.5	355.5	686	184	3.73
C1D	R40	30,332	0.0857	0.55	112	187	71	2.37
	R30	7,072	0.0200	0.5	35.8	70	18	3.9
	R20	28,090	0.0793	0.45	156.7	332	54	6.1
	MB	4,717	0.0250	0.8	17.1	18	0.0108 m^3/m^3	
C1E	R30	28,895	0.0816	0.5	140.8	271	72	3.76
	R20	47,543	0.134	0.45	211.4	390	73	5.34

Table 8:4- Lot runoff calculation – Catchment C2

Catchment C2								
Sub catchment	Land use	Area m^2	Pre Flow m^3/s 5yr ARI	Post Development Coefficient.	Post Flow L/s 100 yr ARI	Volume m^3	No. of lots	Volume per lot m^3
C2	R30	34,702	0.098	0.5	216.7	468	112	4.18
	R20	38,711	0.109	0.45	186.4	358	64	5.59

Table 8:5- Lot runoff calculation – Catchment RR1

Catchment RR1								
Sub catchment	Land use	Area m^2	Pre Flow m^3/s 5yr ARI	Post Development Coefficient.	Post Flow L/s 100 yr ARI	Volume m^3	No. of lots	Volume per lot m^3
RR1	R80	35,745	0.101	0.65	206.8	432	137	3.15
	R40	9,867	0.0279	0.55	16.7	16	10	1.6
	R30	22,254	0.0629	0.5	110.9	216	57	3.79

Table 8:6- Lot runoff calculation – Catchment RRC

Catchment RRC							
Sub catchment	Land use	Area m^2	Pre Flow m^3/s 5yr ARI	Post Development Coefficient.	Post Flow L/s 100 yr ARI	Volume m^3	Volume per m^2
RRC	HC	38,216	0.2024	0.8	57.7	15	0.00267

Table 8:7- Lot runoff calculation – Catchment GP1

Catchment GP1								
Sub catchment	Land use	Area m^2	Pre Flow m^3/s 5yr ARI	Post Development Coefficient.	Post Flow L/s 100 yr ARI	Volume m^3	No. of lots	Volume per lot m^3
GP1	R80	4,188	0.0118	0.65	26.6	58	17	3.41
	R40	53,163	0.1502	0.55	234.5	431	150	2.87
	R30	121,674	0.3437	0.5	537.9	989	278	3.56

Table 8:8- Lot runoff calculation – Catchment AS1

Catchment AS1								
Sub catchment	Land use	Area m^2	Pre Flow m^3/s 5yr ARI	Post Development Coefficient.	Post Flow L/s 100 yr ARI	Volume m^3	No. lots	Volume per lot m^3
AS1	R30	35,056	0.099	0.5	135.4	232	70	3.31

Table 8:9- Lot runoff calculation – Catchment AS2

Catchment AS2								
Sub catchment	Land use	Area m^2	Pre Flow m^3/s 5yr ARI	Post Development Coefficient.	Post Flow L/s 100 yr ARI	Volume m^3	No. lots	Volume per lot m^3
AS2	R40	12,973	0.0366	0.55	67.0	133	43	3.09
	R30	41,800	0.1181	0.50	159.4	271	82	3.3

Additional Runoff from New Roads

New roads will need to detain additional stormwater they generate for a 1yr ARI rainfall event and a 100yr ARI rainfall event. The 1yr rainfall event can be accommodated within bio-retention pockets in the road reserve to address stormwater quality and quantity in more frequent rainfall event. The much larger 100yr rainfall event is to be retained within the larger piped network for new roads and gradually released into the existing piped network at predevelopment rates.

There are approximately 5,896 linear metres of new road proposed with an average reserve width of 17.9m, which is a total road reserve surface area of $105538m^2$. For a 1-year ARI rainfall event, assume a runoff coefficient of 0.9 for new roads, a stormwater treatment area of 2% of the impervious area, and an average bio-retention area of 3 metres by 10 metres. The number of bio-retention pockets can be calculated using the following equation.

$105538m^2 \times 0.9 = 81718m^2 \times 0.02 = 1900m^2$ of area required for bio-retention.

This means 63 bio-retention pockets will be required at 1 for every 93 metres of road for a 1 year ARI rainfall event.

To detain runoff in the larger 100 year ARI rainfall event the following equation applies.

New road length = 5896m at 17.9m width

New road area = 105538m²

Predevelopment runoff coefficient = 0.4

Predevelopment flow rate (5yr ARI) = 0.2981m³/s

Post development runoff coefficient = 0.9

Post development flow rate (100yr ARI) =1221.2 L/s

Volume of runoff generated = 3,355m³

Volume generated per square metre of new road = 0.03179m³/m2

It is intended that additional stormwater generated in a 100-year ARI event will be detained within the larger pipe system in proposed new roads, and gradually released into the existing pipe system in existing roads at the predevelopment flow rate. This means pipes in new roads must be sized accordingly to detain the 100-year ARI rainfall event. Based on the additional volume of 3,335m³ the pipe size can be determined in the following manner:

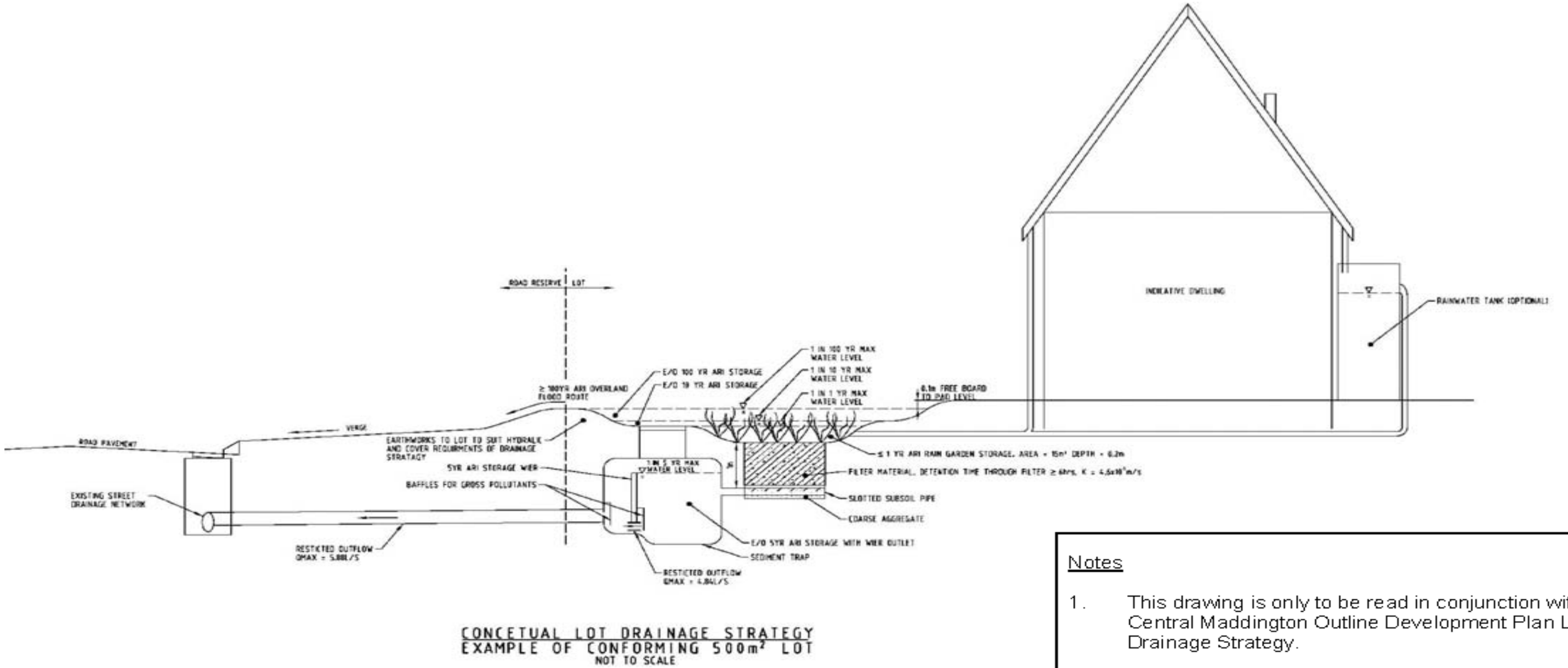
Length of pipe required (LP) = volume required to be stored (VS) / π multiply (radius (R) of pipe)².

Therefore:

$LP = 3{,}355m^3 / \pi \times (0.2025)^2$

= 5274 metres of 900 Ǿ pipe for 5896 metres of new road

The calculations and figures above consider the proposed new road network in its entirety. In reality drainage will be addressed for sections of road (shown in Figure 8:9) through submission of UWMP's by developers. As such the calculations and figures are indicative only and will need to be confirmed through UWMP's.



Notes

1. This drawing is only to be read in conjunction with Central Maddington Outline Development Plan Lot Drainage Strategy.

2. Volumes and levels are indicative only based on 500m² lot size. Refer to drainage strategy report for actual guidelines.

3. Drawing is indicative only of possible lot drainage concept all detailed designs are to be approved by Council prior to subdivisional approval being given.

4. Rain water tank is shown as optional and for illustration purposes. Provision of rainwater tanks is subject to the DAP and UWMP, and is not a direct requirement of this drainage strategy.

5. Rain garden design, soil and plan selection shall be subject to requirements of UWMP or equivalent.

Figure 8:8 – Lot Drainage Strategy - Concept Plan

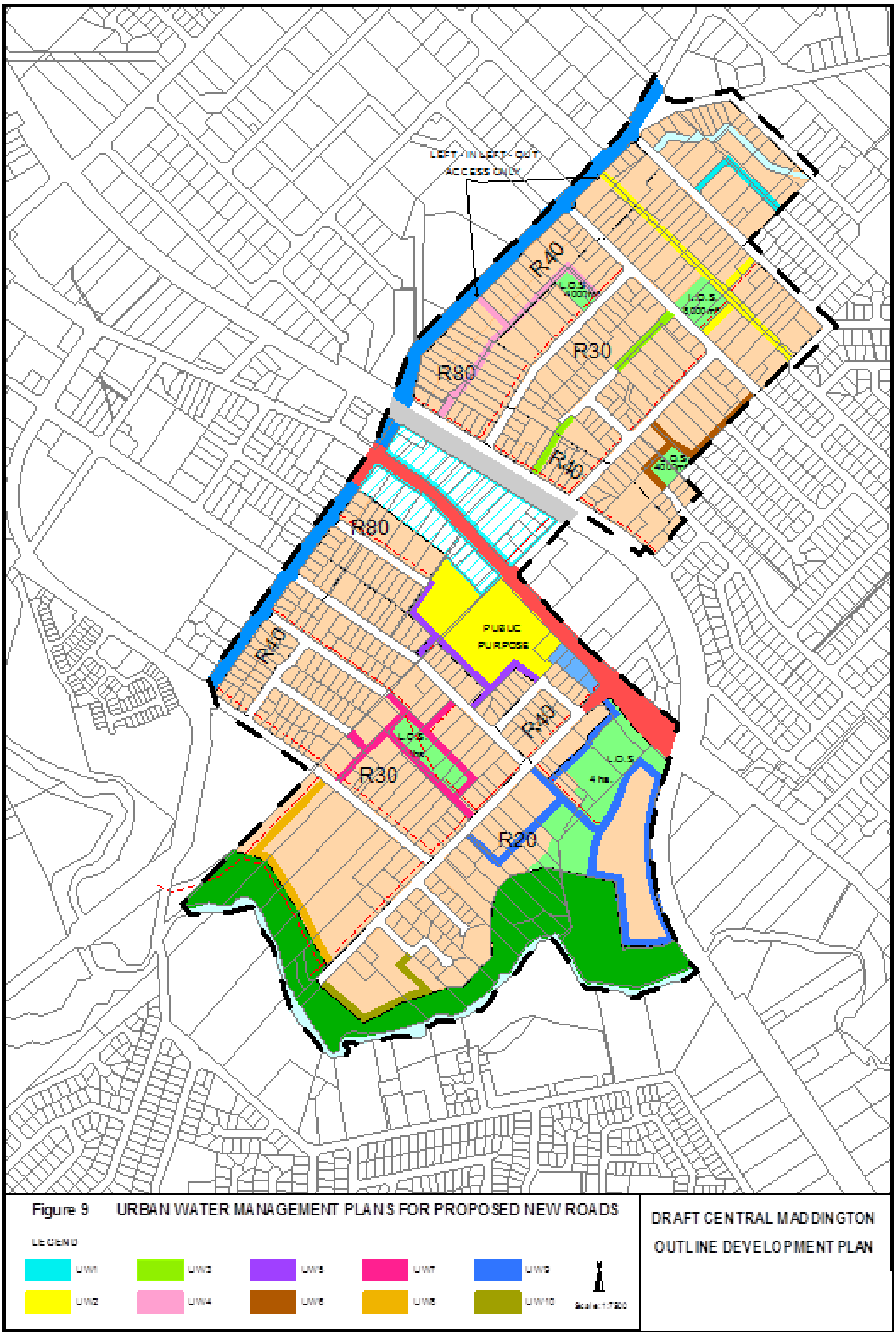


Figure 8:9 – Indicative Proposed New Road Layout

8.6.3. Stormwater Quality Control Measures

Existing district drainage infrastructure was designed to address stormwater disposal requirements without any specific emphasis on water quality aspects. Contemporary drainage quality control technology involves retention/detention and the use of vegetation and soil media to remove sediments and particulates, and to attenuate nutrients. They can reduce pollutants in stormwater such as nitrates and phosphates which are typically found in garden fertilizers, as well as hydrocarbons from road surfaces in the form of oils generated by motor vehicles.
The following objectives and strategies for improving the quality of stormwater from new residential construction and new roads are aimed at detaining and treating potentially polluted stormwater as close to the source as possible and prior to being conveyed to the receiving waters of the Canning River. By considering all the site conditions and with the help of the Decision- Support Matrix for strategy selection, the best stormwater management strategies for the site have been selected and they are given below.

Table 8:10- Stormwater Quality Management Strategies

Objective	Criteria	Strategy	Implementation	BMP
Maintain surface water quality at pre-development levels (winter concentrations) and, if possible, improve the quality of water leaving the development area to maintain and restore ecological systems in the sub-catchment in which the development is located.	*Drainage* All post-development stormwater run-offs entering the drainage network is to receive treatment prior to discharge to a receiving environment. *Pollutant] controls* Pollutant outputs of the post-development stormwater run-off should not exceed pre-existing catchment conditions and	▸ Bio-retention pockets are to be introduced into verges of new roads and engineered to accommodate additional stormwater runoff for a 1yr ARI rainfall event. ▸ Bio-retention areas are to be provided on individual lots and engineered to accommodate additional stormwater runoff for a 1yr ARI rainfall event. ▸ Bio-retention pockets to be engineered with suitable filter media to reduce hydrocarbon road runoff pollutants. ▸ Other possible	▸ Proposed new dwellings or lots requiring new road frontage must prepare and submit a UWMP for approval by the City prior to approval for subdivision or development. ▸ Stormwater detention system for new roads designed in accordance calculations (only summary of the pre and post development runoff calculations are given with thesis) ▸ Stormwater bio-retention systems for new roads designed for a 1 yr ARI rainfall event	C3 C1 C2

	where possible, improve water quality in accordance with National Water Quality Management Strategy (ANZECC and ARMCANZ, 2000).	quality control measures that could be included in new roads are: - buffer strips - bio-retention swales - rain gardens - bio-filtration pockets - median swales - gross pollutant traps ▸ Monitoring stations will be set up throughout the ODP area to monitor nitrate and phosphate loadings.	in accordance with calculations (only summary of the pre and post development runoff calculations are given with thesis) ▸ A monitoring program will be undertaken by a qualified consultant	

The most significant reductions in total phosphorus and total nitrogen can be achieved through bio-retention pockets and filter medium located in road reserves of new roads. However, reductions are also expected to be achieved through bio-retention on individual lots depending on the nature of development, particularly during the first flush from winter rain which collects the accumulation of pollutants from roof and especially from hardstand surfaces like carparks. Due to the clay nature of the site, it would be required to provide subsoils underneath the filter media to pick up the treated water and discharge receiving environment. This requirement needs to be further assessed at the detail design stage (UWMP).

8.6.4. Groundwater management Strategy

The quality of groundwater would usually be controlled through water sensitive design and best management practices. However, due to the poor infiltration properties of the soil, the potential for contaminated stormwater to infiltrate to groundwater is negligible. The effect of deep aquifer groundwater level is very less compare to the groundwater effect due to the perched over the highly reactive clay layer. This needs to be carefully assessed at the detained design stage as case by case scenario and depending on the nature of the groundwater, subsoils drainage system needs to be designed.

The focus of water quality in this report is tailored toward managing stormwater, where the implementation of structural controls will be most effective.

8.7. Conclusion

Development of a local water management strategy for the case study area (Central Maddington) is carried out through a step by step process to ensure that the proposed development manages the total water cycle in a sustainable manner while adhering to the principles of water sensitive urban design. And also this LWMS provides concept designs, guideline controls and management measures for

- Maximise the efficient use of water resources
- To maintain pre-development total water cycle balance within development areas
- To maintain surface and ground water quality at predevelopment levels and, if possible improves the quality to maintain and restore ecological systems.
- To prevent the deterioration of ecosystem health
- To protect infrastructure assets from flooding and water logging
- Deliver best practice water management taking due cognisance of sustainability and precautionary principles

CHAPTER 9

9 CONCLUSIONS AND RECOMMENDATIONS

9.1. Conclusions

This research evaluates the effectiveness and efficiency of infiltration based urban stormwater management for residential land development. The effect of urbanisation on the natural water balance and water cycle management in land development areas is the main key target of the study. The outcome of this study shows very useful results in evaluating the impacts of residential land development process on urban hydrology. This include direct aspects of both infill and greenfield land developments that are currently practiced in Western Australia. The findings of this study will be very useful for hydrologist, drainage engineers, land developers, local city councils, other authorities and policy and decision makers to reach their design objectives by implementing sustainable land development practices to ensure minimum impacts on urban hydrology.

It is recommended that hydraulics designers use the minimum permeability value in their designs as it gives a good safety factor to the design and the maximum value in designs which focused at lot scale or close to the sampling locations. The average figure can be used in the designs which consider the large area such as sub precincts or sub division in preparing local and urban stormwater management plans.

An intensive literature review is conducted broadly on urban stormwater management. Specific attention is paid towards the effects of land use change, climate change and the effect of groundwater (groundwater and surface water interaction) on urban stormwater management. The effects of land use change on urban stormwater management are thoroughly analysed throughout the study, whereas, the effects of climate change and groundwater on urban stormwater management is widely discussed in case studies. Literature review further confirmed that the permeability of an insitu soil or the imported fill material plays an important role and is the main governing factor when practising the infiltration based stormwater management in any urban development catchment.

The permeability of a particular soil sample is a function of series of factors such as type of soil, physical properties, different depth, and the effect of groundwater. It varies even within the same soil type as it is not homogeneous. The spatial variability in soil cannot be avoided because they are geologically formed over thousands and millions of years on a landscape. Based on the analysis conducted, it is recommended that the permeability capacity reduces with the depth and the recommended drop of permeability between 1m to 1.5m is 3%.

The unified soil classification analysis results show some samples are poorly graded sand and the rest are well graded sand. However, the results clearly presented that the average permeability of well graded sand is much higher than that of poorly graded sand. In addition, these results pointed out that the number of finer particles (particle size less than 75µm) present in a soil sample plays an important role with respect to their soil permeability. If any development follows infiltration based stormwater strategy, requires imported fill over the existing soil then the well graded sand can be recommended than the poorly graded sand.

Even though, it was found that the permeability of a soil sample depends on series of factors, the whole analysis conducted within this research can be concluded that the percentage of silt and clay, site compaction and the presence of ground water level are the major factors that greatly influenced the permeability capacity of soil.

Based on the analysis conducted to assess the relationship between the permeability and the ground water level, it is recommended to use zero permeability in designs if the proposed stormwater management infrastructure is interacted with groundwater level for more than 6 months of a year. By knowing the ground water levels, it would be easy to specify and recommend a better solution for the stormwater management.

These results would help designers make correct decision on selecting best storm water management strategy.

One of the best outcomes of this study is identification of relationship between soil permeability and the silt and clay percentage of the soil. This relationship was developed for both existing soil and the imported clean sand fill material. Study further found that, most the areas contained less than 2% of silt and clay and very few soil profiles stay within the range between the 2% and 10%. Soils with a high plasticity index tend to be clay, those with a lower plasticity index tend to be silt, and those with no plasticity index (non-plastic) tend to have little or no silt or clay. Sand and gravel are coarse grained soils that usually promote permeability. The apparent particle density of a soil sample is constant and permeability capacity is totally independent of its particle density.

The final results indicated that the permeability of existing soils varies in a range from 0 to 20 m/day while the percentage of silt and clay from 0 to 10% and also percentage of water absorption capacity varies 0% to 10% whereas this relationship for imported soils shows very high range compare to the existing soils. Moreover, this analysis clearly showed that soil permeability can be varied in a particular range of same silt and clay percentage and the soil permeability can be expressed in term of water absorption capacity of the sample. This relationship is very important in understanding the behaviour of soil permeability considering the other factors such as level of compaction, density, void ratio and porosity. Based on the current Australian standard, the extended analysis has determined that the maximum allowable permissible permeability capacity of the standard fill material (contains maximum of 5% silt and clay with the blockage factor of 2) is 5m/day.

Further analysis was conducted to explore the difference between the field-tested soil permeability and the soil permeability estimated using empirical formula. It confirms that estimating the soil permeability of a soil sample using empirical formula or the grading characteristics can relatively lead to underestimation or overestimation. Among a wide range of soil types, the best overall closest estimation of permeability is given by Hazen formula (Hazen,1892). However, this formula consists of only one variable. As the soil permeability depends on other parameters like void ratio, porosity, viscosity and the temperature, the Hazen formula is not specific enough to represent the correct permeability. It is clear that these empirical formulas overestimated the soil permeability values and neither were appropriate nor reliable to estimate the soil permeability due to different possible reasons such as, applicable conditions, different environment with different temperature, porosity, density or compaction. After analysing all the test results, it is realized that the soil permeability is a function of a series of variables and it is difficult to develop an empirical formula to represent all the soil types.

The empirical formula that normally used to calculate the porosity has under estimated its real value. However, the comparison shows that both values from empirical formula and the experimental results were very similar to each other and can be applicable only for the d_{10} range between 0.1mm and 0.25mm.

The selection of the best stormwater management requires consideration of multiple factors, such as soils permeability, catchment management objectives, site characteristics (scale factor), target pollutants, social values, and capital and operating costs to achieve a balance between quantity and quality management objectives and to create a sustainable outcome. Considering all these factors and the potential benefits and limitations of available stormwater management strategies, the strategy selection matrix has been prepared. This strategy selection table and the basic references produces key guidance to the designers in selecting of sustainable best stormwater management strategies or finding of best combination of these measures to suit local circumstances. Strategy selection matrix would be useful for land developers as well as authorities, decision makers and policy makers to come up with sustainable land development proposals.

The case study of developing local water management strategies for Maddington redevelopment area has demonstrated different aspects of urban hydrology and stormwater management. The selection of best management strategy based on the main objectives and the existing site constraints is well presented using this case study. The effect of new urban land use change on the new proposed development was properly analysed through this case study.

9.2. Recommendations for further study

- The scope of the study is limited to the evaluation of the effectiveness and efficiency of infiltration based urban stormwater management for residential land development. Literatures confirms that, there are only few research studies that have been conducted on finding strategies to control the natural water balance to mimic the pre-development condition in land use change. As climate change and groundwater fluctuations are also main factors affecting the hydrology of urban development lands, it is recommended to expand the present research towards these two factors, as both climate change and the groundwater are the other two factors that directly influence urban storm water management.

- As per the current practice and based on the stormwater management manual for Western Australia, the minimum recommended separation from the base of the infiltration based stormwater management measures to the controlled ground water level is only 300mm. However, in practice, the required separation varies between the local authorities and even between the states depending on their own practice and guidelines. On the other hand, there is very few research studies that have been carried out in finding the most suitable separation that is required in order to get the maximum benefit of the infiltration capacity of the soil when designing an infiltration based stormwater management infrastructure.

- For the study area, the relationship between permeability and the silt and clay percentage is defined. This relationship was developed for both existing soil and the imported clean sand fill material in the study area. Therefore, it is recommended to expand this valuable finding to more study areas and help to generalize the findings across Western Australia.

- This research can be further extended with more laboratory test results to minimize the variability which may occur due to less number of tests conducted for several soil types (soil type F and I) and some mismatching data. Further, this study can be extended to identify the permeability values of separate soil supergroups which will help to find an average permeability values for any type of soil with different soil supergroup compositions. These results will be able to provide a more generalized way to calculate the soil permeability by using their percentage of soil supergroup's availability.

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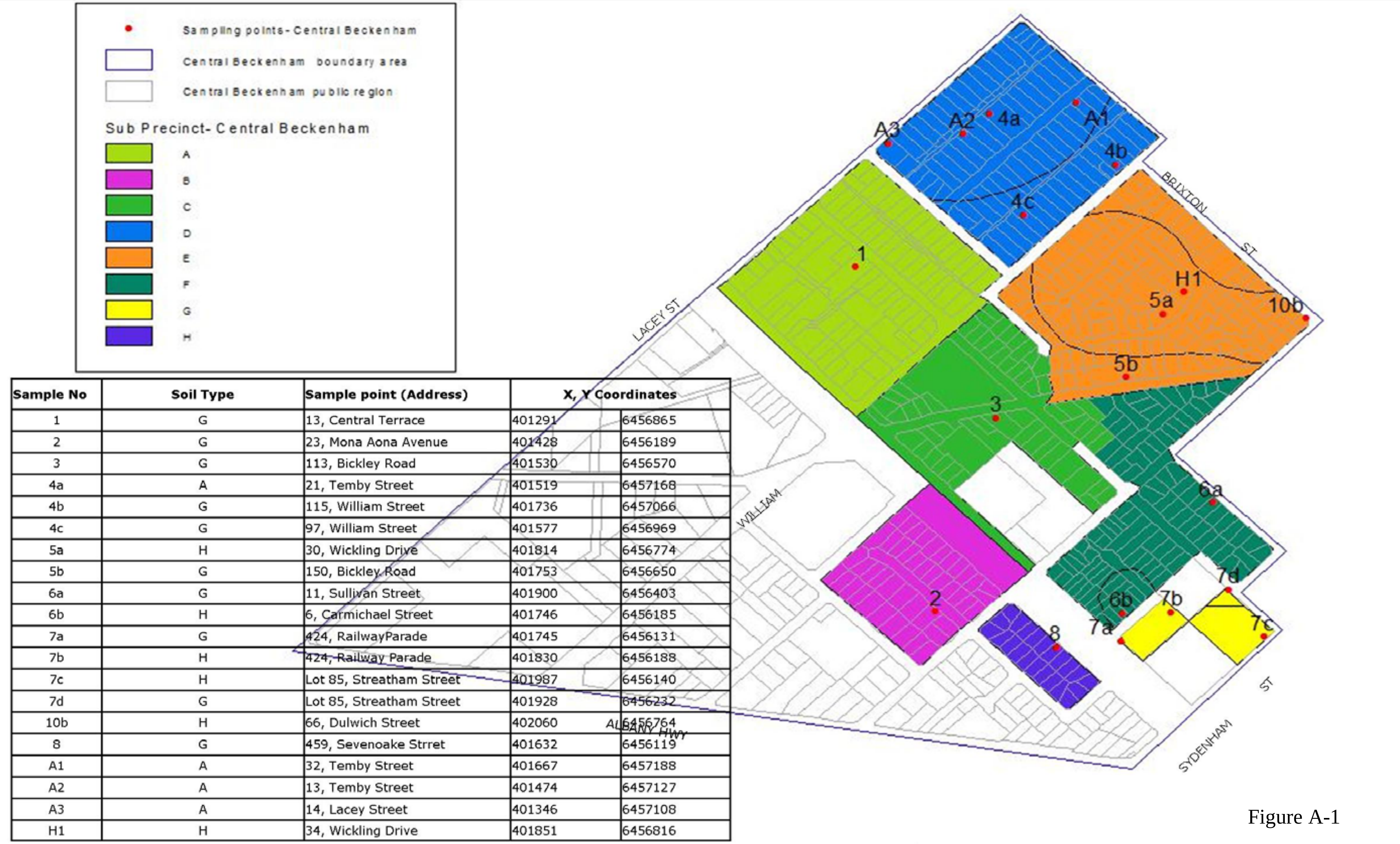
APPENDIX A – FIELD TESTING LOCATIONS



Sample No	Soil Type	Sample point (Address)	X, Y Coordinates	
1	G	13, Central Terrace	401291	6456865
2	G	23, Mona Aona Avenue	401428	6456189
3	G	113, Bickley Road	401530	6456570
4a	A	21, Temby Street	401519	6457168
4b	G	115, William Street	401736	6457066
4c	G	97, William Street	401577	6456969
5a	H	30, Wickling Drive	401814	6456774
5b	G	150, Bickley Road	401753	6456650
6a	G	11, Sullivan Street	401900	6456403
6b	H	6, Carmichael Street	401746	6456185
7a	G	424, RailwayParade	401745	6456131
7b	H	424, Railway Parade	401830	6456188
7c	H	Lot 85, Streatham Street	401987	6456140
7d	G	Lot 85, Streatham Street	401928	6456232
10b	H	66, Dulwich Street	402060	6456764
8	G	459, Sevenoake Strret	401632	6456119
A1	A	32, Temby Street	401667	6457188
A2	A	13, Temby Street	401474	6457127
A3	A	14, Lacey Street	401346	6457108
H1	H	34, Wickling Drive	401851	6456816

Figure A-1

Stormwater Management project Sampling points	LOCAL HOUSING STRATEGY PLAN **Central Beckenham Housing Precinct**

Sam-ple No	Ref. Soil Type	Sample Point (Address)	X, Y Coordinates	
27	D	61, Helm Street	405502	6453090
28	D	5, Cedar Way	405801	6452812
29	D	9, Conifer Street	405780	6453338
30	D	2008, Albany Hwy	404902	6452735
55	D	7, Pitchford Avenue	405345	6452466

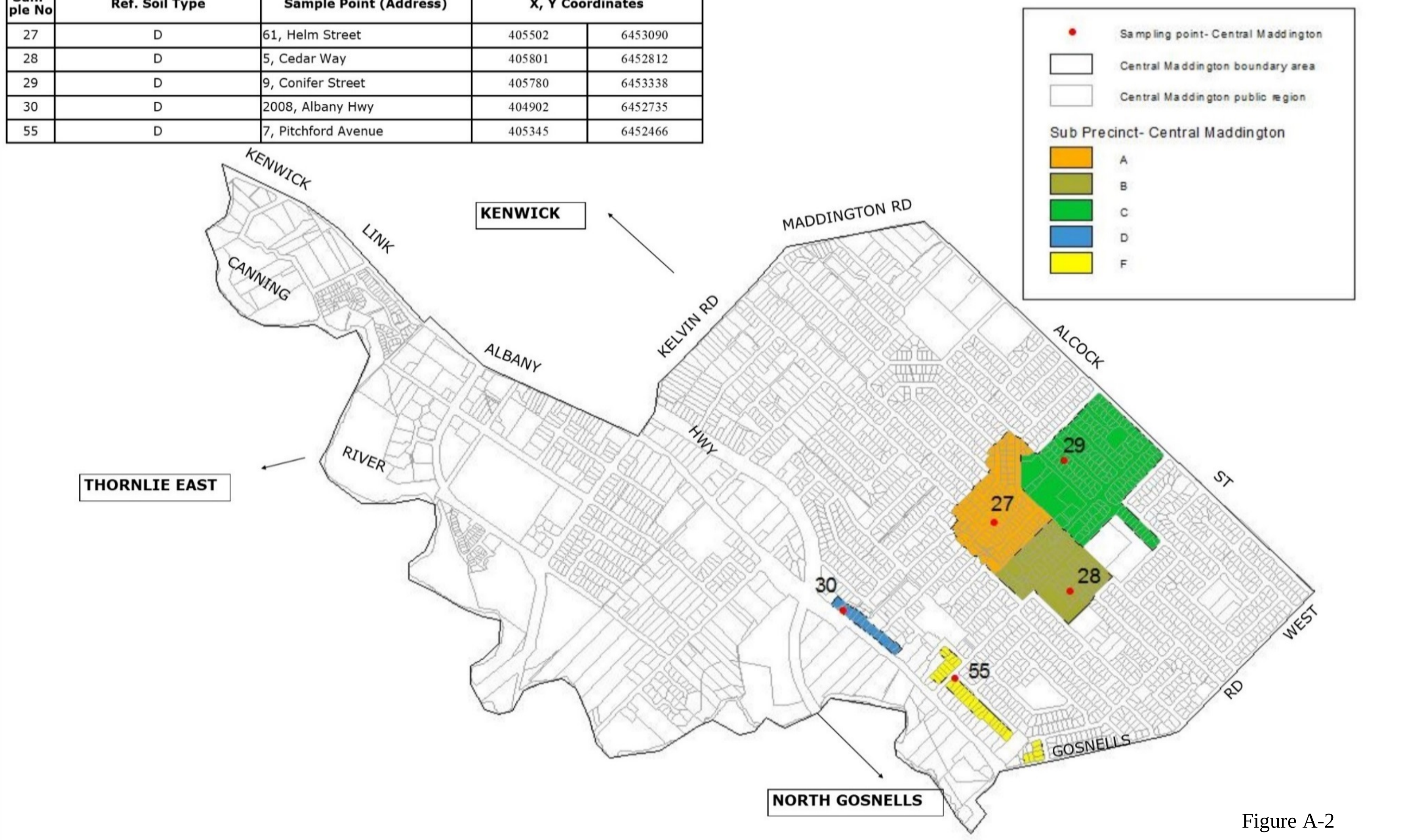


Figure A-2

Stormwater Management project Sampling points	LOCAL HOUSING STRATEGY PLAN **Central Maddington Housing Precinct**

Sample No	Ref. Soil Type	Sample point (Address)	X, Y Coordinates	
18a	G	17, (Lot 32) Dudley Road	402297	6455149
18b	G	10 (Lot 13), Dudley Road	402375	6455162
19a	D	31, Rayal Street	402475	6454706
19b	G	27, Rayal Street	402497	6454723
19c	I	27, Rayal Street	402418	6454834
20a	D	44, Wanaping Road	402953	6455414
20b	G	14, Kenwick Road	402798	6455186
21a	G	31, Kenwick Road	402967	6455164
21b	G	17, Kenwick Road	402796	6455110
22a	B	35, Belmont Road	403887	6455709
22b	B	43, Belmont Road	403879	6455657
23a	B	93, Kenwick Road	403632	6455317
23b	G	75, Kenwick Road	403474	6455272
24a	B	84, Belmont Road	403910	6455262
24b	G	26, Lalor Road	404206	6455306
25a	G	Park next to 19 Gaskin road	404024	6455738
25b	B	54 (Lot7), Belmont Road	403922	6455606
25c	G	8, Duketon Way	403785	6455494
26a	B	83, Belmont Road	403861	6455250
26b	G	13 (Lot 58), Denford Street	403749	6455150
26c	B	9 (Lot 56), Denford Street	403709	6455123
I1	I	17, Royal Street	402427	6454849

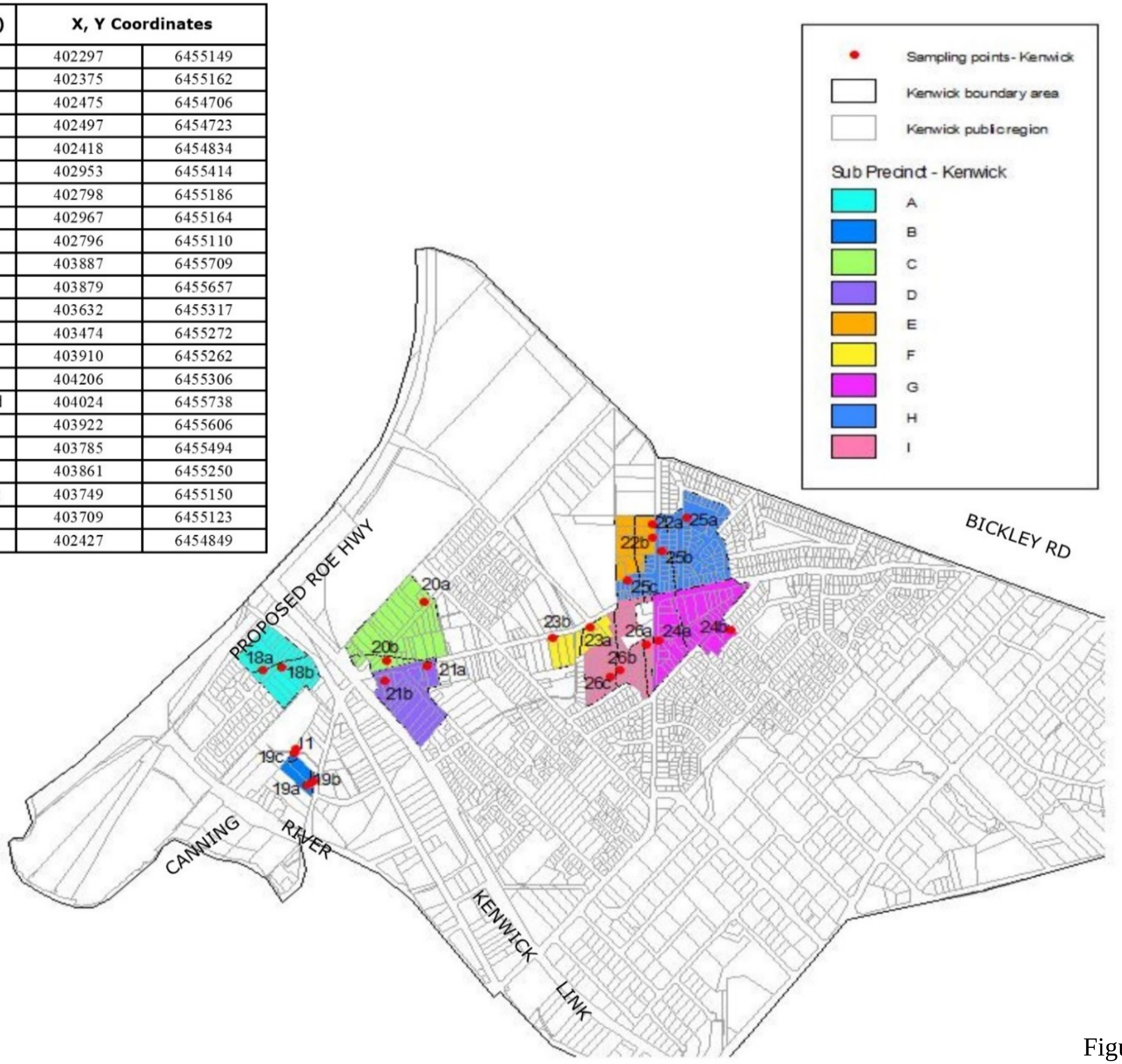


Figure A-3

Stormwater Management project Sampling points	LOCAL HOUSING STRATEGY PLAN **Kenwick Housing Precinct**

Sample No	Ref. Soil Type	Sample Point (Address)	X, Y Coordinates	
15a	B	17(Lot 285) Turley Way	399733	6454519
15b	G	52, Langford Avenue	399902	6454339
16a	B	5 (Lot 619) Simons Court	399993	6454565
16b	B	2, Mudlark Close (Lot 300) Choseley Place	399989	6454013
17	B	29, Langford Avenue	399621	6454466

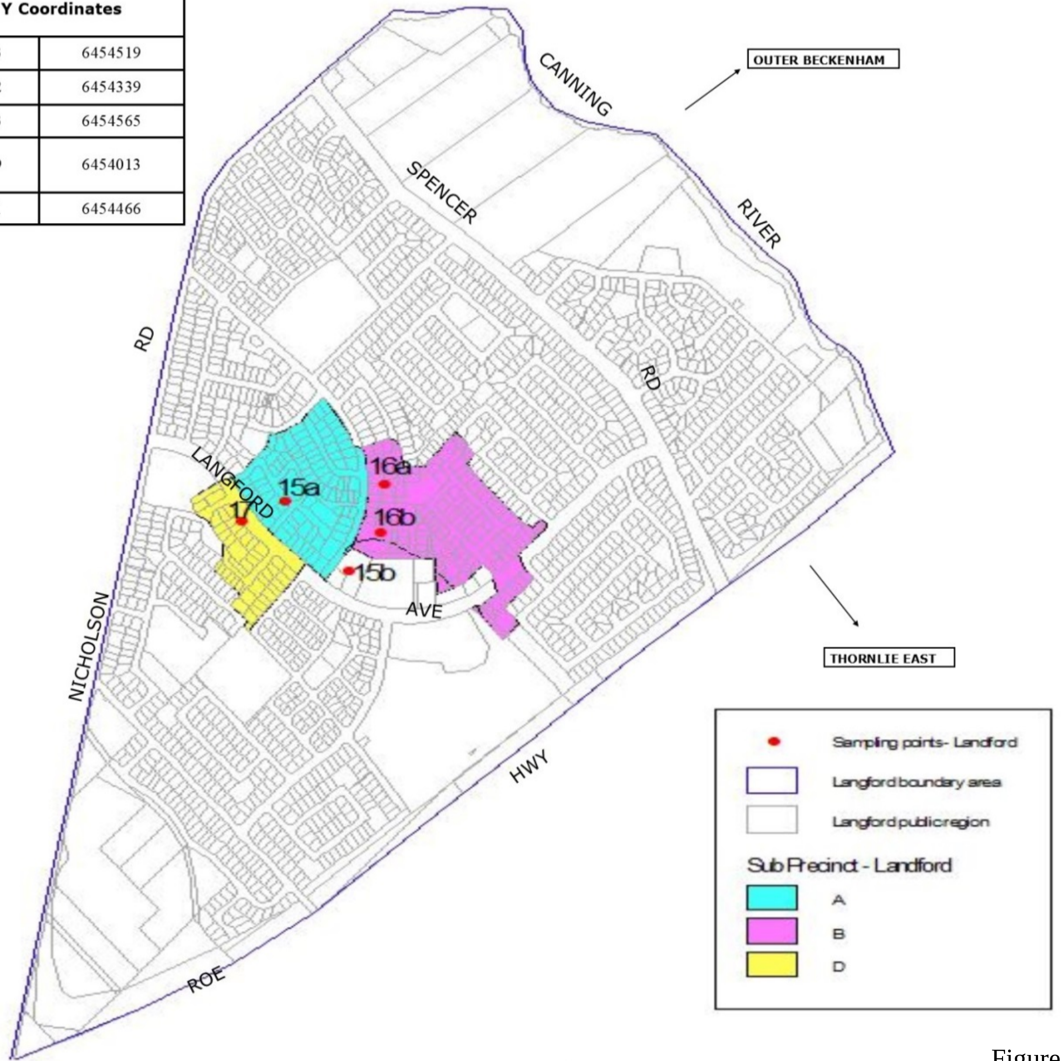
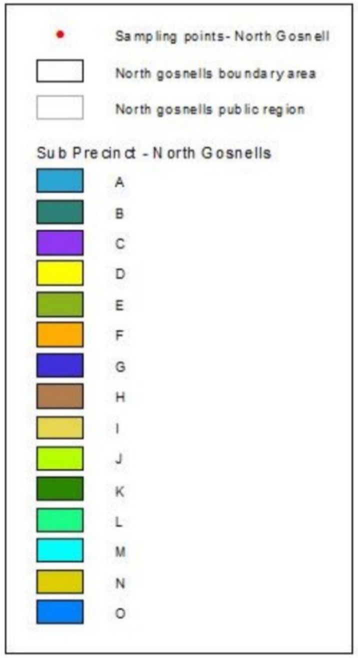
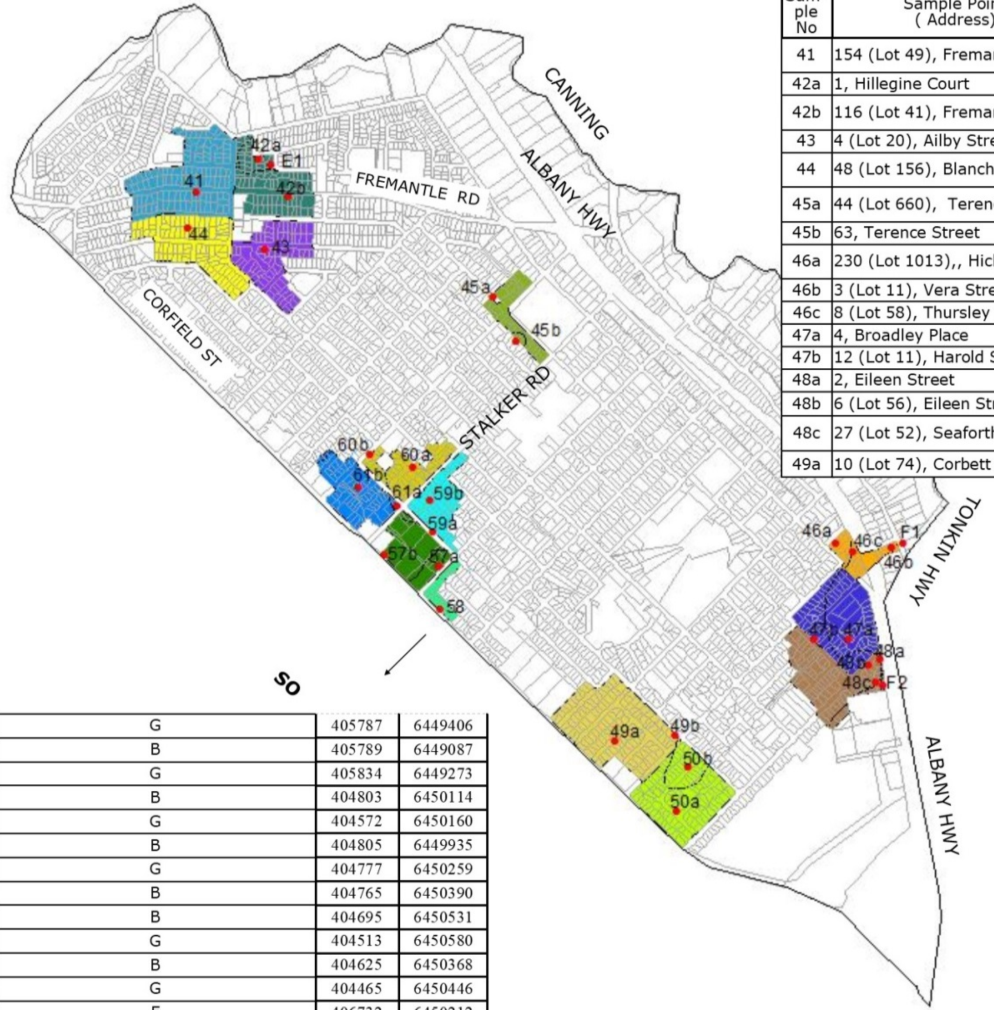


Figure A-4

Stormwater Management project Sampling points	LOCAL HOUSING STRATEGY PLAN **Landford Housing Precinct**



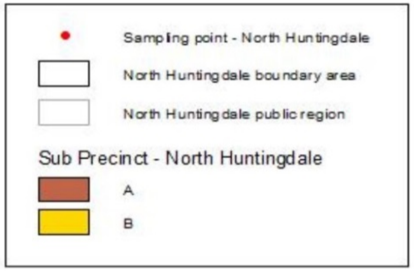


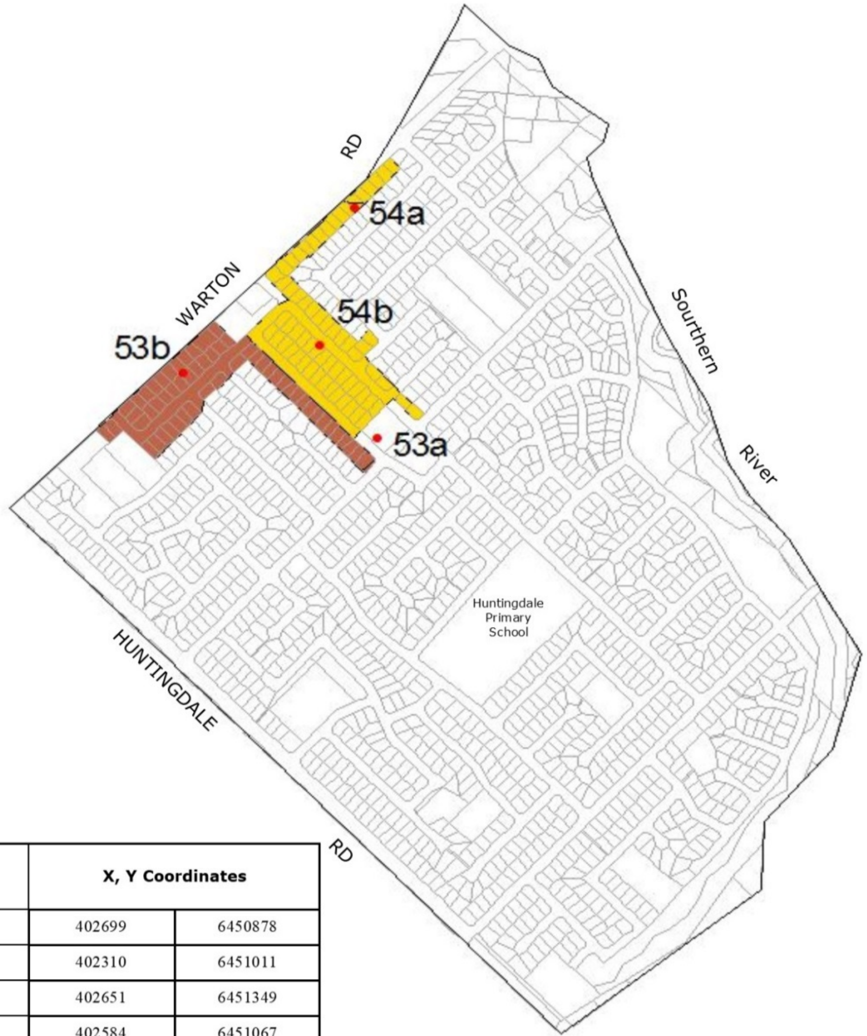
Sample No	Sample Point (Address)	Ref. Soil Type	X, Y Coordinates	
41	154 (Lot 49), Fremantle Road	B	403791	6451678
42a	1, Hillegine Court	E	404049	6451817
42b	116 (Lot 41), Fremantle Road	B	404175	6451663
43	4 (Lot 20), Ailby Street	B	404081	6451437
44	48 (Lot 156), Blanche Street	B	403753	6451531
45a	44 (Lot 660), Terence Street	B	405033	6451245
45b	63, Terence Street	G	405128	6451055
46a	230 (Lot 1013),, Hicks Street	B	406455	6450213
46b	3 (Lot 11), Vera Street	F	406689	6450191
46c	8 (Lot 58), Thursley Way	D	406526	6450171
47a	4, Broadley Place	D	406506	6449810
47b	12 (Lot 11), Harold Street	B	406364	6449812
48a	2, Eileen Street	D	406635	6449723
48b	6 (Lot 56), Eileen Street	B	406595	6449697
48c	27 (Lot 52), Seaforth Avenue	F	406623	6449629
49a	10 (Lot 74), Corbett street	B	405537	6449384
49b	85 (Lot 24), James Street	G	405787	6449406
50a	8 (Lot 7), Bexley Street	B	405789	6449087
50b	5, Ecton Street	G	405834	6449273
57a	135 (Lot 1) Dorothy Street	B	404803	6450114
57b	170 (Lot 1101), Corfield Street	G	404572	6450160
58	194 (Lot 11), Corfield Street	B	404805	6449935
59a	40 (Lot 16), Digby Street	G	404777	6450259
59b	5, Belyea Street	B	404765	6450390
60a	15 (Lot 16), Trent Street	B	404695	6450531
60b	106 (Lot 40), Walter street	G	404513	6450580
61a	19, Digby Street	B	404625	6450368
61b	7 (Lot 61), Mackay Cresent	G	404465	6450446
F1	120, Astley Street	F	406732	6450212
F2	29, Seaforth Avenue	F	406649	6449621
E1	3, Mimy Court	E	404104	6451798

Figure A-5

Stormwater Management project
Sampling points

LOCAL HOUSING STRATEGY PLAN
North Gosnells Housing Precinct



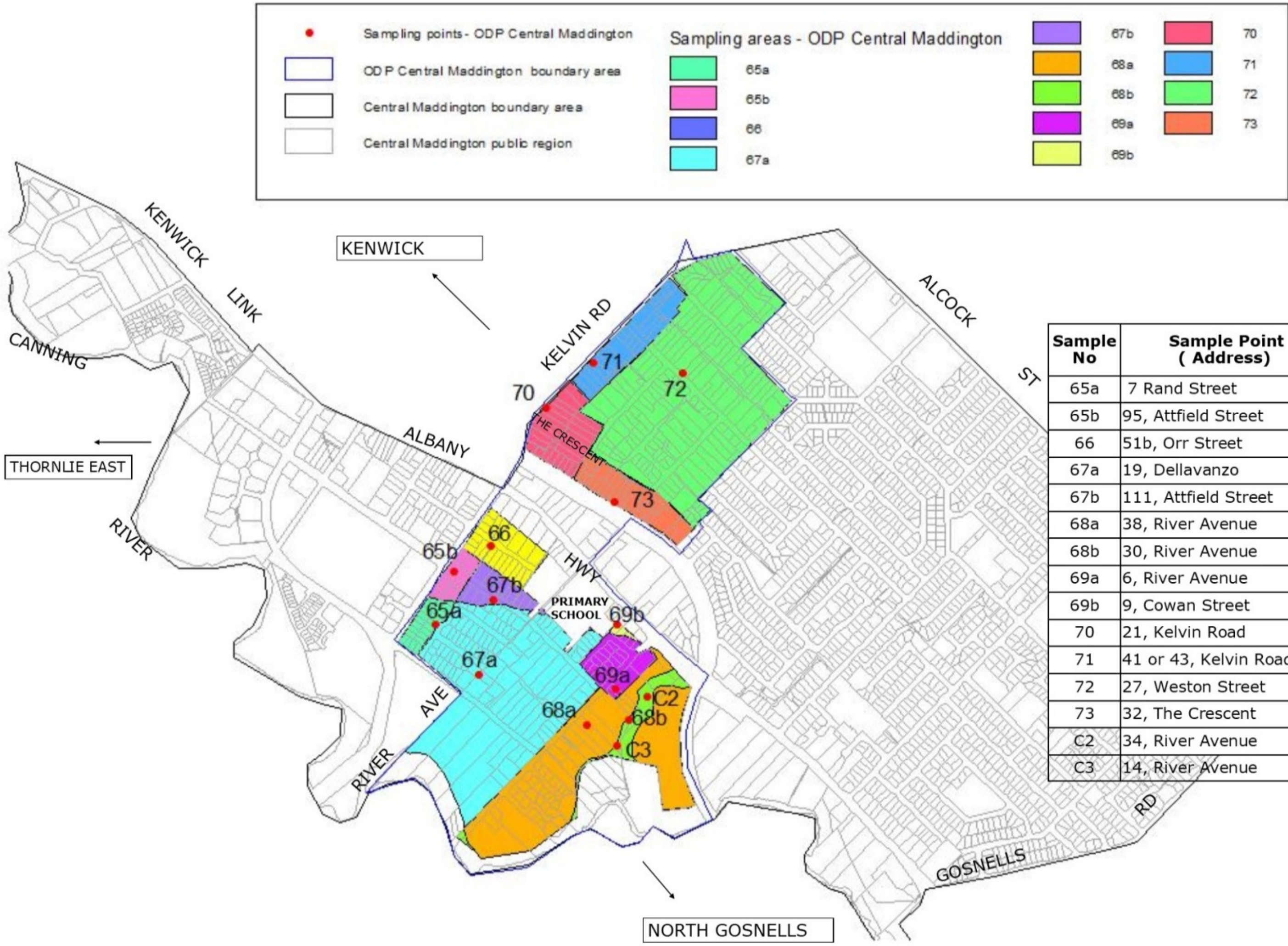


Sample No	Sample Point (Address)	Soil Type	X, Y Coordinates	
53a	Nethercott Street	G	402699	6450878
53b	21(Lot 31), Mildenhall Street	B	402310	6451011
54a	44 (Lot 8), Warton Road	G	402651	6451349
54b	17 (Lot 10), Matilda Street	B	402584	6451067

Figure A-6

Stormwater Management project
Sampling points

LOCAL HOUSING STRATEGY PLAN
North Huntingdale Housing Precinct



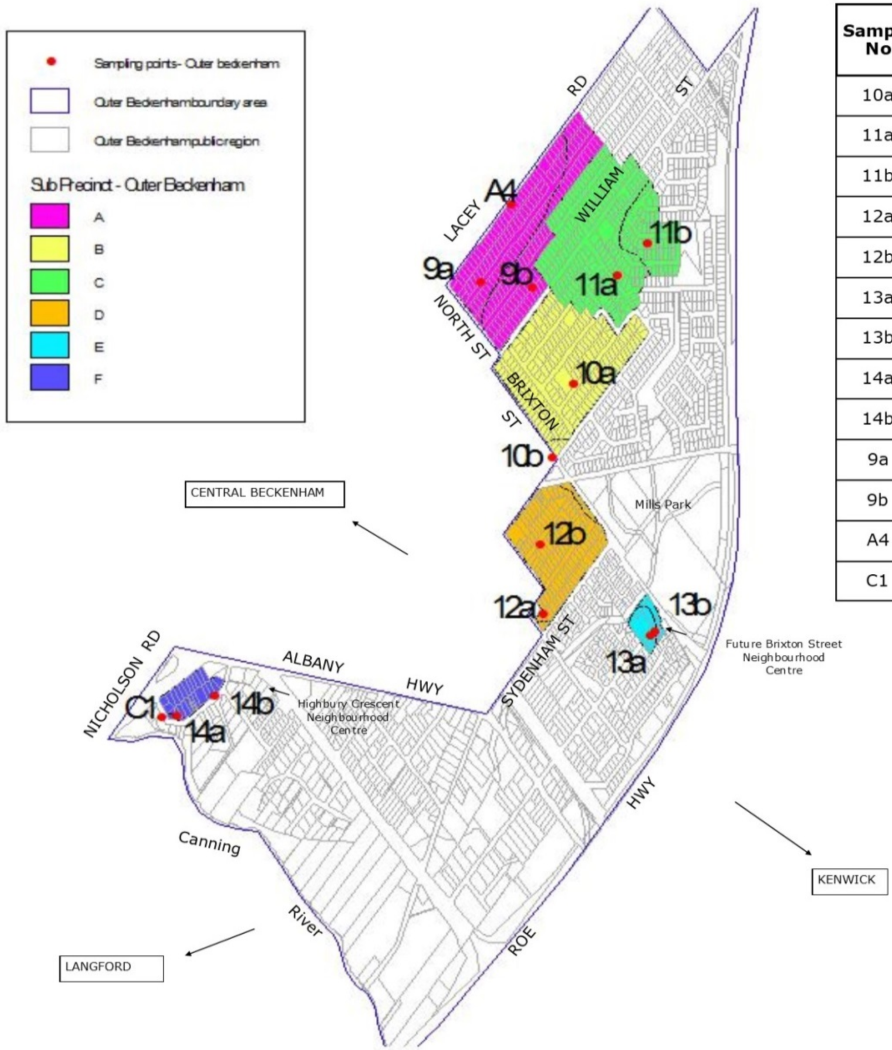
Sample No	Sample Point (Address)	Ref. Soil Type	X, Y Coordinates	
65a	7 Rand Street	E	403791	6451678
65b	95, Attfield Street	D	404049	6451817
66	51b, Orr Street	D	404175	6451663
67a	19, Dellavanzo	E	404081	6451437
67b	111, Attfield Street	D	403753	6451531
68a	38, River Avenue	E	405033	6451245
68b	30, River Avenue	C	405128	6451055
69a	6, River Avenue	E	406455	6450213
69b	9, Cowan Street	D	406689	6450191
70	21, Kelvin Road	D	406526	6450171
71	41 or 43, Kelvin Road	D	406506	6449810
72	27, Weston Street	D	406364	6449812
73	32, The Crescent	D	406635	6449723
C2	34, River Avenue	C	406595	6449697
C3	14, River Avenue	C	406623	6449629

Figure A-7

Stormwater Management project
Sampling points

OUTLINE DEVELOPMENT PLAN

Central Maddington Housing Precinct



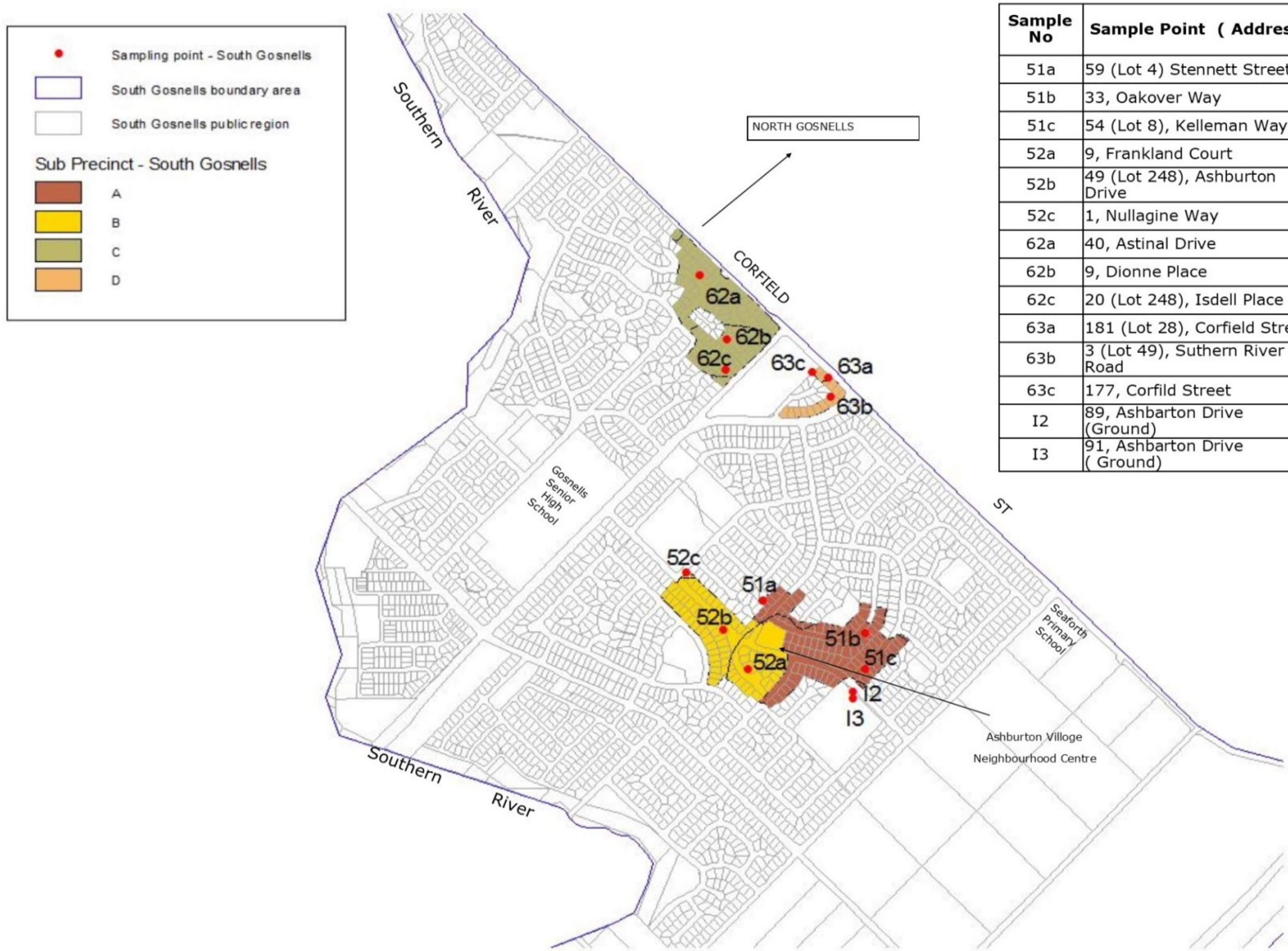
Sample No	Sample Point (Address)	Ref. Soil Type	X, Y Coordinates	
10a	16, (Lot 150) Faversham Street	G	402160	6457016
11a	20 (Lot 445), Tooting Street	G	402361	6457393
11b	13(Lot 158), Lunar Way	H	402499	6457501
12a	74, Streatham Street	H	402013	6456225
12b	6, Lowth Road	G	402004	6456461
13a	131(Lot 51), Ladywell Street	G	402514	6456150
13b	133(Lot 52), Ladywell Street	H	402534	6456165
14a	27 (Lot 29), Highbury Crescent	C	400326	6455871
14b	9 or 7, Highbury Crescent	G	400504	6455939
9a	11 (Lot 105), Celebration Street	A	401729	6457374
9b	26 (Lot 233), Jubilee Street	G	401967	6457353
A4	88, Lacey Street	A	401869	6457637
C1	40, Highbury Cresent	C	400260	6455868

Stormwater Management project
Sampling points

LOCAL HOUSING STRATEGY

Figure A-8

Outer Beckenham Housing Precinct



Sample No	Sample Point (Address)	Ref. Soil Type	X, Y Coordinates	
51a	59 (Lot 4) Stennett Street	G	404415	6449326
51b	33, Oakover Way	B	404741	6449223
51c	54 (Lot 8), Kelleman Way	I	404741	6449104
52a	9, Frankland Court	B	404367	6449104
52b	49 (Lot 248), Ashburton Drive	G	404292	6449235
52c	1, Nullagine Way	D	404174	6449417
62a	40, Astinal Drive	G	404215	6450372
62b	9, Dionne Place	D	404301	6450164
62c	20 (Lot 248), Isdell Place	B	404298	6450066
63a	181 (Lot 28), Corfield Street	G	404627	6450045
63b	3 (Lot 49), Suthern River Road	B	404633	6449980
63c	177, Corfild Street	D	404577	6450059
I2	89, Ashbarton Drive (Ground)	I	404702	6449033
I3	91, Ashbarton Drive (Ground)	I	404705	6449012

Stormwater Management project

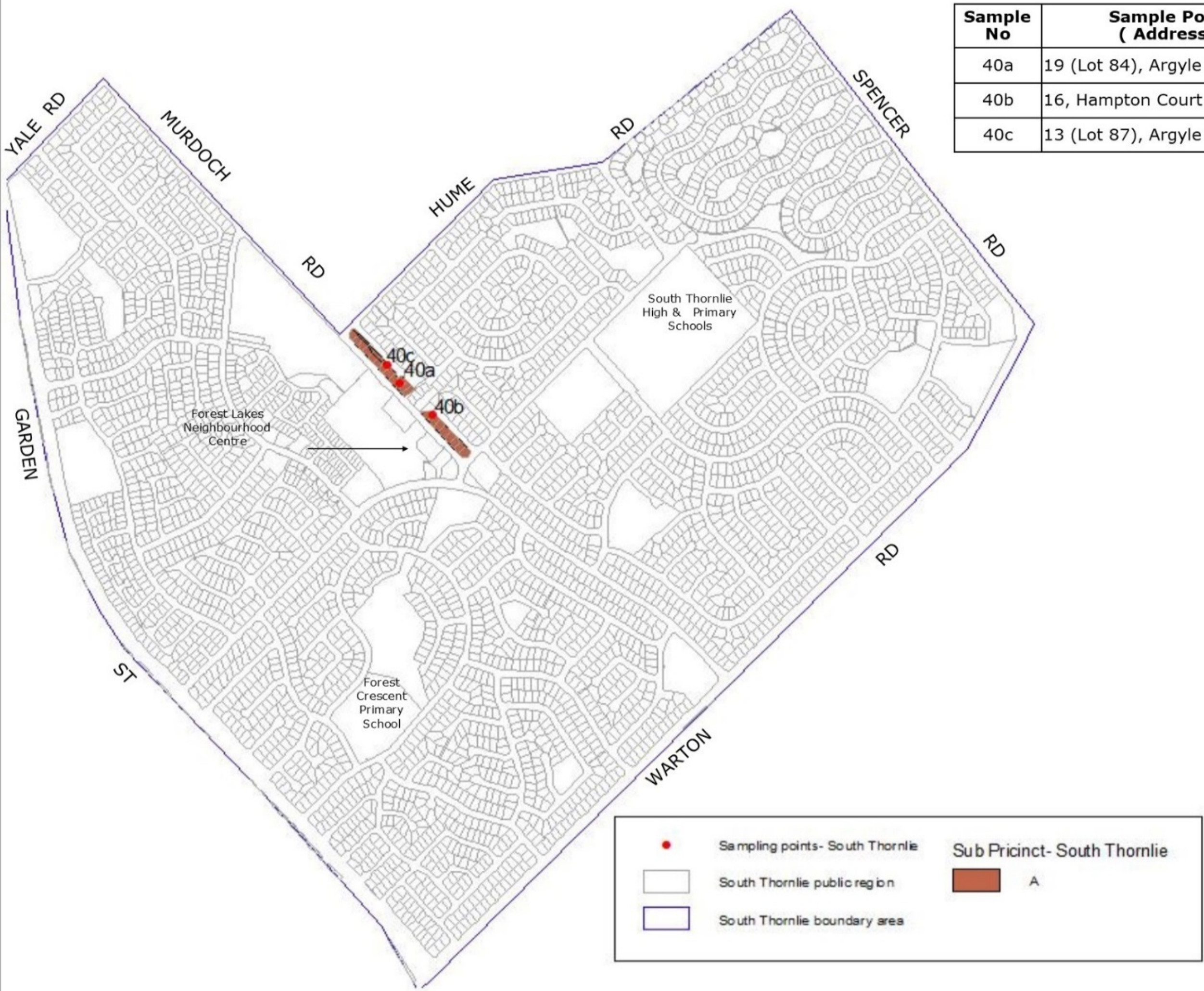
Sampling points

LOCAL HOUSING STRATEGY

South Gosnells Housing Precinct

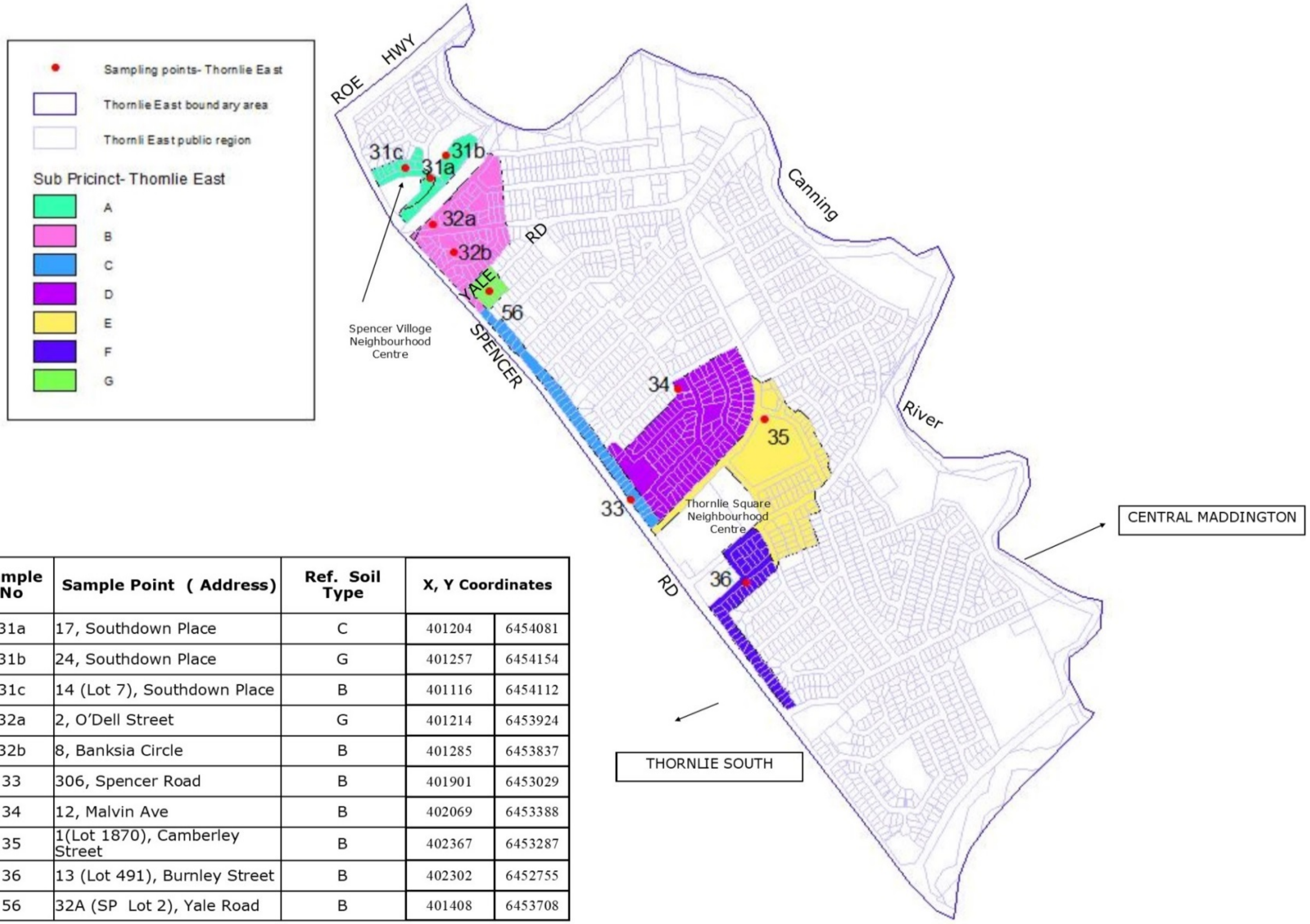
Figure A-9

Sample No	Sample Point (Address)	Ref. Soil Type	X, Y Coordinates	
40a	19 (Lot 84), Argyle Court	G	404415	6449326
40b	16, Hampton Court	G	404741	6449223
40c	13 (Lot 87), Argyle Court	B	404741	6449104



Stormwater Management project
Sampling points

LOCAL HOUSING STRATEGY Figure A-10
South Thornlie Housing Precinct



Sample No	Sample Point (Address)	Ref. Soil Type	X, Y Coordinates	
31a	17, Southdown Place	C	401204	6454081
31b	24, Southdown Place	G	401257	6454154
31c	14 (Lot 7), Southdown Place	B	401116	6454112
32a	2, O'Dell Street	G	401214	6453924
32b	8, Banksia Circle	B	401285	6453837
33	306, Spencer Road	B	401901	6453029
34	12, Malvin Ave	B	402069	6453388
35	1(Lot 1870), Camberley Street	B	402367	6453287
36	13 (Lot 491), Burnley Street	B	402302	6452755
56	32A (SP Lot 2), Yale Road	B	401408	6453708

Stormwater Management project
Sampling points

LOCAL HOUSING STRATEGY

Thornlie East Housing Precinct

Figure A-11

Sample No	Sample Point(Address)	Ref. Soil Type	X, Y Coordinates	
37	11 (Lot 212),Debenham Street	B	401111	6453602
38	54, Yale Road	B	401200	6453510
39	305 (Lot 151) , Spencer Road	B	401833	6453032
64	7 (Lot 160), Kidman Court	B	400880	6453553

Figure A-12

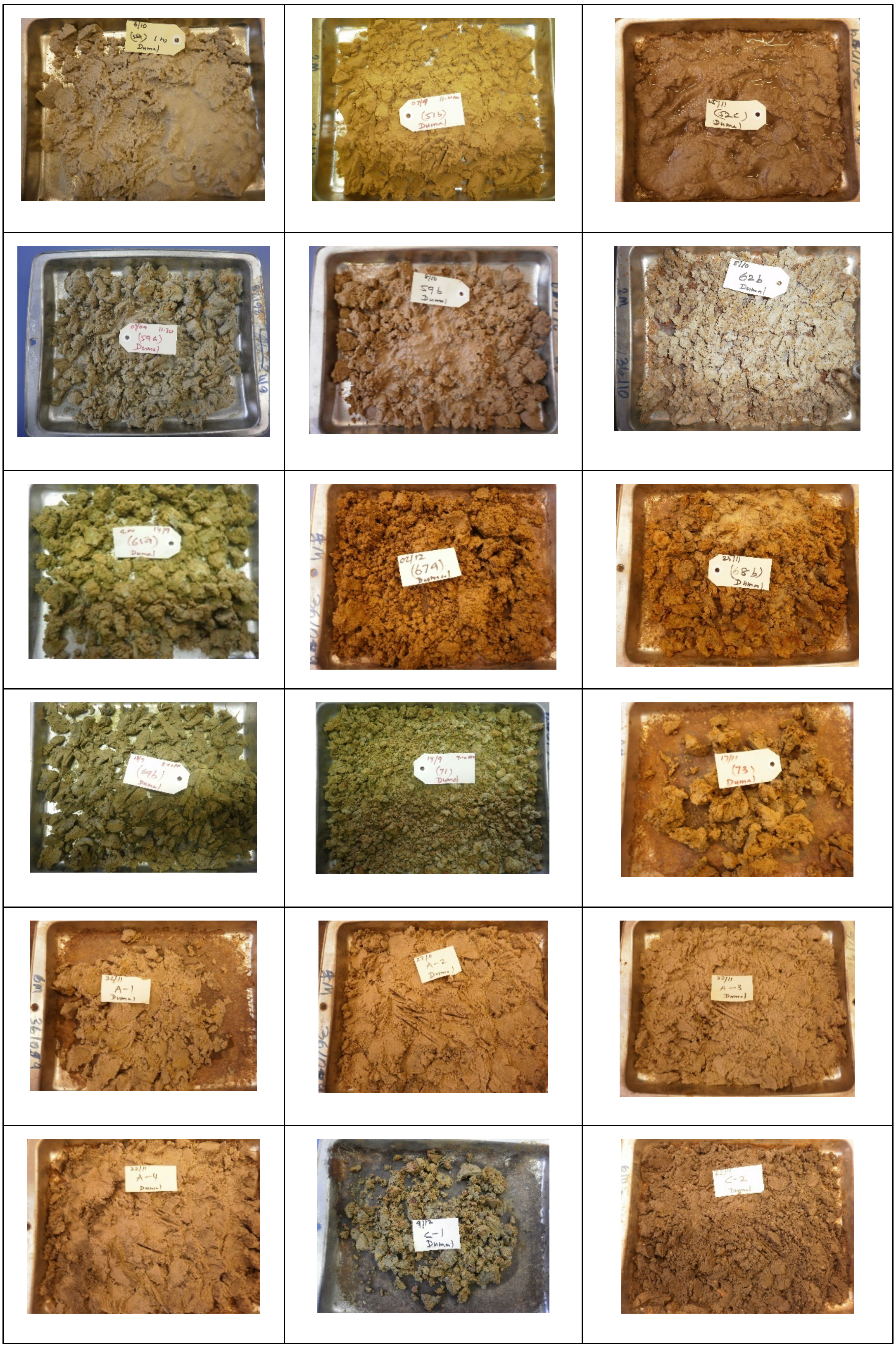
Stormwater Management project
Sampling points

LOCAL HOUSING STRATEG

Thornlie West Housing Precinct

APPENDIX B – PHOTOS OF COLLECTED SOIL SAMPLES



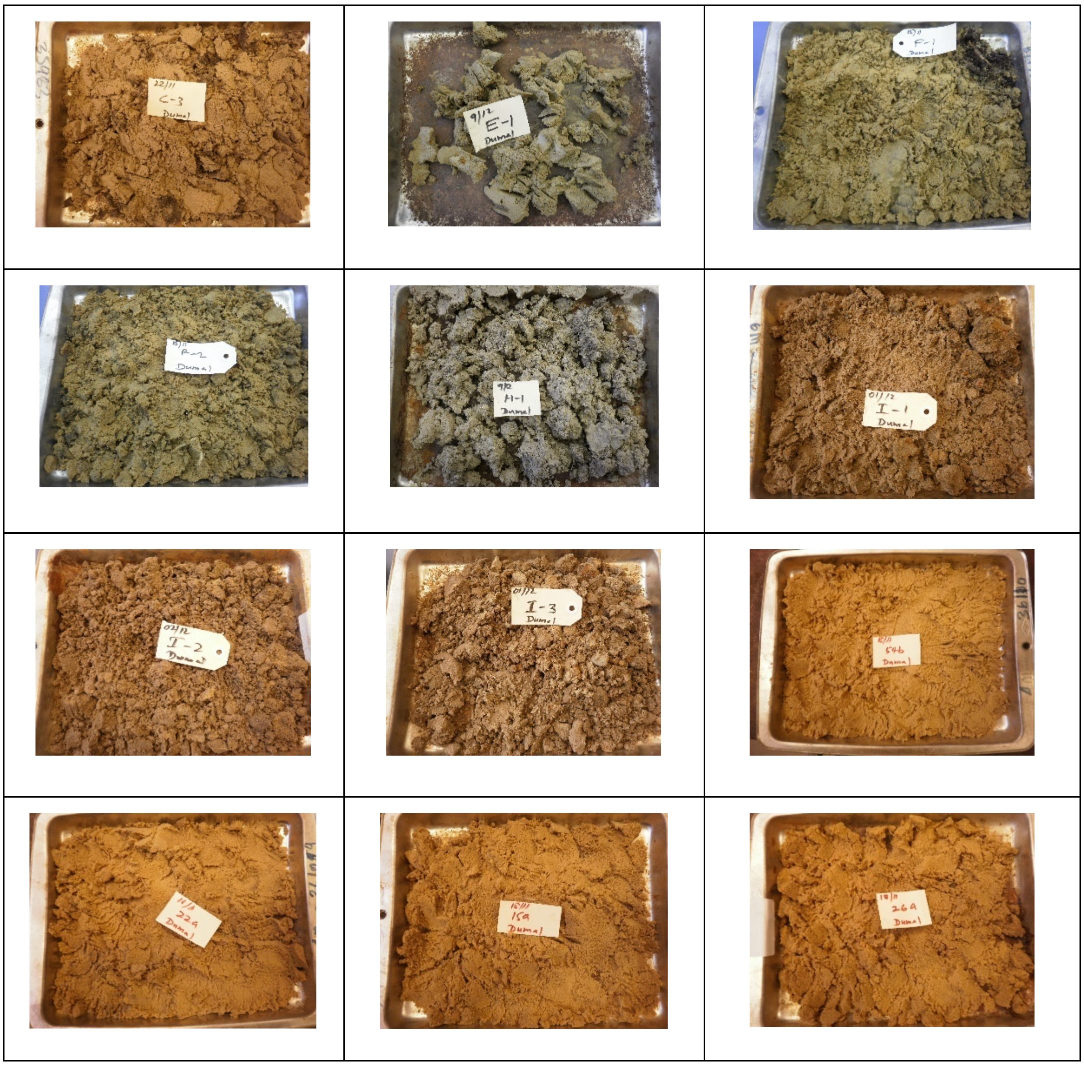


Figure B-1 – Collected Soil Samples