Maximize the Benefits of Water Sensitive Urban Designs in a Local Government Area - Western Australia

D. Kannangara, P. Sarukkalige, and M. Botte

Abstract—**Until recently, stormwater management strategies have failed to adequately consider the criticality of spatially varying soil permeability values and their implications on drainage designs. This case study was carried out in new development areas, focusing on identification of soil properties and development of a typology of suitable stormwater management strategies with respect to applicable infiltration capacities. The Guelph Permeameter was used to investigate the in-situ saturated hydraulic conductivities. Test results were categorized into four main permeability groups, very rapid (> 1.56 m/day), rapid (0.48<1.56 m/day), moderate (0.12<0.48 m/day) and slow (<0.12 m/day), based on the theoretical requirements of stormwater management techniques. Finally, with the help of the existing soil maps, the point represent hydraulic conductivity data were been generalized logically in order to develop the hydraulic conductivity maps representing the areal average as an electronic shape files by using a GIS Arc view mapping software. The future development areas under Central Maddington, Kenwick, Central and Outer Beckenham have been identified as low permeable areas which is not suitable for infiltration based stormwater management strategies whereas the Landford, Thornlie, North Huntingdale and Gosnells has been identified as high permeable areas which is highly recommended for infiltration based stormwater management strategies.**

Index Terms—**Stormwater, Infiltration, Permeability**

I. Introduction

Due to urbanization, the living units have changed from individuals to small gathering to the present cities, towns, and suburbs. As these cities and towns have emerged, inherent characteristics of the original land and surrounding areas have been altered. In many cases, what was once forest and open spaces are now houses and manmade lawns, driveways and roadways, and commercial and industrial areas. This transition in land use has given a number of changes directly to the local environment and has had significant consequence to 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 of established soil structures. This has the effect of changing the local water balance by increasing storm flow rates and decreasing base flow components. As a solution for this, the traditional storm water management schemes have been introduced which helps to remove runoff from the site as soon as possible to avoid flooding during major rains [1]. This system itself has a negative impact on local water balance by effecting to the groundwater resources, which tends to lower the groundwater table gradually. In addition to urban flooding, storm water runoff, leads in delivering of pollutants, channel erosion [2], reducing base flow [3], degraded receiving water quality [4] and damage the aquatic ecosystem [5].

Presently there is a huge demand in infiltration based approaches to control the storm events by providing infiltration based storm water management devices [6]-[7]. Traditionally, storm water runoff from several adjacent lots is captured and stored temporarily in basins or sumps from which water infiltrates into the surrounding soil [8]. Due to increase in housing density in urban cities, the authorities require storm water runoff from developing lots to be retained /detained within property. This valuable concept reduces storm runoff to storm water systems, which are already operating beyond their potential capacity in most of the 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. There are many factors affect on infiltration process, it is very important to study broadly about infiltration systems for maintaining a sustainable, environmental friendly storm water management system in future.

The main factors effecting to the performance of the infiltration based storm water management systems are permeability of different soil layers and depth to the ground water 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 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 or retention of storm water. This would support land development with guidance on the implementation of drainage strategies based on basic underlying parameters. This study aims to develop data inventory of soil permeability of selected land development areas. Study mainly follows field tests to estimate the soil permeability of different soil types and compare them with available literature.

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II. Study Area

A. Location of the Study Area – City of Gosnells

The City of Gosnells is a growing residential area, located in Perth's south-eastern suburbs, about 17 kilometers from the Perth CBD.

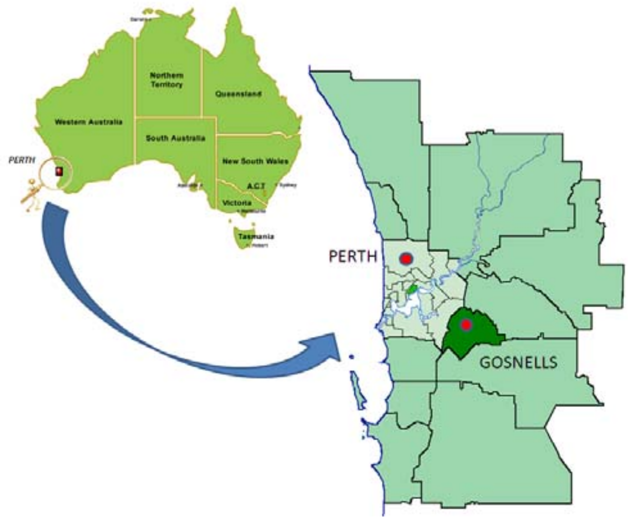

Fig.1. Location of the study area

The City encompasses substantial rural areas in the east and south, and some commercial and industrial areas, particularly along the Albany Highway which one of the major roads runs across the city of Gosnells to down south. The majority of the populations live in suburbs west of the Albany Highway. Significant development did not occur until the post-war years. The population grew from 7,400 in 1954 to about 11,000 in 1966, and then to 21,000 in 1970 (Table I). From the 1950s to the 1980s rapid growth took place along the Albany Highway, the Canning River and the Southern River (the suburbs of Beckenham, Gosnells, Kenwick, Langford, Maddington and Thornlie). The suburb of Huntingdale was developed from the 1970s (see fig. 2). 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 I: Population Growth

year	1911	1921	1933	1947	1954	1961	1971	1986	1996	2009
Population	737	1936	3016	4405	7366	7524	22040	60610	73421	104022

The City of Gosnells comprises significant diversity in terms of residential and economic role and function. With the progressive residential development of the City over many decades, the availability of land for development and the broad range of land uses, areas have developed different roles within the housing market. Older established suburbs, such as Maddington, Beckenham, Kenwick and Gosnells (Central), which are expected undergo a degree of redevelopment, are likely to attract a large number of persons 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, the 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 seeking new housing opportunities elsewhere. Development areas in Canning Vale and Southern River and, in the longer term, Martin (West) are likely to provide a broader range of housing choices for first home buyers through to upgrade markets. Finally, the predominantly rural area of Martin (East)-Orange attracts established and mature families. This variety of function and role of the small areas in Gosnells means that population outcomes differ significantly across the City.

III. Methodology and Data

A. Field Testing

The main intention of this study is to identify the suitable soil types based on their permeability capacities and provide guidelines to implement of onsite infiltration based best stormwater management practices on urban areas aiming to minimize the peak floods events. This research developed an inventory of basic geotechnical properties of several development areas using field tests. Tests were carried out at the local land development areas which have identified as areas under future development, to establish an inventory of infiltration rates, groundwater levels, and soil properties would aid to develop suitable drainage strategies. The Guelph Permeameter kit was used as an on-site investigation tool to investigate field saturated permeability of selected 146 locations at 1.0m depth. There are two methods called direct and indirect method to determine the field saturated permeability (Kfs) of the soil. The direct method uses the following equation to calculate saturated permeability.

$$K_{fs} = (0.0041)(X)(\overline{R_2}) - (0.0054)(X)(\overline{R_1}) \qquad (1)$$

where is field saturated permeability expressed in (cm/sec), is the steady state rate of fall of water in the reservoir when the first head 5 cm of water expressed in (cm/sec), is the steady state rate of fall of water in the reservoir when the first head 10 cm of water expressed in (cm/sec) and the is the reservoir constant corresponds to the cross sectional area expressed in cm2.

B. Secondary Data

The secondary data has been collected from relevant government organizations such as Department of Agricultural of Western Australia, Department of Water of Western Australia, Bureau of Meteorology, Water Corporation and City of Gosnells. The Department of Agriculture has published a handbook entitled "Soil Groups of Western Australia, a simple guide to the main soil of Western Australia", [9] which describes a soil (Schoknecht 2002). 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. Based on the above data, the correlations between soil textures and infiltration rates of different soil types have been found and then extended to provide general formulations for estimate of the infiltration capacity in broad areas. As the ground water table has direct relationship with the infiltration techniques, the variation of the ground water 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 ground water level.

IV. Results and Discussions

A. Soils Available Within the Land Development Areas

Within the selected 64 land development sites, mainly nine types of soil super groups were identified based on the Soil Groups of Western Australia (SGWA) (Schoknecht 2002). Each soil types were examined at the sampling points, tested physically in order to crosscheck the identified soil types. These soil super groups were named as A, B, C, and D, E, F, G, H and I for easy in referencing instead of their corresponding names. Each soil super-groups composition can be found in Table II, comprising of different soil types. The soil super-groups 200, 460, are named as Rocky or Stony Soils and sandy earth. These soil types are present in low percentages and they are included in the following table.

TABLE II: Soil Groups in Land Development Areas

Soil Type	Dominant Status	Dominant Soil Supergroups	Name	Composition of soil Super-groups (S)							
				S1	%	S2	%	S3	%	S4	%
A	Dominant	420	Shallow Sands	420	80	440	15	200	5		
B	Dominant	440	Deep Sands	440	100						
C	Dominant	100	Wet or waterlogged soil	100	70	460	30				
D	Low Dominant	100500S400S	Wet or waterlogged soil, loamy duplexes & sandy duplexes	100	30	500S	28	400S	27	400D	15
E	Co Dominant	400S500S	Sandy duplexes & Loamy duplexes	400S	30	500S	30	100	20	400D	20
F	Co Dominant	500S	Loamy duplexes	500S	55	400S	25	400D	20		
G	Co Dominant	100440	Wet or waterlogged soil & Deep sand	100	40	440	34	400S	16	500S	5
H	Sub Dominant	100	Wet or waterlogged soil	100	52	440	25	540	23		
I	Dominant	100	Wet or waterlogged soil	100	100						

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

B. Soil Permeability Classification

Implementation of a best stormwater management system is not just an engineering process, but also environmental, planning, landscape design, architectural, 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. Although the Soil infiltration is playing a major role in stormwater management and only the range of infiltration values would be allowed designers to achieve their objectives successfully. For example, infiltration measures cannot be used in very high permeable soils with the shallow ground water table. In such cases designers cannot achieve their water quality objective through infiltration and another stormwater quality management strategy needs to be considered before it reached to the receiving water body. On the other hand, the clayey soils which have very low permeability are not suitable for any types of infiltration based stormwater management options. Therefore the best available stormwater management options which have been explained in the stormwater management manual in Western

Australia were assessed clearly in order to identify the border range of permeability categories as given in Table III.

TABLE III: PERMEABILITY CATEGORIES

Color	Hydraulic Conductivity Range (m/day)	Category
	1.56 <	Very High
	0.48 < 1.56	High
	0.12 < 0.48	Moderate
	< 0.12	Low

C. Onsite Permeability Tests Results

Using the Guelph Permeameter kit, totally 146 onsite tests were conducted. The results show the soil permeability at 1.0m below the existing ground level. These observed permeability values were grouped into the four categories as described in Table III. Statistical distribution of the permeability of each soil type (See Table IV) is carefully analyzed to identify the percentage agreement of observed field tested permeability with the literature based data. Based on the number of field tests carried out, the permeability distribution is shown in Table IV.

TABLE IV: DISTRIBUTION OF FIELD TESTS IN DIFFERENT PERMEABILITY RANGES

Soil Type	Onsite Test					% of Agreement			
	VR	R	M	S	Total	VR	R	M	S
A	5			1	6	83.3			16.7
B	23	15	8	2	48	47.9	31.3	16.7	4.1
C			4	2	6			66.7	33.3
D	2		11	10	23	8.7		47.8	43.5
E			5	1	6			83.3	16.7
F			2	1	3			66.7	33.3
G	5	6	11	21	43	11.6	14.0	25.6	48.8
H			5	2	7			71.4	28.6
I			1	3	4			25.0	75.0
Total	35	21	47	43	146	24	14.4	32.2	29.4

Table IV shows that the soil type A and B shows 83.3% and 79.2% of high permeability values to represent shallow and deep sand which is approximately similar to the literature data. Although it was expected 100% to lie within the high level of permeability range of soil type B, 16.7% of medium and 4.1% of slow permeability values were recorded. However, the soil type A and B have very high infiltration capacities which is very important for implementing of infiltration based stormwater management strategies. The soil types C, E, F, H, and I have given moderate and slow permeability values. According to the SGWA (Schoknecht 2002), these soil types composite with wet or waterlogged soil (100), sandy duplexes (400) and loamy duplexes (500) in different percentages. The results of the soil type C clearly demonstrate a close relationship to the soils super-groups 100 and 460 showing 66.7% of moderate permeable and 33.3% slow permeable values respectively. The literature indicates that the soil types D and G should consist of combinations of many soil super-groups distributed in the same soil properties (See Table II). As shown in table II, these two soil types have represented combinations of three or more permeability categories giving evidences to identify the relationship among different soil properties through the tested locations.

The overall results in Table IV demonstrate that onsite test results have given an evidence to develop relationship with different soil types and the identified range of permeability categories. These relationships were expanded to generalize the local soil permeability of different land development sites in the study area. Further, this study can extended to identify the permeability values of separate soil super-groups which will be helped to find an average permeability values for any type of soil with a different soil super-groups compositions. These results will be able to provide a more generalized way to calculate the soil permeability by using their percentage of soil super-groups availability. With the help of the existing soil map, the point represent hydraulic conductivity data were been generalized logically and developed an area represent shape file maps(Fig 2) by using a GIS Arc view mapping software such that the target audience including land owners, engineering consultants, land developers, architects, building and construction industry professionals, strategic urban planners, urban designers, landscape architects and development assessment staff involved in the formulation and evaluation can easily access relevant data.

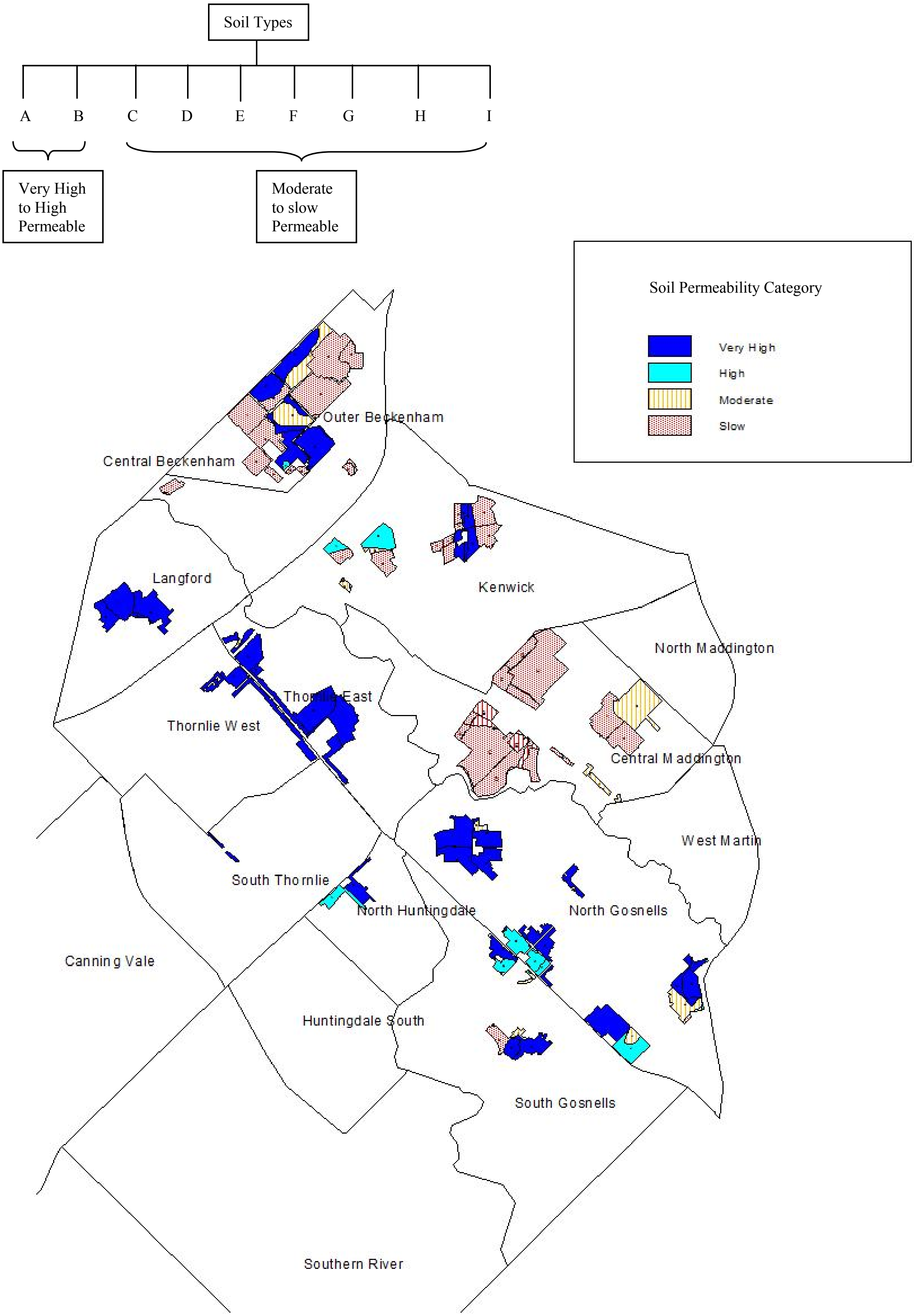

Fig. 2. Hydraulic Conductivity Maps

V. Conclusion

The soil permeability plays an important role in selecting infiltration based stormwater management strategies. Due to the lack of studies on soil properties, design of stormwater management control structures in land development area is not in proper order. This study developed a data inventory of soil permeability of selected land development areas in Western Australia. Study mainly follows field test to estimate 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 show that the soil type A and B shows 83.3% and 79.2% of high permeability values to represent shallow and deep sand which is approximately similar to the literature data. Although it was expected 100% to lie within the high level of permeability range of soil type B, 16.7% of medium and 4.1% of slow permeability values were recorded. Results further show that the soil types C, E, F, H, and I have given moderate and slow permeability values. The results of the soil type C clearly demonstrate a close relationship to the soils super-groups 100 and 460 showing 66.7% of moderate permeable and 33.3% slow permeable values respectively. Tests in soil types D and G also agree well with literature based soil properties. The overall results demonstrate that onsite test results have good agreement with literature based soil data.

The future development areas under Central Maddington, Kenwick, Central and Outer Beckenham have been identified as low permeable areas which is not suitable for infiltration based stormwater management strategies whereas the Landford, Thornlie, North Huntingdale and Gosnells has been identified as high permeable areas which is highly recommended for infiltration based stormwater management strategies.

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References

[1] C. P. Pedini, M. Asce, F. Limbrunner, R. M. Vogel, "Optimal location of infiltration-based best management practices for storm water management", *Journal of water resources planning and management*, 2005, 441-448.

[2] D. B. Booth, D. Hartley and R. Jackson, "Forest Cover, Impervious-Surface Area and the Mitigation of Storm water Impacts", *Journal of the American Water Resources Association*. 2002, 38(3):835-846.

[3] B. K. Ferguson, P. W. Suckling, "Changing rainfall-runoff relationships in the urbanizing peach tree creek Watershed, Atlanta, Georgia", *Water Resources Bulletin*, 1990, 26(2):313-322.

[4] M. V. Carle, P. N. Halpin, C. A. Snow, "Patterns of Watershed Urbanization and Impacts on Water Quality", *Journal of the American Water Resources Association*. 2005,41(3):693-708.

[5] L. Wang, J. Lyons, P. Kanehl, R. T. Bannerman, "Impacts of urbanization on stream habitat and fish across multiple scales", *Environmental Management*. 2001, 29(2):255-266.

[6] H. J. K. Dodds, A. A. Bradley, K. W. Potter, "Evaluation of hydraulic benefits of infiltration based urban storm water management", *Journal American water resources associates*. 2003, 39(1), 205-215.

[7] K. W. Potter, "Managing storm water at the sources", *Transactions of the Wisconsin academy of sciences art and letters*, 2004, 90, 67-73.

[8] R. Jennifer, T. Wevill, T. Fletcher, A. Deletic, "Variation among plant species in pollutant removal from storm water in biofiltration systems", *Water research*, 2008, 42, 4-5, 893-902.

[9] N. Schoknecht, Soil Groups of Western Australia, Edition 3 a simple guide to the main soil of Western Australia, *The Department of Agriculture Western Australia*, 2002.

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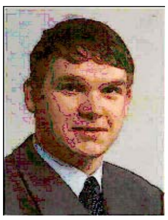

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