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Geotechnical Assessment of Soil Permeability in Land Development Areas

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Abstract. Infiltration is identified as one of the best operational and sustainable methods to handle urban stormwater. Until recently, in stormwater management designs and selection of best stormwater management strategies, permeability value of different soils were not been considered as major factor. Due to the increasing housing density local land development authorities requires storm water runoff from developing lots to be retained / detained within the property. Due to lack of information on local soil properties, specifically permeability rates within the soil predominant in land development areas, it is difficult to assess storm water retention/ detention requirement. This case study was carried out within the new development areas in Gosnells in Western Australia mainly focusing on identification of different soil types with respect to their infiltration capacities in selection of best stormwater management strategies. The Guelph Permeameter have been used to investigate the saturated permeability of different soil types. Based on the above tests, the results have been categorized in to four main types of 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). Finally, with the help of the existing soil map, the point represent permeability data were been generalized logically. These results have been used to develop permeability maps representing the areal average. The soil types and their observed permeability values compared with the literature; soil classification data of Department Agriculture. The comparison shows that field test data has a higher agreement with literature based soil classification. These field tests will be extended to identify the best stormwater management practices for the selected land development areas. The result will be useful for land developers as well as authorities, decision makers and policy makers to come up with sustainable land development strategies.

Keywords: Permeability, soil groups, infiltration, Storm water

1. Introduction

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 (Pedini et al. 2005). 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 (Booth et al., 2002), reducing base flow (Ferguson and Suckling, 1990), degraded receiving water quality (Carle et al., 2005) and damage the aquatic ecosystem (Wang et al., 2001).

Presently there is a huge demand in infiltration based approaches to control the storm events by providing infiltration based storm water management devices (Dodds et al. 2003; Potter 2004). 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 (Jennifer et al, 2008). Due to increase in housing density in

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urban cities, the authorities requires 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.

2. Methodology and Data

2.1. 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 K_{fs} is field saturated permeability expressed in cm/sec, $\overline{R_1}$ is the steady state rate of fall of water in the reservoir when the first head 5 cm of water expressed in cm/sec , $\overline{R_2}$ 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 X is teh reservoir constant corresponds to the cross sectional area expressed in cm^2

2.2. 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”, 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.

3. Results and Discussions

3.1. 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 supergroup composition can be found in Table 01, comprising of different soil types. The soil supergroups 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 01- Soil Groups in land development areas

Soil Type	Dominant Status	Dominant Soil Supergroup	Name	Composition of soil Supergroups (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

3.2. 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 02.

Table 02- Permeability categories

Permeability Range (m/day)	Category
1.56 <	Very Rapid permeability (VR)
0.48 < 1.56	Rapid permeability (R)

0.12 < 0.48	Moderate permeability (M)
< 0.12	Slow permeability (S)

3.3. 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 2. Statistical distribution of the permeability of each soil type (as described in Table 1) is carefully analysed 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 3.

Table 03 – 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 3 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 supergroups 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 supergroups distributed in the same soil properties (Table 1). As shown in table 3, 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 3 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 generalise 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 supergroups which will be helped to find an average permeability values for any type of soil with a 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 availability.

4. Conclusions

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 supergroups 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.

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