URBAN STORMWATER MANAGEMENT: CHALLENGES AND POTENTIAL SOLUTIONS

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Abstract

Management of stormwater brings considerable economic, social and environmental benefits to the community in various ways. Controlling stormwater quantity is primarily important to prevent urban flooding and water stagnation. Also improving stormwater quality is timely important issue for sustainable management of urban stormwater. Urban development accompanied by increasing in impervious surfaces such as roofs, roads and paving, compaction of soil and modifications to vegetation, which in turn affects the catchment hydrology and water quality. Stormwater quality is an issue in Western Australia because the states stormwater typically flows into the state's rivers and ocean or infiltrates back into the groundwater system which is used for drinking in the state. Unplanned land development also created serious issues in high density residential areas leading to urban flooding. Onsite stormwater management has been identified as one of the best approach to manage the stormwater in this area. This paper demonstrates three case studies from Western Australia to highlight the challenges and potential solutions for stormwater management in terms of stormwater source control, flood vulnerability and stormwater quality assessments.

Keywords: Stormwater management, urbanization, water quality, infiltration, flood.

1. Introduction

Urban development accompanied by increasing in impervious surfaces such as roofs, roads and paving, construction of manmade drainage systems, compaction of soil and modifications to vegetation. Urbanization causes a lot of change to the characteristics of the catchment, which in turn affects the natural hydrological cycle of the area. Numerous studies have been conducted in the recent past to analyse the impact of urbanization on urban hydrology. However, still there is a lack of information on the environmental effects of urban land use change on urban hydrology. Even though studies on land use change and catchment hydrology based on rural watersheds are numerous, studies based on urban catchments are still lacking (Siriwardena et al 2006).

Stormwater management mainly concerns two main categories; stormwater quality and stormwater quantity. Both processes are equally important in terms of sustainable urban stormwater management. Traditionally, the emphasis of stormwater management has been primarily focused on capacity, and the ability to cater for the ever-expanding urban limits. In recent years, attention has moved towards sustainability and the effects of unplanned stormwater management on the environment. In the recent years, in an attempt to accept this new trend, a variety of environmentally friendly systems has been designed. Water sensitive urban design (WSUD) is one of the philosophical approaches to urban planning and design that aims to minimize the hydrological impact of urban development on the surrounding environment. WSUD philosophy is based on some key principles such as protect natural systems, integrate storm water treatment into the landscape, protect water quality, and reduce runoff and peak flows.

The quality of stormwater is becoming more of an issue around the world as general water quality awareness increases. Stormwater runoff picks up natural and human-made contaminants that accumulated on surfaces during the dry days and transports them to the receiving waters bodies such as rivers, lakes and ocean. The forms and concentrations of contaminants from runoff are closely related to various types of land use because human activity is different according to land use (Ha and Stenstrom, 2003, Goonetileke et al, 2005). Stormwater quality is an issue in Western Australia because the states stormwater typically flows into the state's rivers and ocean or infiltrates back into the groundwater system which is used for drinking in the state. Currently in Western Australia, there are no stormwater quality management procedures in place. Regional reports show that state stormwater may contain different substances including heavy metals, nutrients, petroleum hydrocarbons, suspended solids and microbiological organisms, all depending on the land use of that area. The problem of stormwater pollution is becoming worse because of population growth, which results in increased impermeable surfaces.

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. These impervious surfaces are characterized by reduced infiltration and accelerated runoff which has the potential to result in localised flooding. In an undeveloped catchment, the characteristics of the area allow high levels of infiltration and slow rate of drainage of water during a storm event. This is not the case in an urban setting as there is an increase in the impervious area. This increase in impervious area has a number of negative effects of the hydrological cycle including the reduced rate of infiltration and drainage time. These effects cause a lot of problems to hydrology of the urban area, such as the increased volumes of runoff and lowering of the groundwater table. Therefore traditionally the requirement of urban storm water management of such areas was capturing runoff collected in the catchment and transporting it as quickly as possible downstream to avoid flooding.

The absence of proper stormwater management causes to disasters such as urban flood inundation. Stormwater management has taken billions of dollars to plan and implement in Australia (Bureau of Transport and Regional Economics, 2002). Some cost-effective approaches have been introduced in the last few decades to get the maximum results from a minimum price. Case studies are often introduced in order to produce cost-effective approaches on decisions regarding stormwater. Cost-effectiveness is often accompanied with sustainability. Sustainable development is highly regarded in the last few decades due to the increase in awareness of green environment. Sustainability does not only mean environmentally friendly, but also to increase the life-cycle of certain product to ensure minimum changes and maintenance that will generate a lesser environmental value. In urban area, stormwater storage management and runoff control are important factors in managing stormwater. The utilisation of stormwater storages is to ensure the maximum usage and temporary volume control of stormwater at all times in urban area (Zoppou, 2001). Runoff control in urban areas is equally important to the existence of stormwater storage. The increase in direct runoff due to the increase in impervious surfaces contributes to the change in stormwater management of certain areas. On the other hand, the 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 on-site stormwater management, 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 countries.

This paper demonstrates different aspects in stormwater management; urban flooding and flood vulnerability, stormwater source control, and stormwater quality assessments. Paper further discussed three case studies from Western Australia to elaborate the applications. Results of these case studies explain importance of all these aspects in sustainable stormwater management.

2. Case Study 1: Hydrological modelling of urban flood vulnerability

The use of geographical mapping or numerical modelling is often introduced to analyse the runoff intensity of an area. Studying and understanding of urban catchment hydrology is important to implement proper stormwater management strategies to mitigate urban flood associated disasters. Numerical modelling can be used as a tool to analyse the behaviour of urban hydrology and urban stormwater management systems. In hydrological modelling, analysing of all the parameters affect to urban catchment hydrology within a single model is a quite complex process. Therefore selecting and prioritizing modelling parameters and catchment characteristics those significantly impact on urban hydrology is needed. Sensitivity of catchment characteristics towards the peak flow rate variation is important, when deciding a specific numerical model to represent an urban hydrological catchment. Also it helps to select the characteristics those should be given more attention to simplify the modelling process, increase the accuracy of results, decrease the possible error level and decrease the time of model run. This case study concentrated on four major catchment characteristics those depends on land use. Numerical model was created to analyse a small scale urban catchment and to analyse the sensitivity of selected catchment characteristics.

Canning Vale catchment in Western Australia is selected to analyse the impacts of land use change on stormwater management. Catchment size is approximately 250ha and basically a flat area of 1:2000 approximately (Connell, 2009). The most of the rainfall receives to the catchment during the winter from May to September of the year. The land-use varies from industrial and residential to water logged swales, while about 75% of the catchment is residential and having lots with low permeable paved surfaces covering about 75% of a lot by building roofs and infrastructure like paved access ways. Also the ground water level is within 0.5 – 0.7 m from the ground level in most of the areas, which is preventing the possibility of infiltration of runoff to the sub soil even in small rainfall event. The groundwater effect to the stormwater drainage systems capacity is more visible when there are swales and basins presented near or along with the drainage system. It has been observed the submerged manholes and pipes during the winter and rainy season, which are conveying the groundwater rather than surface runoff through the stormwater drainage. Canning Vale catchment is having a good drainage system incorporate with pipe network, basins, open swales and open drains. Most of the drainage system is digitized with GIS mapping according to the as-built drawings. Also there are data monitoring devices with computerized network in few major locations to measure the flow data, rainfall and ground water level which were used to calibration and verification of the model.

2.1 Flood vulnerability mapping

The hydrological approach was selected to develop flood maps with its accuracy than the other approach. The rainfall scenarios of average recurrent intervals of 1 in 1 year, 1in 5 year, 1 in 10 year and 1 in 100 year flood events were used to predict the possible flood areas and depths.

The historical rainfall data were obtained from the intensity - frequency - duration curves. Critical duration for this event was selected as 1 hour by running the model for 8 separate durations from 10 minutes to 3 days. The results for 1 in 100 year critical duration rainfall event are showing in the flood maps as shown in Figure 1. The results show the vulnerable area for 0.10 m to about 0.7 m flood depths in both maps. Water heights show above 0.7 m around basin because the basin was modelled in the 2D layer giving its current water level and can be neglected considering the basin capacity. Flood map shows one more cluster of above 0.7m water depth northwest to the catchment, which is again due to a basin, out of the catchment. Boundary condition was implemented in this area to count the water, without dissipating from the model and these water depths also can be neglected when deciding development guide lines using the results. Area flooded about 0.6m to west of the basin is a public open space and having historical flood issues. In the historical records there have been flood issues along channel. Areas showing flood depths of about 0.24m are the swales and they are normally filled with water even for small rainfall events. The modelling process has a lag time, and the surface runoff which is routing through the hydrological layer will not simulate to calculate the flood depths until they flow back from manholes, but overall flood depth representation is adequate after comparing with the historical data. Further enhancement can be done by using the topographical contours with the contour gap of about 0.2 m.

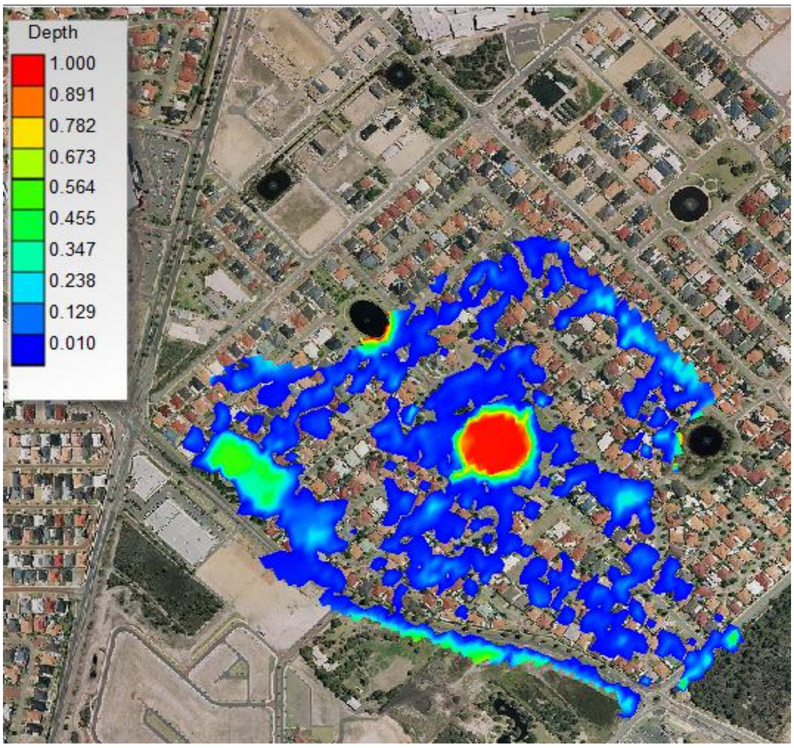

Figure 1: Flood inundation mapping for 1 in 100 year critical duration flood event for catchment

3. Case Study 2: Infiltration based onsite stormwater management

Due to the increasing housing density local land development authorities requires storm water runoff from developing lots to be retained / detained within the property. Infiltration is identified as one of the best operational and sustainable methods to handle this requirement. Due to lack of information on local soil properties in land development areas, it is difficult to assess storm water retention/ detention requirement. 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. 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". 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.

This case study was carried out in 64 housing precincts which have been identified as future residential development areas in the City of Gosnells, one of the fastest growing metropolitan areas in Western Australia. Main aim of the study is focusing on identification of different soil types with respect to their infiltration capacities in selection of best stormwater management strategies. The completion of this project will help the authorities concerned to get a better understanding of the soils' behaviour and how and up to what the particle size distribution extends is going to influence the 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.

3.1 Field testing and mapping

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. 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). 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.

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). 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. 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 maps (Figure 2) 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.

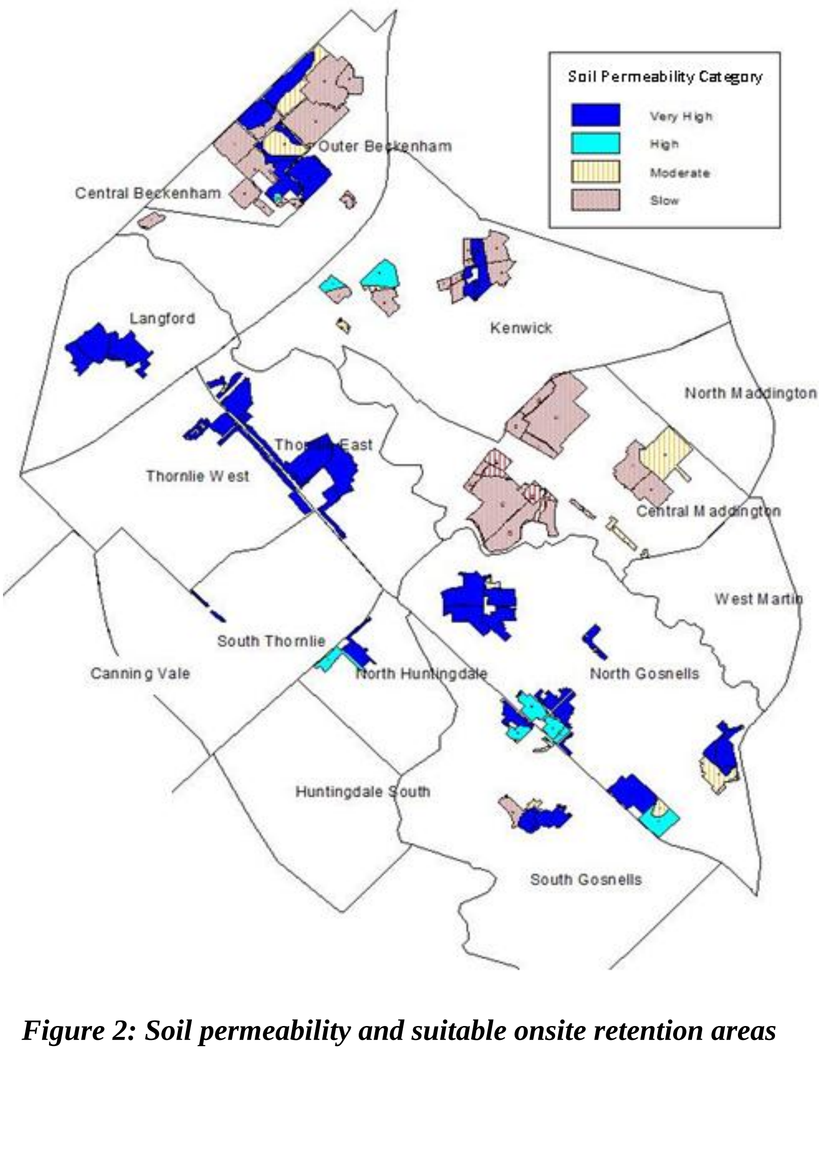

Figure 2: Soil permeability and suitable onsite retention areas

4. Case Study 3: Stormwater quality assessment

To control stormwater pollution effectively, development of innovative land-use-related control strategies will be required. An approach that could differentiate land-use effects on stormwater would be a first step in solving this problem. Several studies have shown that the contribution of stormwater pollutants must be considered in order to correctly implement an environmental preservation method for a receiving water body. A common objective of most urban water quality studies has been to strive to relate land use to pollutant loadings (Hall and Anderson, 1986, Parker et al., 2000; Shinya et al, 2000). The main scope of this case study is to develop relationships between stormwater quality versus land use type and developing recommendations and guidelines for stormwater management.

The land use areas focused on in this study include residential, commercial and industrial lands around the Town of Victoria Park in Western Australia. Town of Victoria Park is located 3km southeast of Perth; it has an area of 17.62km2 which consists of mainly commercial and residential areas, also minority of industrial area. Five sampling locations with varying land uses have been used for this study; commercial, residential, industrial, and two areas with mix land use patterns. Stormwater samples were collected at drainage outlets of the compensation basins of each study area. These outlets were selected based on the surrounding land use, ease of access, site safety and stormwater drainage outlet type so that sample collection would be possible.

4.1 Temporal Variation of Stormwater Quality

Using the sample collected at every 10mins interval, the temporal variation of stormwater quality has been investigated. Figure 3 shows the temporal variation of Nutrients at commercial, residential and industrial land use observation locations. Also the rainfall intensity has been also integrated in the figures to show the responses of rainfall on water quality. The first flush principle is well demonstrated in these figures, when the highest amount of pollutant concentration occurs at the beginning of the storm event. Other peaks in pollutant concentrations occur in correlation with the maximum peaks in rainfall intensity. This demonstrates the amount of pollutants increase in stormwater with relation to intensity of the storm events.

When compare the Nutrient at different land use catchments, commercial land use receives the peak concentration of phosphate 10 minutes after the peak rainfall intensity. Other Nutrients at commercial lands are relatively low compared to phosphate. This is likely to be due to the amount of vehicle use as the majority of this area is used for car parking, contributing to the higher amounts of phosphate. Nutrient concentration levels in the residential land use area also follow the rain intensity pattern by having the highest concentrations recorded simultaneous with the highest rain intensity. Nitrate levels appear to have the opposite occurring by decreasing during the increasing of rain intensity. Ammonia is at its highest concentration with the first flush of stormwater and then only small amounts are recorded afterwards for the remainder of the storm event. Phosphate is the most common nutrient in residential land use stormwater, having a high concentration with the first flush and then remaining high. In the industrial land use area, Ammonia and phosphate followed the same pattern. In this site, nitrate concentration levels follow the opposite pattern to the ammonia concentration levels. As nitrate levels increase there is a decrease in both ammonia and phosphate concentration levels. The opposite happens when nitrate levels decrease. Nitrate concentrations decreases when rain intensity increases. This site recorded very small concentrations of nitrite for the whole duration of the storm event demonstrating nitrite is not an issue in this industrial land use area.

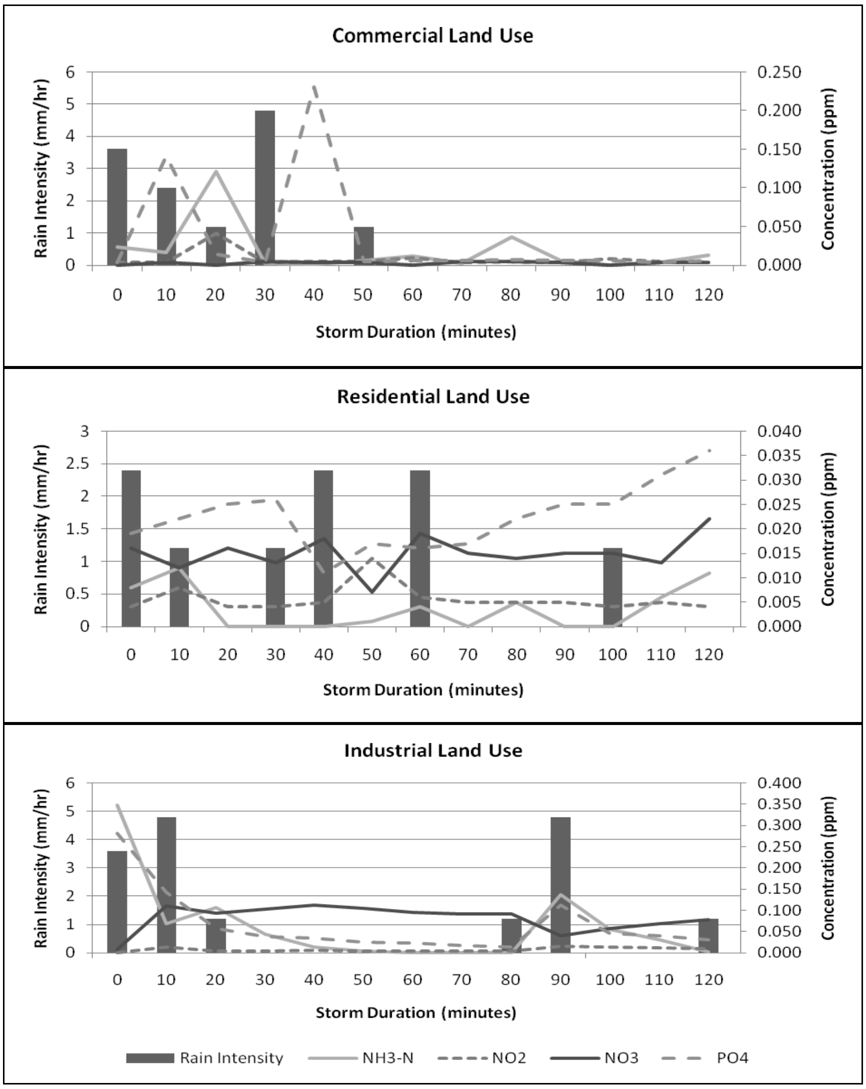

Figure 3: Temporal variation of nutrient concentrations and rain intensity

5. Summary and conclusions

To achieve a sustainable stormwater management practices, controlling stormwater quantity and quality is timely important issues. Urban developments and land sue changes significantly affects the catchment hydrology and water quality. This paper discussed three examples for stormwater management in Western Australia. First case study explains the assessment of flood vulnerability in high density residential area, Canning Vale. It uses numerical modelling approach for the assessment. Second case study discussed the importance of the consideration of local soil properties on onsite infiltration based stormwater management. This study uses field tests and soil testing as the key study mode. Third case study shows the relationship between different land use types and stormwater quality. Laboratory testing of stormwater quality enhanced the value of the study. The results of these studies will be useful for land developers as well as authorities, decision makers and policy makers to come up with sustainable land development strategies.

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