Using Water-Sensitive Urban Design to improve drainage capacity

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ABSTRACT

Water Sensitive Urban Design (WSUD) integrates water cycle management into urban planning and design. When applying the WSUD practices to urban areas, environmental degradation can be minimized, while improving aesthetic and recreational appeal at the same time. However, the effects of WSUD measures on water flow regimes are not fully known. The objective of the research was to determine suitable WSUD measures for a catchment in Adelaide, Australia by producing an updated and more reliable rainfall-runoff model using historical flow data. After this, the use of several suitable WSUD measures were simulated on the catchment to gain insight into their effect on drainage capacity.

Keywords

Water-Sensitive Urban Design, water cycle management, rainfall-runoff model, stormwater management, urban water resilience

INTRODUCTION

Traditional urban and industrial development alters landscapes from permeable vegetated surfaces to a series of impervious interconnected surfaces resulting in large quantities of stormwater runoff, requiring management. Historically, there has been a strong focus on the design of stormwater management systems that rapidly convey stormwater runoff directly to streams with little or no focus on ecosystem preservation. Heavy rainfall flows rapidly into streams carrying pollutants and sediments washed off from impervious surfaces, resulting in streams carrying elevated concentrations of pollutants, nutrients and suspended solids. Increased peak flow also alters the morphology and stability of channels and other drainage systems.

Water-Sensitive Urban Design (WSUD) is a relatively new approach that recognises the need for an integrated management approach to potable, waste and stormwater management. It enables cities to adapt and become resilient to the pressure which population growth, urban densification and climate change place on ageing and increasingly expensive water infrastructure. This paper addresses the effectiveness of Water-Sensitive Urban Design on drainage capacity and peak flow reduction in urban catchments. In order to do so, a rainfall-runoff model for the study area (the Frederick St. catchment in Adelaide, Australia) was developed. After this, the effects of several WSUD measures were simulated to determine their effects on drainage capacity and peak flows during storm events.

Scope

The rising water demand and diminishing resources led to water management being marked as a key priority for South Australia. Due to climate change and the rising demand for water, many water related targets have been set up for wastewater, irrigation, ground water and stormwater management.

It is expected that the ratio of infill to fringe development for new housing will shift to a more infill-orientated ratio in Adelaide. Infill development means that new housing development will occur within existing neighbourhoods. This increased housing intensity poses challenges to infrastructure in the existing urban environment of the Greater Adelaide region (Government of South Australia, 2013). Amongst other things, this means that metropolitan catchment areas where infill development takes place will be likely to experience changes in stormwater runoff flow regimes. One of those areas is the Frederick Street catchment, a 44.7-Ha urban catchment which was the study area of this report. It is expected that infill development in the Frederick Street catchment will have serious effects on the drainage system of the neighbourhood.

Water-Sensitive Urban Design measures

For many water related problems in the metropolitan area of Adelaide, Water Sensitive Urban Design (WSUD) seems like a promising way to deal with the challenges. Water-Sensitive Urban Design is a design approach which aims to integrate the urban water cycle into urban design. It includes:

- Integrated management of groundwater, surface runoff (including stormwater), drinking water and wastewater to protect water related environmental, recreational and cultural values;
- Storage, treatment and beneficial use of runoff and wastewater;
- Using vegetation for water quality purposes;
- Utilising water saving measures to minimise requirements for drinking and non-drinking water purposes.

Therefore, Water-Sensitive Urban Design incorporates all water resources, including surface water, groundwater, urban and roof runoff and wastewater. Water-Sensitive Urban Design can play an important role in improving water handling capacity. Because most WSUD measures focus on retention of rainfall, peaks in drainage flows during heavy rainfall can be reduced, and the drainage will be spread out across a longer period of time. Some well-known examples of Water-Sensitive Urban Design are bioretention basins, wetlands, rain gardens and rainwater tanks.

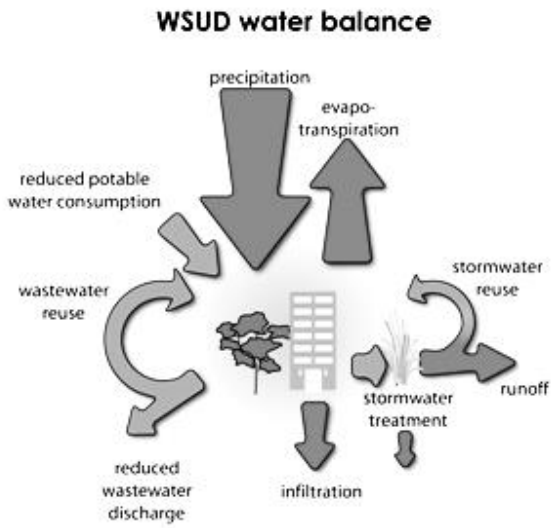

Figure 1: The WSUD water balance (Hoban & Wong, 2006)

The South Australian government has listed 16 different WSUD measures. However, not all of them can be used in urban environments. After an analysis it was found that there were two measures which fitted the purpose within the catchment best: bioretention basins and rainwater tanks. This was because of the restricted room for measures due to the urban environment, and the small slope (around 0.5%) of the catchment. The two selected WSUD measures are explained briefly below.

Rainwater tanks

A rainwater tank is designed and to capture and store rainwater from gutters or downpipes on a building. A rainwater tank only collects rainwater or mains water. Captured water is then available for commercial, industrial or domestic uses. Rainwater from a tank can be used to irrigate gardens or meet interior demands. Using rainwater for a combination of uses can lead to optimum mains water saving and possibly large reductions in runoff charges for the catchment. It should be noted that rainwater tanks provide limited water quality control, primarily through sedimentation processes.

Bioretention Basins

Bioretention systems are Water-Sensitive Urban Design measures that involve some treatment by vegetation prior to the filtration of runoff through a prescribed media. Following treatment, water may infiltrate to the subsoil. Bioretention basins provide water quality treatment as well as flow control. The basins are characterised by the ability to detain runoff in a depression storage above the bioretention system. The most common implementations of bioretention systems for streetscapes are bioretention swales and bioretention basins. For an urban area with very little available space, bioretention basins seem to be the most appropriate measure.

However, the low void ratios of soils used in these systems (typical value is 0.2) and their limited infiltration rates (typically 150 to 300 mm/h) limits their potential to provide flood control. Therefore, a combination of rainwater tanks and bioretention systems seems to be a logical combination to deal with all aspects of the changing flow regimes.

RESEARCH OBJECTIVE AND METHODOLOGY

The objective of the project was to determine suitable WSUD measures for the catchment by producing an updated version of the catchment model using historical flow data. The existing model (from 1993) was updated using new spatial data and then calibrated. When the model was calibrated, the use of several suitable WSUD measures were simulated on the catchment to assess their effect on flow frequency. It is intended that any changes which might have occurred in the area will not have an effect on the flow regime of the catchment. Therefore, using Water-Sensitive Urban Design to maintain the old flow frequencies by improving drainage capacity was desired.

Study area

The research focused on the Frederick Street catchment in Glengowrie, a suburb of Adelaide. Over the years, infill development has taken place in the area, and this process is likely to continue. The housing development leads to an increase in impervious area, which influences the flow regime of the catchment, leading to bigger peak flows during runoff causing rainfall events. Building a new drainage system for the entire catchment is an expensive and time-consuming solution which will also cause a lot of nuisance. This is why alternative approaches are being taken into consideration. Water-Sensitive Urban Design seems a promising solution to the problem. It needed to be investigated if Water-Sensitive Urban Design could be applied in the catchment area in order to reduce the effects caused by infill development on flow frequency.

Because of the good availability of data and the relatively small (typically urban) size of the catchment area, the Frederick Street catchment represented an ideal opportunity to explore the effects of urban infill development on runoff flow rate and volume. The outcomes of this research can therefore be seen as a good example for other urban catchments. It is important to understand the impact of infill development and how to overcome these impacts with WSUD tools.

This might lead to sustainable solutions which do not involve drastic and costly adjustments to urban drainage systems.

Model development

In order to work with a reliable and up-to-date model, changes within the catchment area need to be taken into account (for example housing development or changes in soil conditions). The most important change in the Frederick Street catchment will be housing development, which leads to an increased impervious area. First, the percentage of growth of the impervious area was investigated. In order to assume the growth percentage of impervious area within the catchment, available data about the catchment area (dating from 1993) was updated by using the spatial information system QGIS and satellite images from 1993 and 2013. Changes in the amount of pervious and impervious area were then analysed and used to update the model rainfall-runoff model. After this, the model was calibrated. Model parameters include for example storage losses, Manning's *n* values for pervious and impervious areas and infiltration rates for soil. A sensitivity analysis of all relevant model parameters was done to ensure a good calibration.

Following the calibration, the model was used to simulate Water-Sensitive Urban Design principles, in order to develop recommendations for implementing WSUD at the allotment level (with infill development) or in the streetscape in the catchment. The model will also be used to simulate the flow regime of the catchment in 2040. For that year, a number of scenarios (with and without WSUD measures and including urban infill development) were analysed in order to determine whether Water-Sensitive Urban Design can be an effective way to reduce peak flows in the Frederick Street catchment in the future. The result was a newly calibrated model with updated spatial information, and an overview of the flow regimes in 1993, 2013 and the predicted flows for 2040 with and without several Water-Sensitive Urban Design measures.

Several software programmes were used for this research. The most important ones will be briefly described below.

Storm Water Management Model (SWMM)

The use of the two selected WSUD measures was simulated using EPA SWMM 5.1. EPA SWMM is a dynamic rainfall-runoff simulation model used for single event or long-term (continuous) simulation of runoff quality and quantity from primarily urban areas. The runoff component of SWMM operates on a collection of subcatchment areas that receive precipitation and generate runoff and pollutant loads. The routing portion of SWMM transports this runoff through a system of pipes, channels, storage/treatment devices, pumps, and regulators. SWMM tracks the quantity and quality of runoff generated within each subcatchment, and the flow rate, flow depth, and quality of water in each pipe and channel during a simulation period compromised of multiple time steps. This was done for several future scenarios with and without additional WSUD measures.

GIS

The scenarios for housing development were developed by using satellite images to monitor the changes which have occurred in the area over the past 20 years. This was done using GIS software. The outcome was then used as a guideline to predict were future infill development might take place. An increase in the housing density of a subcatchment will lead to an increase in impervious area, and therefore rainfall will be transported downstream quicker and in greater amounts because of the decrease in soil infiltration and evapotranspiration.

RESULTS

By analysing spatial data from 1993 and 2013, and using estimates on infill development for the catchment area until 2040, several changes in catchment property were assumed. The results are shown below.

Catchment property	*1993*	*2013*	*2040*
Total area (ha)	44.7	44.7	44.7
Impervious area directly connected to drainage	30%	34%	40%
Impervious area indirectly connected to drainage	17%	17%	17%
Pervious area	53%	49%	43%

Table 1: Predicted change in catchment properties

The current flow regime of the Frederick Street catchment has been assessed and a model has been set up to analyse the impact of infill development on the flow regime. Redevelopment within the catchment area is expected to lead to an overall increase of 12% in runoff volume, and an 11% increase in peak flows by 2040 if no WSUD measures would be implemented.

WSUD Measure	*Change in total runoff volume*	*Change in peak flows*
No measures	+ 12%	+11%
1 kL rainwater tanks for new houses	+ 10%	+ 8%
1 kL rainwater tanks for all houses	0 %	- 3%
Bioretention basins	+ 9%	-31%

Table 2: Predicted change in peak flows and yearly runoff volumes between 2013-2040 for several scenarios

It was found that both WSUD measures were effective in preserving pre-redevelopment flow regimes when it came to peak flow reduction. However, despite spectacular peak flow reduction bioretention basins were found to be not effective enough when it comes to combatting rising runoff volumes.

CONCLUSION

Water-Sensitive Urban Design can be used to preserve the existing flow regimes of the Frederick Street catchment. For street scale WSUD measures, rainwater tanks and bioretention systems are showing promising simulation results for reducing runoff volumes and peak flows. The most effective way of reducing runoff volumes is the installation of rainwater tanks. Peak flow reduction on the other hand can be achieved by both rainwater tanks and bioretention basins. Although bioretention basins achieve a higher overall reduction of peak flows, it should be noted that for very extreme storm events they are not capable of significant peak flow reduction due to their limited ponding volume.

The proposed WSUD measures provides delicate, sustainable, and relatively cheap solutions for the expected increase in peak flows and runoff volumes, possibly saving local governments and residents a lot of money and nuisance. Further research should prove which solution (or a combination of solutions) fits the study area best in terms of feasibility and cost effectiveness. The project focused on an urban catchment in Australia, but its results can also serve as a guideline for the Dutch Water-Sensitive Urban Design practice, which needs to be developed further.

ROLE OF THE STUDENT

Robin Noordhoek was an undergraduate student working under the supervision of Dr. Marcela Brugnach (University of Twente) and Dr. Baden Myers (University of South Australia) when the research in this report was carried out. The development of an up-to-date rainfall-runoff model, the calibration and validation as well as the assessment of the effectiveness of feasible WSUD measures on the proposed problems were done by the student.

The research was carried out between May-August 2014 and was part of a bigger project regarding Water-Sensitive Urban Design and its implications on flow regimes, conducted by the Centre for Water Management and Reuse (connected to the University of South Australia), located in Adelaide, Australia.

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