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Contents

Abstract

Urbanisation leads to both quantitative and qualitative changes to storm water runoff. While the quantity changes have received much attention in the past, now the quality changes are beginning to receive significant attention. The quality changes are primarily due to a range of anthropogenic activities common to urban areas, which result in the generation of various types of pollutants. These pollutants accumulate on urban catchment surfaces and are eventually washed off by storm water runoff creating irreversible impacts on receiving water environments. In this context, structural storm water treatment measures are introduced, promoting pollutant removal through physical, chemical and biological processes. They also detain, retain and regulate storm water runoff to improve water quantity and quality characteristics.

Bioretention basins and constructed wetlands are among the most common storm water treatment systems, and their treatment performance is closely dependent on hydrologic and hydraulic characteristics. Consequently, the in-depth understanding of the role of hydrologic and hydraulic factors in bioretention basin and constructed wetland treatment performance is important for effective urban storm water design strategies. This research monograph presents the outcomes of a detailed investigation into the influence exerted by hydraulic and hydrologic factors on the treatment performance of bioretention basins and constructed wetlands.

In relation to bioretention basins, the research outcomes confirmed that the antecedent dry period is an important factor influencing pollutant removal efficiency. A relatively long antecedent dry period will result in comparatively low moisture content in the filter media, which can enhance the runoff retention capacity and consequently improve treatment performance. This implies that planting of vegetation with high evapotranspiration capacity would enhance treatment efficiency. Additionally, it was found that pollutant leaching influences bioretention basin treatment performance, particularly reducing the ability for nutrient removal. This highlights the importance of the selection of appropriate filter media and its timely replacement.

In the case of constructed wetlands, it was found that large and small rainfall events are subjected to different treatment. The pollutant load reductions in the initial sector of the runoff hydrograph from large rainfall events were relatively low due to the rapid mixing. This highlights the need to establish an inlet pond to initially intercept the flow entering the constructed wetland so that the inflow is stabilised. This is also supported by the fact that the initial sector of the runoff hydrograph generally carries higher pollutant loads, namely the first flush effect. Additionally, the provision of a bypass system is recommended to control the runoff to the constructed wetland. This will protect the treatment system from erosion damage resulting from high runoff rates.

This research monograph further showcases an innovative approach for using conceptual models to analyse storm water treatment system performance. The approach adopted has the capability to generate key hydraulic data for individual rainfall events in relation to the treatment systems investigated. This is a significant advancement from conventional approaches for the analysis of treatment system performance, which is based on the use of lumped parameters. The knowledge presented provides practical guidance and recommendations for improved urban storm water management to assist researchers, design engineers, decision-makers, urban planners and storm water quality model developers.

Chapter 1
Storm Water Treatment

Abstract Urbanisation leads to changes in storm water quantity and quality due to the increase in impervious surface areas. While the quantity changes include increase in runoff volume and peak flow and decrease in the time to the peak, the quality changes are primarily due to the fact that a diversity of anthropogenic activities contributes a range of pollutants to the urban environment. These pollutants are washed off by storm water runoff and transported to receiving waters. In this context, structural storm water treatment measures are commonly introduced to mitigate storm water quality degradation. This chapter presents reviews of typical structural storm water treatment systems used in urban areas, providing an overview of their design and the inherent treatment processes. The systems discussed include gross pollutant traps, vegetated swales/bioretention swales, detention/retention basins, infiltration systems, bioretention basins and constructed wetlands.

Keywords Urbanisation · Storm water treatment · Storm water quantity · Storm water quality

1.1 Overview

Impacts of urbanisation on the natural water cycle are clearly evident. Urbanisation results in the spread of impervious areas and a diversification of land use, with vegetated lands converted to impervious areas such as roofs, roads, driveways, car parks and other paved surfaces (Barron et al. 2011). These changes lead to both quantity and quality impacts on the water cycle, which are widely recognised as significant environmental threats (Liu and Qin 2009; Liu et al. 2015). While the quantity changes, such as increase in runoff volume and runoff peak and decrease in the time to the peak, have received much attention in the past, the quality changes are beginning to receive significant attention (Goonetilleke et al. 2005). The quality impacts are due to the fact that urban areas typically consist of residential, commercial and industrial land uses where anthropogenic activities typical to these areas generate a range of pollutants (Liu et al. 2012a). These pollutants are washed

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off by storm water runoff into receiving waters and create irreversible environmental impacts (Liu et al. 2012b). Community concerns regarding the importance of managing urban storm water pollution in order to protect the key environmental values of receiving waters has resulted in regulatory authorities being increasingly challenged to provide appropriate and prudent management of urbanisation impacts. Storm water treatment measures are among the most important components of storm water management.

Storm water treatment measures consist of non-structural and structural measures. Non-structural measures do not involve fixed permanent facilities, but entail regulations and/or economic instruments for changing stakeholder behaviour in relation to pollutant generation. Structural measures are treatment devices installed to capture or divert pollutants transported by storm water. Use of non-structural and structural measures in combination in storm water treatment is contextualised by using a range of terms across the world. In Australia, Water Sensitive Urban Design (WSUD) is the term commonly used to refer to the strategy to protect the urban water environment, while Low Impact Development (LID) is the term used widely in China. Best Management Practices (BMPs) is the term used in the United States. Sustainable Urban Drainage System (SUDs) and Storm water Quality Improvement Devices (SQIDs) are also terms used in a range of other countries to describe storm water management strategies.

Structural storm water treatment measures promote pollutant removal or mitigation through physical, chemical and biological processes, while also detaining or retaining polluted storm water to improve water quality. Figure 1.1 shows the common processes inherent in structural storm water treatment measures. They treat storm water runoff by preventing pollutant movement, removing pollutants and protecting and enhancing the environmental, social and economic values of receiving waterways. Selection of appropriate treatment measures depends on site

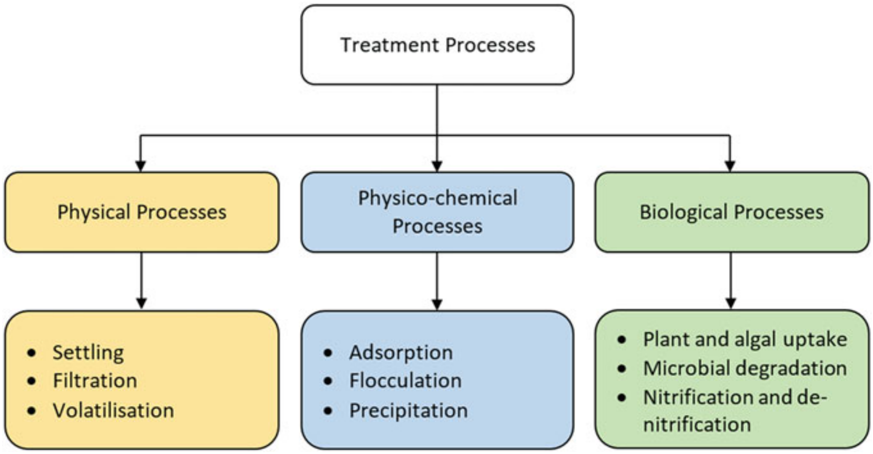

Fig. 1.1 Storm water treatment processes

conditions, target pollutants, local rainfall characteristics and catchment characteristics (Liu et al. 2013). The commonly used pollutant treatment measures are gross pollutant traps, vegetated swales (bioretention swales), detention/retention ponds (basins), infiltration systems, bioretention basins and constructed wetlands.

1.2 Common Structural Treatment Measures

1.2.1 Gross Pollutant Traps

Debris larger than 5 mm are defined as gross pollutants (Allison et al. 1997). Typically, gross pollutants include urban-derived litter and vegetation debris. These large pieces of urban debris get flushed from surfaces into the storm water system during rainfall events and can lead to poor waterway aesthetics and bad odours, and be a threat to aquatic biodiversity. Shaheen (1975) noted that 20 % of the weight of pollutants accumulated on road surfaces is litter. Additionally, organic matter such as leaves and grass clippings are primary litter on public roads. Madhani et al. (2009) found that organic matter accounts for 20–80 % of anthropogenic litter in Queensland, Australia. Due to their large size, gross pollutants are generally the most visible water pollution indicator to the community.

Gross pollutant traps (GPTs) are typically considered as a storm water pre-treatment measure. They play an important role in reducing the amount of urban derived gross pollutants exported to receiving waters. They also play a very important part in the treatment train (a series of measures combined in series for effective pollutant removal) by protecting downstream storm water treatment measures from clogging and malfunction. A number of different types of GPTs are used for storm water treatment. Each GPT has different design specifications with specific performance ability in trapping gross pollutants. Based on the way that GPTs operate, they can be classified into five types as given in Table 1.1 while Fig. 1.2 shows two typical GPT devices.

1.2.2 Vegetated Swales/Bioretention Swales

A vegetated swale or bioretention swale is an excavated trench filled with porous media (bioretention component) to create a broad, commonly parabolic or trapezoidal shallow channel (swale component) having vegetation cover on the side slopes and top layer. A vegetated swale or bioretention swale supports the achievement of storm water treatment objectives by disconnecting impervious areas from downstream waterways. The swale component promotes pre-treatment of storm water by removing coarse to medium sediments, whilst the bioretention

Table 1.1 GPTs devices and their characteristics

GPTs types	Typical devices	Comments
Drainage entrance treatment	• Grated entrance screens • Side entry pit traps (SEPTs) • Baffled pits	• Used at the entry point of the drainage system and traps gross pollutants from a catchment when water enters the drainage system
In-line screens	• Litter control devices (LCDs) • Release nets • Trash racks • Boom diversion systems • Return flow litter baskets	• Placed in the drainage channel to trap the gross pollutants present in the storm water runoff • Requires continuous monitoring and maintenance to remove the trapped gross pollutants
Self-cleaning screens	• Continuous deflective separation (CDS) • Downwardly inclined screens	• Improves the performance of in-line screens • Operates with a self-cleaning system
Floating traps	• Floating debris traps (FDTs) • Flexible floating booms	• Specifically used to trap floating gross pollutants
Sediment traps	• Sediment settling basins • Circular settling tanks • Hydrodynamic separators	• Commonly used at the downstream end of the drainage channel • Removes gross pollutants remaining in the storm water and prevents them from entering the storm water treatment facilities that follow

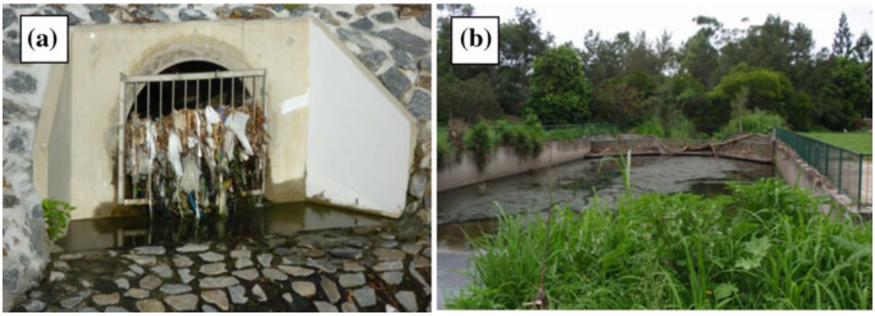

Fig. 1.2 Typical GPT devices. **a** Trash rack. **b** In-line screen

component removes finer particulates and associated pollutants through filtration, infiltration, adsorption and biological uptake. Figure 1.3 shows a typical road-side swale.

(a)

(b)

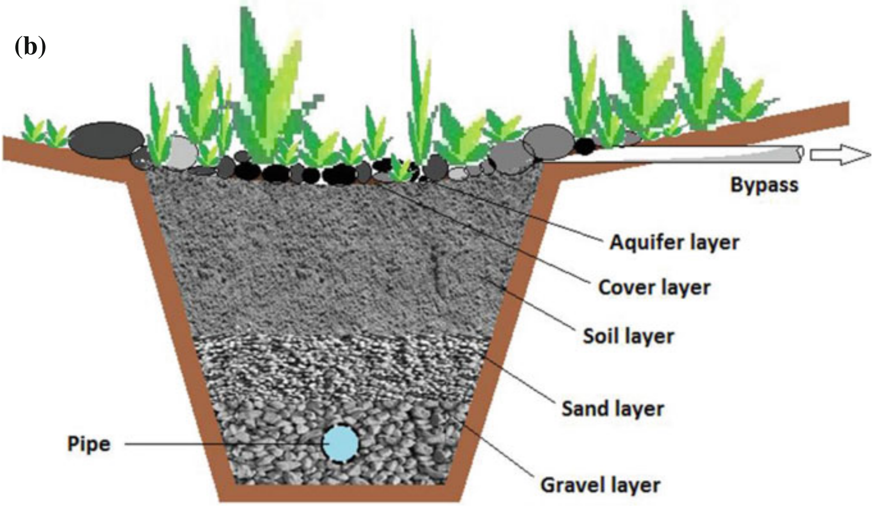

Fig. 1.3 A typical road side swale. **a** A road side swale. **b** Cross section

Vegetated swales or bioretention swales are typically used in road medians, verges, car park areas, and parks and recreation areas where flow velocities are low, as alternative to kerb and gutter arrangements. These treatment devices are commonly designed with side slopes no steeper than 3:1 and with longitudinal slopes of between 1 and 4 %, in which they can generate appropriate velocities promoting high infiltration. For slopes steeper than 4 %, check dams are typically constructed across the base, at intervals along the invert of the swale, to reduce flow velocities and to protect from erosion.

1.2.3 Detention/Retention Basins

Detention/retention ponds/basins are storm water facilities that provide storage for storm water runoff to be retained or detained. The key difference between retention and detention basins being that, in the case of detention basins, storm water is detained for a period of time and then slowly released into a waterway through a designed outlet. In the case of retention basins, storm water is retained and not released into a waterway. Detention/retention basins allow infiltration of storm water during the detention period. Therefore, these basins provide downstream protection and flood control by attenuating peak flow and reducing runoff volume.

The primary mechanism of pollutant removal in detention/retention basins is by the physical settling of suspended solids, which include particle-bound pollutants such as nutrients, heavy metals and hydrocarbons. However, a better result in improving storm water quality is achieved when these basins are combined with other storm water measures, forming a treatment train. Figure 1.4 provides a typical treatment train, where a detention basin is one of the devices employed. In combination with storm water wetlands, for instance, which will result in very fine and dissolved pollutants being removed by the wetland, whilst coarser sediments/solids will be trapped and remain in the basin, and accordingly, the wetland will be protected from damage. Furthermore, retention basins can also provide aesthetic and recreational benefits as well act as a water supply for irrigation or fire protection. Figure 1.5 provides the image of a retention basin.

1.2.4 Infiltration Systems

Infiltration systems capture storm water runoff and promote infiltration into surrounding soils. The primary focus of infiltration systems is managing storm water quantity by reducing storm water runoff volumes and peak flows. However, they also contribute to storm water quality improvement through infiltration of storm water into the subsurface soils. Storm water pre-treatment measures such as sedimentation basins and swale systems are required to be installed before infiltration systems. This is to avoid clogging of the infiltration system. Typical infiltration systems primarily include leaky wells/soakwells, infiltration trenches and porous/modular pavements. Figure 1.6 shows a typical infiltration system-infiltration trench.