Chapter 2
Stormwater Treatment Design

Abstract The implementation of scientifically robust stormwater management strategies needs to be underpinned by effective treatment systems. In this regard, stormwater quality models play a critical role for predicting pollutant loads and for determining important treatment system design parameters. A stormwater quality model is process driven, with the replication of pollutant build-up and wash-off processes being two key components. This chapter discusses the limitations in current modelling approaches and the need to have an in-depth understanding of pollutant processes and the role played by influential rainfall and catchment factors to enhance the accuracy and reliability of modelling results. Currently, only a limited number of parameters are incorporated in the model setup to represent the influence of catchment and rainfall characteristics on stormwater quality. This approach is inadequate as stormwater pollutant processes are complex and influenced by a range of factors. This highlights the importance of having an in-depth understanding of the role of rainfall and catchment characteristics on urban stormwater quality.

Keywords Hydrologic modelling · Stormwater quality · Stormwater pollutant processes · Stormwater treatment design · Stormwater quality modelling

2.1 Background

In an era where urban stormwater quality is recognised as a particular concern, the implementation of stormwater treatment strategies is common worldwide. As discussed in Chap. 1, stormwater quality is highly variable in the context of pollutant sources, species and loads, and is influenced by a range of factors such as rainfall characteristics and catchment characteristics. This underlines the complexity required for stormwater treatment approaches and treatment design. For treating stormwater quality, commonly adopted treatment approaches can be termed as a combination of structural and non-structural measures. Structural measures are treatment devices installed in or constructed at a site to mitigate changes to

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stormwater quantity and quality as a result of urbanisation. Non-structural approaches do not involve fixed permanent facilities, but entail changing behaviour in relation to pollutant generation and restricting pollutant entrainment to stormwater systems through regulations and/or economic instruments.

An overarching stormwater treatment strategy, which is a combination of structural and non-structural measures, is common in most parts of the world, though different terminology is used to describe these strategies. 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 widely used in China to refer to the strategy used for stormwater management. Best Management Practices (BMPs) is the term used in the United States. Sustainable Urban Drainage System (SUDs) and Stormwater Quality Improvement Devices (SQIDs) are also terms used in a number of other countries to define stormwater management strategies.

These stormwater treatment strategies subscribe to the common objective of mitigating the negative impacts of urbanisation on the water environment, by attempting to restore the pre-urbanised hydrologic and water quality characteristics. Typical structural stormwater treatment systems used are gross pollutant traps (GPTs), constructed wetlands, bioretention basins (rain gardens), sedimentation basins and vegetated swales (filter strips). Figure 2.1 shows examples of these typical structural stormwater treatment devices.

In terms of structural treatment systems, the ability to effectively treat stormwater is the most essential criterion for design. In stormwater treatment system design, answers to a number of key questions as listed below determine the overall functionality of the systems:

- What types of devices should be provided for a given catchment?
- Where should these be located?
- What sizes should these be and does it require a treatment train strategy (which is a combination of stormwater treatment devices in series with different treatment functions/objectives)?

Apart from these key questions to be answered at the design stage, a range of engineering design concepts are applied to determine the size and shape of the system, the characteristics of the structures to be used for conveyance and media to be used for treatment. In order to determine these important parameters and characteristics, hydrologic and water quality models are commonly used as an integral part of stormwater treatment design.

In this chapter, the discussion primarily focuses on stormwater modelling, which is an essential step in the treatment design. The discussion encompasses current modelling approaches and influential factors in relation to model reliability and accuracy. Additionally, this chapter also discusses how rainfall and catchment characteristics influence stormwater quality and the implications for enhancing the modelling approach adopted.

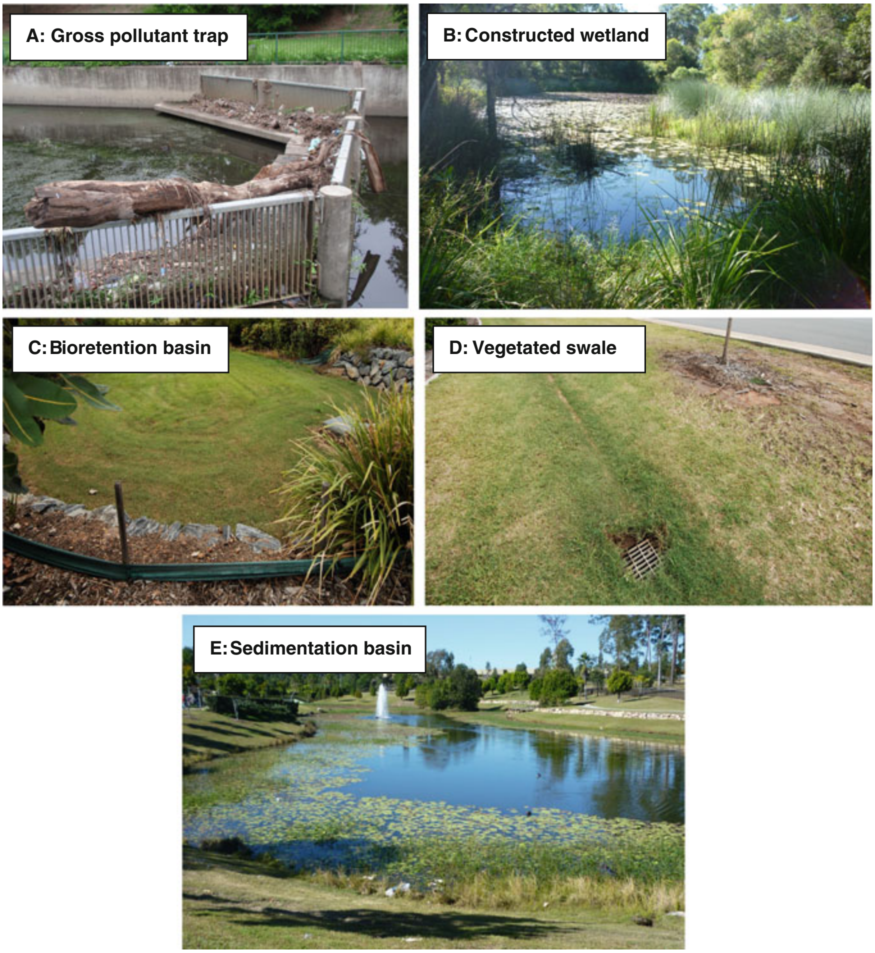

Fig. 2.1 Typical structural stormwater treatment systems **a** gross pollutant trap **b** constructed wetland **c** bioretention basin **d** vegetated swale **e** sedimentation basin

2.2 Use of Models in Stormwater Treatment Design

Modelling approaches used should be capable of estimating the quantity and quality of stormwater based on the catchment characteristics and rainfall characteristics for the range of pollutant species of interest. In this context, modelling outcomes provide designers with important guidance and datasets, significantly contributing to effective stormwater treatment design. Therefore, the accuracy and reliability of modelling approaches are of particular concern. Inadequacy of the modelling approach could lead to overestimation or underestimation of stormwater quantity and quality characteristics, resulting in ineffective treatment or high cost of construction and maintenance. For instance, in the case of the estimated stormwater runoff volume being too small, a large number of rainfall events will exceed the capacity of the treatment device and will achieve only limited treatment. Alternately, if the volume is overestimated, there will be increased cost as well as further treatment becoming negligible after a certain threshold.

2.3 Stormwater Models

Any model is an approximation of reality, and the reality is the urban stormwater system. A model is therefore only capable of replicating reality to the extent where scientific knowledge prevails. In model development, even the best available scientific knowledge has to be simplified to maintain practical viability. This means that a model can only replicate to a point. Therefore, significant efforts to explore cutting edge knowledge relevant to stormwater quantity and quality are critically needed to improve model replication accuracy and by implication, treatment design.

In the case of an urban stormwater model, the basic conceptualisation of transforming rainfall to runoff is termed as a hydrologic model, while estimation of pollutant loads transported by the runoff is termed as a water quality model. Generally, the hydrologic model and water quality model are simultaneously simulated to generate combined outcomes. The common approach used in most models, as illustrated in Fig. 2.2, is a simplification of the natural system as follows:

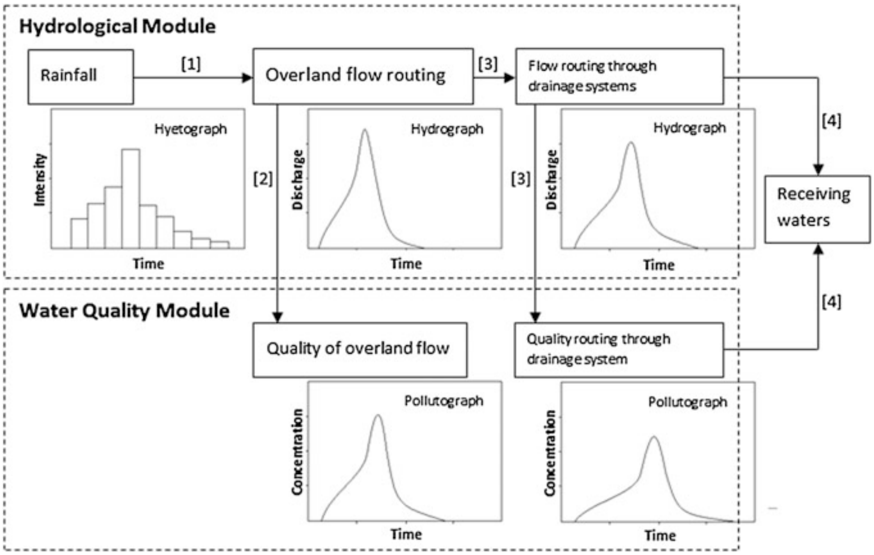

Fig. 2.2 Hydrologic and water quality models

- Rainfall is transformed to overland runoff based on catchment characteristics [1], where the surface runoff picks up pollutants on the catchment surfaces [2];
- Surface runoff, which incorporates pollutants, flows into the drainage system [3];
- The surface runoff with pollutants flows into the receiving waters via the drainage system [4].

2.3.1 Hydrologic Models

Hydrologic models commonly consist of two conceptual modules, namely, rainfall loss module and runoff routing module. The loss module is responsible for estimating the fraction of rainfall that is available to produce surface runoff, by eliminating losses such as infiltration and depression storage. A routing module transforms the effective rainfall (fraction of rainfall available to produce surface runoff) to a runoff hydrograph based on catchment characteristics. In this regard, rainfall is the input to the model and catchment characteristics play a critical part in influencing the loss module and routing module. The key influential catchment characteristics in relation to hydrologic modelling include:

(1) The topography of the catchment in terms of the direction and magnitude of the ground slope;
(2) The subsurface characteristics;
(3) The land use and land cover;
(4) The spatial distribution of urban areas (Mansell 2003).

The loss module replicates a typical hydrologic process in a catchment as illustrated in Fig. 2.3. A fraction of rainfall will contribute to runoff whilst the rest is lost due to evaporation or percolation into the ground. Different mathematical

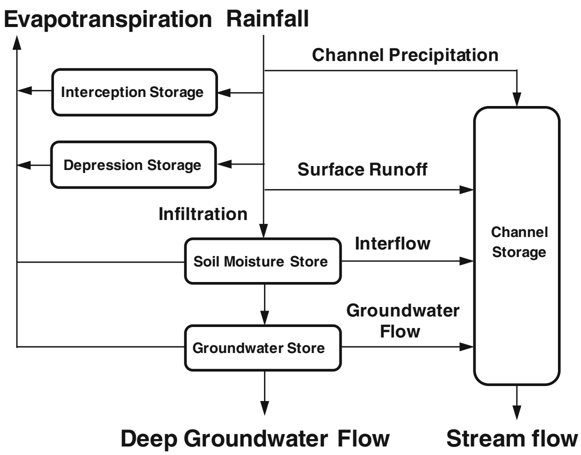

Fig. 2.3 Loss module in a hydrologic process

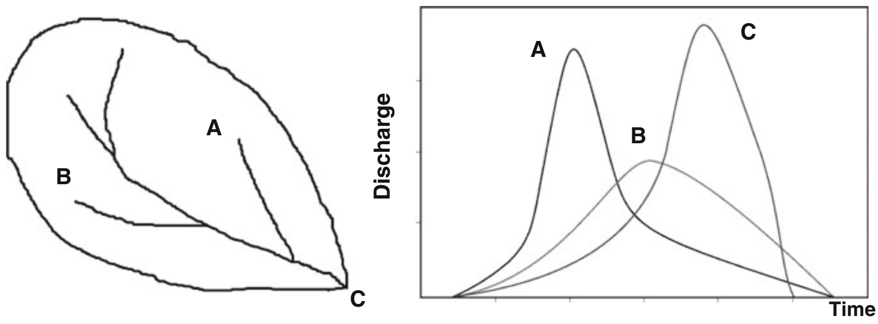

Fig. 2.4 Routing module in a hydrologic process

procedures are used to simulate the different components in the hydrologic process. As an example, Horton's infiltration equation is commonly used to estimate the precipitation-infiltration process, whilst Manning's equation is used to determine the characteristics of the free-surface flow driven by gravity.

A routing module is illustrated in Fig. 2.4. The stormwater runoff flows over the catchment surface and reaches the outlet, where the hydrograph forms. The hydrograph shape is strongly influenced by catchment characteristics. For example, a sharp rising limb with a high peak generally represents a catchment with a steep slope and large fraction of impervious surfaces, while a later peak in the hydrograph indicates that the impervious surfaces are located far from the catchment outlet.

2.3.2 Water Quality Models

Water quality models are used to estimate concentrations or loads of pollutants originating from a catchment. The data required for water quality modelling is mainly related to rainfall characteristics, catchment characteristics and pollutant build-up and wash-off. There are two fundamental approaches for undertaking water quality modelling, namely, the event-based approach and the long term continuous approach.

2.3.2.1 Event-Based Models

In the event-based approach, the processes that pollutants undergo can be divided into two types: pollutant build-up process and wash-off process. Pollutant build-up refers to pollutant accumulation on urban surfaces during dry weather while pollutant wash-off is the process that involves mobilising accumulated pollutants during stormwater runoff events (refer to Sect. 1.2.2). A range of empirical equations, as listed in Table 2.1, have been used to simulate these two processes in modelling approaches.

Table 2.1 Examples for empirical equations used in water quality models

Pollutant processes	Equations	Definitions	References
Build-up	• $y = a + \frac{b}{x}$ • $y = a + b \ln x$ • $y = ae^{-bx}$ • $y = \min(c, ax^{b})$	*x*-antecedent dry days; *y*-build-up load accumulated; *a*, *b* and *c*-coefficients	(Ball et al. 1998; Egodawatta 2007; MIKE URBAN 2008; O'Loughlin and Stack 2003)
Wash-off	• $W = W_0(1 - e^{-KIt})$ • $F_W = \frac{W}{W_0} = C_F(1 - e^{-KIt})$	*W*-weight of material mobilised after time *t*; W_0-initial weight of material on the surface; *I*-rainfall intensity; *K*-wash-off coefficient; F_W-fraction of wash-off; C_F-capacity factor	(Egodawatta et al. 2007; Sartor et al. 1974)

Models listed in Table 2.1 are primarily used to replicate suspended solids behaviour. Suspended solids are a major pollutant in their own right and commonly regarded as an indicator pollutant, due to the association of other pollutants with suspended solids. In this regard, other pollutant loads are generally estimated by assuming that the ratio of a particular pollutant to that of suspended solids is a constant for a given land use. Additionally, as shown in Table 2.1, pollutant build-up load is a function of antecedent dry days while pollutant wash-off is a function of rainfall intensity. In most event-based water quality models, antecedent dry days and rainfall intensity are the key parameters in the simulation of pollutant build-up and wash-off.

2.3.2.2 Long Term Continuous Models

Different from event-based models that focus on estimating pollutant loads and/or concentrations for a particular rainfall event or a series of rainfall events, long term continuous models focus on long-term pollutant load estimation, such as on a monthly or an annual basis. These types of models are generally used for urban planning and stormwater management decision-making.

In current engineering practice, the Model for Urban Stormwater Improvement Conceptualisation (MUSIC), which is a long term continuous model, is common. MUSIC is a stochastic stormwater quality model that assigns a particular water quality to events over a long term continuous period, such as 20 years, so that they fall into a pre-assigned probability distribution. Therefore, these models are generally termed as probabilistic models (McAuley and Knights 2009). Based on parameters related to land use or rainfall characteristics, long term continuous models are capable of estimating the annual pollutant export from a catchment. The same as for event-based models, different empirical equations are used by different models and have varying degrees of complexity.

2.4 Factors Affecting Model Accuracy

As a model replicates only a fraction of reality by utilising a simplifying form of scientific knowledge relating to the natural system, all modelling approaches are subject to uncertainty, due to a number of reasons. The presence of uncertainty in a modelling approach could lead to inaccurate outcomes if the uncertainty sources are not adequately understood. This highlights the importance of understanding uncertainty sources and underlying characteristics in stormwater quality modelling approaches. In this section, three important uncertainty sources, namely, model structure, input parameters and modelling approach, are discussed in detail.

2.4.1 Model Structure

Uncertainty resulting from the model structure is primarily related to the lack of knowledge on the influential factors in relation to stormwater quality, such as the influence exerted by rainfall and catchment characteristics in real-world systems. It depends on how accurately the models are developed to replicate the true system for a given situation. For example, current stormwater quality models estimate pollutant loads based only on land use and impervious surface fraction. However, the reality is that other than these two factors, a range of other catchment characteristics such as urban form, urban area locations and other site-specific characteristics, have a significant influence on water quality. Urban form commonly refers to the physical layout and design of the urban area (Breheny 1992). The definition of urban form is provided in Sect. 2.5.1. In other words, even though catchments may have the same land use type and impervious surface fraction, the stormwater quality generated from these catchments could still be different (Liu et al. 2012a). This could be attributed to the difference in the distribution of impervious surfaces and urban form. In this context, the model structure developed without considering other catchment characteristics could lead to inaccuracy in modelling outcomes and inaccurate stormwater treatment design.

2.4.2 Input Parameters

Inadequate input parameters, which primarily refer to the use of unrepresentative lumped parameters, are among the most important sources of model uncertainty. They affect model accuracy due to the lack of consideration of the variable nature of input parameters in a given situation. This is because lumped parameters generally are not able to accurately represent changes in stormwater quality throughout a rainfall event or within a particular land use, and this could lead to errors in modelling results. Taking land use as an example, most stormwater quality models commonly estimate pollutant loads for a particular land use by considering the land use as a lumped parameter without adequately representing their specific characteristics. However, the real-world situation is that there could be significant differences in different areas in terms of the influence exerted on pollutant processes, even though these areas have the same land use. For example, pollutants could accumulate at a higher rate in a residential catchment with high population density during the dry period (pollutant build-up) when compared to a residential catchment with low population density or different urban forms such as townhouse/detached housing development, although these catchments can be broadly categorised as residential development (Egodawatta and Goonetilleke 2006). Additionally, for some water quality parameters, variability in pollutant build-up within the same land use has been found to be even higher than the variability between different land uses (Liu et al. 2012b). This is attributed to the high degree of complexity of specific characteristics, such as traffic density, within the same land use rather than among different land uses. Consequently, assigning a single specific input parameter for a particular land use may not necessarily represent reality.

2.4.3 Modelling Approach Used

The use of an inappropriate modelling approach is a common source of model uncertainty. Even though the modelling approach itself cannot lead to uncertainty, it could undermine model accuracy if it is not adequate in the context of objectives and expectations. For instance, in the case of investigating relationships between rainfall characteristics and stormwater quality, using models based on stochastic concepts (such as the long term continuous model, MUSIC) could lead to errors. The stochastic modelling approach is to assign stormwater quality values to each rainfall event based on stochastic principles, where stochastic parameters are assigned to a rainfall event irrespective of the underlying characteristics. This approach does not necessarily consider the variable nature of stormwater quality with rainfall characteristics and thereby is not taken into consideration in the investigation into relationships between rainfall characteristics and stormwater quality. These facts highlight the influence of the selected modelling approach on model accuracy.

A further example is the application of solids as the indicator pollutant in conventional water quality models. Most of the event-based modelling approaches assume that other pollutants are attached to solids and transported along with these solids. However, an appreciable amount of pollutants are, in effect, not adsorbed to solids, but primarily present in dissolved form. Consequently, the approach of using solids as an indicator fails to accurately estimate these dissolved pollutants. For example, the research study undertaken by Miguntanna et al. (2013) found that nitrogen is primarily present in dissolved form whilst phosphorus is primarily present in particulate form. Consequently, the approach of using solids as an indicator is not appropriate in a situation where it is necessary to estimate dissolved pollutants such as nitrogen.

2.5 Understanding Influential Factors of Stormwater Quality-Improving the Modelling Approach

As the accuracy of stormwater models closely relies on how accurately the models replicate the natural systems, an in-depth understanding of the influence of external factors on stormwater quality can contribute to improving the modelling approach. Section 1.2.2 highlighted the primary influential factors in relation to stormwater quality as being catchment characteristics and rainfall characteristics. Catchment characteristics generally encompass a range of factors, such as land use and land cover, impervious surface area fraction, urban form and urban area location, whilst rainfall characteristics describe the variations in rainfall events primarily in relation to duration and intensity. In this section, a detailed discussion regarding these two factors with a focus on improving the modelling approach is provided.

2.5.1 Catchment Characteristics

Catchment characteristics generally play a significant role in pollutant build-up and hence, stormwater quality. Their role influences the pollutant species and loads generated, pollutant accumulation rate and the spatial and temporal distribution of the pollutants accumulated.

2.5.1.1 Land Use and Land Cover

Land use refers to the human modification of the natural environment for a specific purpose within the built environment. In terms of urban catchments, land use is typically categorised into residential, commercial and industrial. These different land use types are characterised by differences in various anthropogenic activities, such as traffic volume, vehicle types, vegetation cover and maintenance activities and population density. In addition to an individual land use, a mixed land use within a catchment contributes to the further complexity of factors which influences stormwater quality. Generally, a mixed urban catchment with range of land use types tends to produce high diversity of pollutant species (Lee et al. 2009). This could lead to a greater complexity in pollutant composition in stormwater runoff. This highlights the importance of linking urban planning with water quality improvement strategies.

Land cover refers to the physical material on the land surface such as grass, asphalt, concrete and roof surfaces. Land use and land cover have a significant influence on the urban environment. In terms of the water environment, different land use and land cover can produce different pollutant species and loads during dry periods (build-up) and hence play a key role in stormwater quality. Industrial land use tends to produce more solids, particularly fine particles, than other land uses

(Miguntanna et al. 2010). This can be attributed to the presence of specific industrial enterprises, traffic characteristics and loading and unloading activities. In the case of land cover (such as roof and road), solid loads from roofs have been noted to be significantly less compared to road surfaces, and to be of much finer in texture (Egodawatta et al. 2009). This is because, compared with roads, roofs are relatively difficult on which to hold pollutants due to the smooth surfaces and atmospheric deposition is the primary contributor to pollutants build-up on roofs.

2.5.1.2 Impervious Surface Fraction

Impervious surface fraction is considered as the one of the most important factors influencing stormwater quality. Compared with pervious surfaces, pollutants on impervious surfaces can be easily removed by stormwater runoff due to the low surface roughness and transported to receiving waters. This needs to be viewed in the context of how impervious area characteristics influence stormwater runoff characteristics. The impervious surface fraction primarily influences pollutant wash-off loads and runoff volume. However, past research studies have found that in modelling approaches, the impervious surface fraction itself is not adequate for accurately estimating stormwater quality. Other parameters, such as the impervious surface type (such as roof and road), are also important characteristics that should be taken into account in modelling. Even though pollutant build-up and wash-off from roof and road surfaces can be replicated using the equations provided in Table 2.1, the coefficients used for these two impervious surfaces are different. For example, as shown in Table 2.2, the wash-off capacity factor (C_F, the capacity of a specific rainfall intensity to mobilise pollutants available on impervious surfaces) for roofs is higher than for roads (Egodawatta 2007). This is attributed to the fact that pollutants on roofs are more easily washed off compared to roads, due to their relatively reduced roughness and steeper slope.

However, in catchments with relatively higher percentages of roof area, the transport of pollutants to the catchment outlet has been found to be slower, particularly when experiencing small rainfall events (Alias 2012). This is due to the fact that distance between the roof and the catchment outlet is commonly longer, compared to a road in an urban catchment. This further confirms the inadequacy of only taking into consideration the impervious surface fraction in water quality modelling.

Table 2.2 Wash-off capacity factors for roads and roofs (Egodawatta 2007)

Rainfall intensity (mm/h)	C_F values	
	Roads	Roofs
20–40	0.3–0.5	0.75–0.91
40–90	0.5	0.91
90–115	0.5–1	0.91–1.0

2.5.1.3 Urban Form

Urban form is an important factor in relation to the impact of urbanisation on the water environment. Urban form, which refers to the physical layout and design of the urban area, including population density, street layout, transportation network and urban design features, can affect water quantity and quality (Breheny 1992). For example, street layout can affect the distribution of drainage systems and the time and velocity of surface runoff while population density and the transportation network are responsible for pollutant generation. Researchers such as Goonetilleke et al. (2005) have found that high-density residential development would be the preferred option in terms of safeguarding water quality, since this type of urban form results in a relatively smaller footprint. Unfortunately, there has been only limited research undertaken to investigate the relationship between urban form and stormwater quality.

2.5.1.4 Urban Area Location

Urban area location is defined as the spatial distribution of urban areas in a catchment. It primarily relates to the distance of the various urban areas from the drainage system or catchment outlet. Changes in urban area location can modify the runoff process, such as the starting time of pervious surface runoff, flow velocity and pollutant load and thereby stormwater quality. When pervious surfaces are located away from the drainage system, the pervious surface runoff may not reach the drainage system, or it will be significantly delayed due to the relatively long travel distance. Also, the required rainfall amount needed to activate pervious surface runoff would have to increase, since a greater runoff loss would occur due to percolation into the ground. Figure 2.5 shows a conceptual illustration of the variations in the inception of runoff due to different pervious and impervious area configurations.

2.5.2 Rainfall Characteristics

Rainfall characteristics are the key influential factor in pollutant wash-off. It is well known that rainfall intensity has an important influence on pollutant wash-off due to the rainfall kinetic energy. The square of the rainfall intensity is used to assess the kinetic energy available in rainfall for the wash-off process (Brodie and Rosewell 2007). However, it is also noted that only a fraction of pollutants built up on the surface are washed off and this is dependent on rainfall intensity (Egodawatta et al. 2007). Vaze and Chiew (2002) proposed two possible alternative concepts of wash-off, namely source limiting (Fig. 2.6a) and transport limiting (Fig. 2.6b). The former represents the scenario where pollutants accumulate from zero and then revert back to the original state after a wash-off event. The latter represents the scenario where

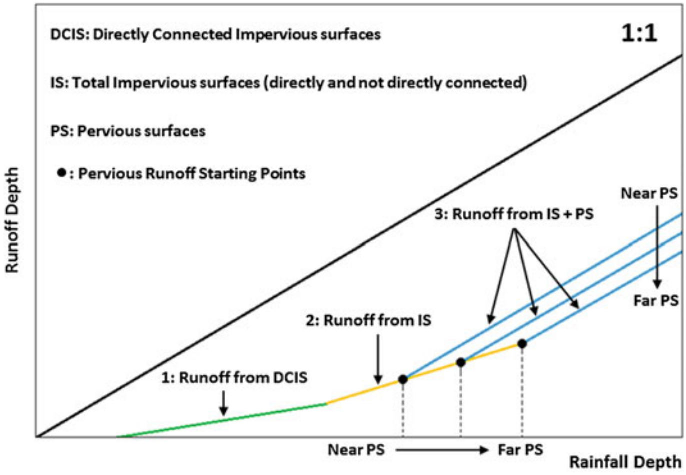

Fig. 2.5 Conceptual illustration of the variations due to different pervious and impervious area configurations (when pervious areas are located further away, runoff has to travel further to enter the drainage system and hence leads to greater continuing loss. This results in a reduced amount of runoff reaching the drainage system)

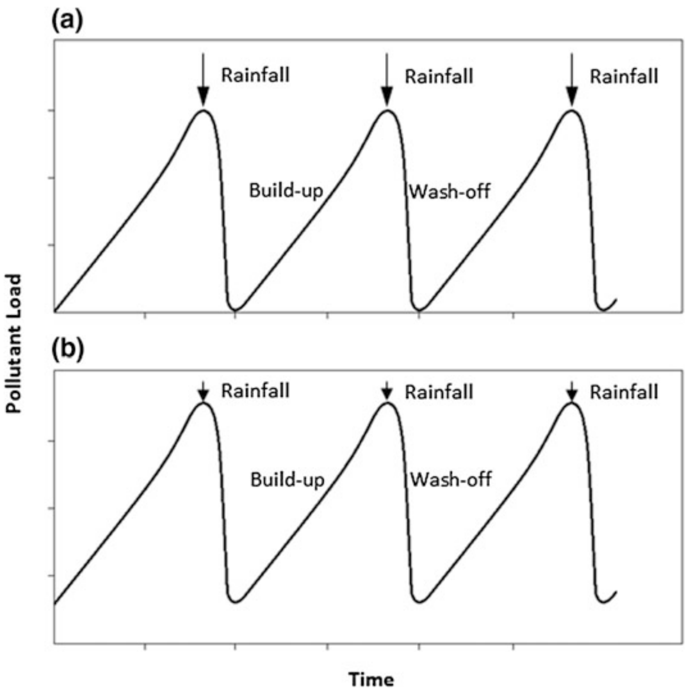

Fig. 2.6 Hypothetical representation of surface pollutant load over time **a** source limiting **b** transport limiting

only a fraction of the pollutants is removed by the wash-off process and the pollutant load is restored back over time to almost the same level as before the rainfall event. Both, the source limiting scenario and the transport limiting scenario may vary for different pollutant types.

In terms of the transport limiting scenario, a capacity factor (C_F, see Table 2.1) has been defined to assess the capacity of solids wash-off. The capacity factor varies between 0 and 1 depending on the rainfall intensity (Egodawatta 2007). When the rainfall intensity is less than 40 mm/h, the capacity factor (C_F) will increase linearly from 0 to 0.5, which is followed by a constant value of 0.5 for 40–90 mm/h intensity, and then varies from 0.5 to 1 as the intensity increases beyond 90 mm/h (see Fig. 2.7). This would imply that it is inaccurate for current models to consider water quality as a continuous function of rainfall intensity rather than a step-wise function, as illustrated in Fig. 2.7.

Although using lumped rainfall characteristics such as average rainfall intensity, it is possible to investigate stormwater quality characteristics, in reality, different sectors of the rainfall event (sectional effect) have different characteristics in the context of their influence on pollutant wash-off. Therefore, the different sectors of a runoff event could exert different influences on stormwater quality. This can be viewed in the context of the occurrence of the first flush phenomenon, which refers to the wash-off of a relatively higher pollutant load at the initial part of a runoff event. Accordingly, it can be concluded that the common approach of using lumped rainfall parameters could overshadow the critical relationships between pollutant wash-off and rainfall characteristics and will not provide an in-depth understanding of the pollutant wash-off process. For example, the occurrence of high intensity in the initial period of a rainfall event will generate a relatively higher magnitude first flush. This is despite the fact that the total rainfall amount could be the same

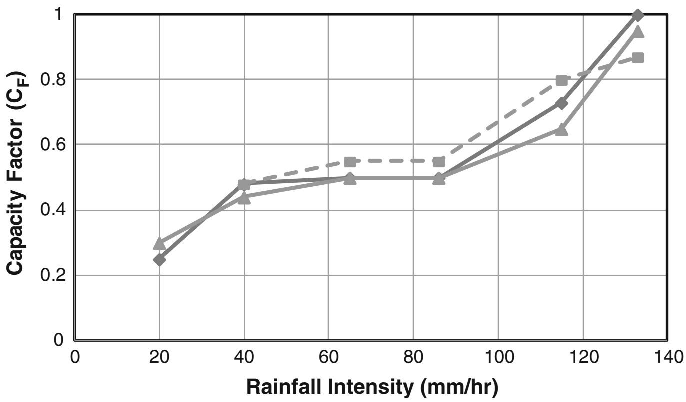

Fig. 2.7 Capacity of solid wash-off with rainfall intensity (Egodawatta 2007) (the three curves represent three residential road surfaces in Gold Coast, Queensland, Australia investigated by Egodawatta 2007)

(Alias et al. 2014a, b). This underlines the fact that the rainfall pattern also plays a critical role in the pollutant wash-off process. In this context, applying this knowledge to current modelling approaches is beneficial for enhancing the accuracy of the estimation of water quality, leading to more effective stormwater treatment design.

2.6 Summary

This chapter has focused on hydrologic and water quality modelling approaches for structural stormwater treatment design. As the primary tool for stormwater treatment design, water quality modelling outcomes require accuracy and reliability. These strongly depend on an in-depth understanding of pollutant processes and the role played by influential factors, including rainfall and catchment characteristics, in influencing the various pollutant processes.

Pollutant build-up and wash-off are the key pollutant processes in relation to stormwater quality. They represent pollutant generation, accumulation and transportation. Current water quality models are primarily developed based on these two processes. However, due to the fact that any model is capable of replicating reality only to an extent based on the prevailing scientific knowledge, the accuracy of modelling outcomes can be questionable. This relates to common issues, such as inadequate model structure, input parameters and modelling approach used.

In this context, significant efforts to explore cutting edge knowledge relevant to stormwater quantity and quality are critically required in order to improve model replication accuracy and thereby, treatment design. Furthermore, it is also essential to understand the influence of catchment characteristics and rainfall characteristics on stormwater quality. Other than conventional catchment characteristics such as land use and impervious surface fraction, other characteristics, including impervious area distribution, urban form and urban area location, are also recommended to be taken into consideration in the modelling approach, due to their role in influencing stormwater quality. Furthermore, it is noteworthy that taking lumped rainfall characteristics such as average rainfall intensity as the factor influencing water quality is not adequate, since other rainfall parameters such as rainfall pattern have been found to exert a significant influence on pollutant wash-off. The practical application of this knowledge can significantly improve model reliability and accuracy, leading to more effective stormwater treatment design.

References

Alias N (2012) First flush behaviour in urban residential catchments. Ph.D, Queensland University of Technology

Alias N, Liu A, Egodawatta P, Goonetilleke A (2014a) Sectional analysis of the pollutant wash-off process based on runoff hydrograph. J Environ Manage 134:63–69

Alias N, Liu A, Goonetilleke A, Egodawatta P (2014b) Time as the critical factor in the investigation of the relationship between pollutant wash-off and rainfall characteristics. Ecol Eng 64:301–305

Ball JE, Jenks R, Aubourg D (1998) An assessment of the availability of pollutant constituents on road surfaces. Sci Total Environ 209:243–254

Breheny MJ (1992) Sustainable development and urban form. Pion

Brodie I, Rosewell C (2007) Theoretical relationships between rainfall intensity and kinetic energy variants associated with stormwater particle wash-off. J Hydrol 340:40–47

Egodawatta P (2007) Translation of small plot pollution mobilisation and transport measurements from impermeable urban surfaces to urban catchment scale. Ph.D, Queesland University of Technology

Egodawatta P, Goonetilleke A (2006) Characteristics of pollution build-up on residential road surfaces. In: 7th international conference on hydroscience and engineering. Philadelphia. http://eprints.qut.edu.au/12660/

Egodawatta P, Thomas E, Goonetilleke A (2007) Mathematical interpretation of pollutant wash-off from urban road surfaces using simulated rainfall. Water Res 41:3025–3031

Egodawatta P, Thomas E, Goonetilleke A (2009) Understanding the physical processes of pollutant build-up and wash-off on roof surfaces. Sci Total Environ 407:1834–1841

Goonetilleke A, Thomas E, Ginn S, Gilbert D (2005) Understanding the role of land use in urban stormwater quality management. J Environ Manage 74:31–42

Lee SW, Hwang SJ, Lee SB, Hwang HS, Sung HC (2009) Landscape ecological approach to the relationship of land use patterns in watersheds to water quality characteristics. Landscape Urban Plan 92:80–89

Liu A, Goonetilleke A, Egodawatta P (2012a) Inadequacy of land use and impervious area fraction for determining urban stormwater quality. Water Resour Manage 26:2259–2265

Liu A, Goonetilleke A, Egodawatta P (2012b) Inherent errors in pollutant build-up estimation in considering urban land use as a lumped parameter. J Environ Qual 41:1690–1694

Mansell MG (2003) Rural and urban hydrology. Thomas Telford Publishing, London

McAuley A, Knights D (2009) Water sensitive urban design stormwater quality modelling guide. Northerm Territory Department of Planning and Infrastructure, Sydney

Miguntanna N, Goonetilleke A, Egodawatta P, Kokot S (2010) Understanding nutrient build-up on urban road surfaces. J Environ Sci 22:806–812

Miguntanna N, Liu A, Egodawatta P, Goonetilleke A (2013) Characterising nutrients wash-off for effective urban stormwater treatment design. J Environ Manage 120:61–67

MIKE URBAN (2008) MIKE URBAN model user manual. Danish Hydraulic Institute (DHI), Denmark

O'Loughlin GG, Stack B (2003) DRAINS user manual. Watercom Pty Ltd, London

Sartor JD, Boyd GB, Agardy FJ (1974) Water pollution aspects of street surface contaminants. J Water Pollut Control Fed 46:458–467

Vaze J, Chiew FHS (2002) Experimental study of pollutant accumulation on an urban road surface. Urban Water 4:379–389

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