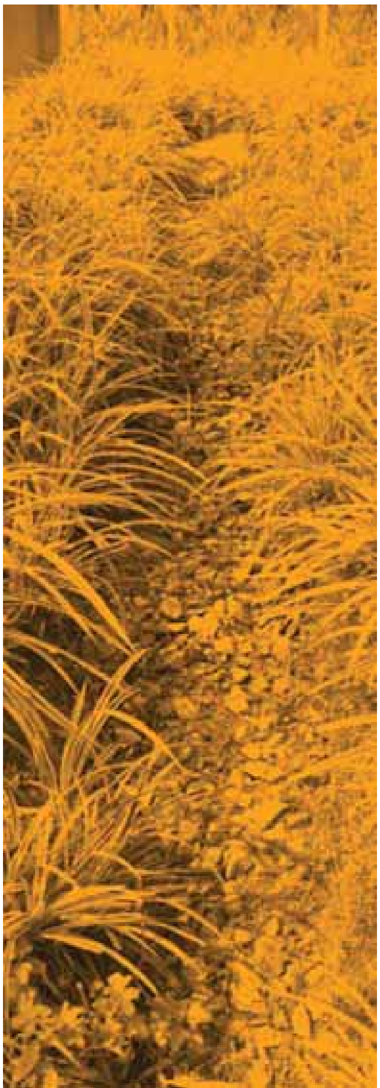
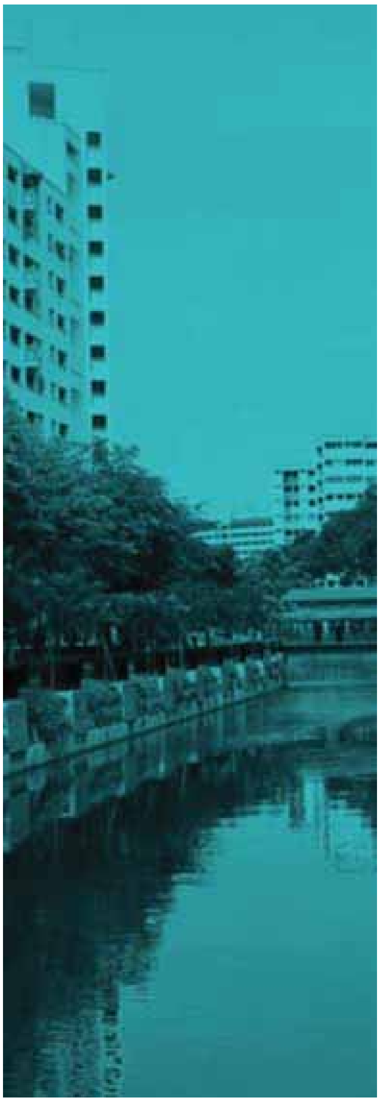
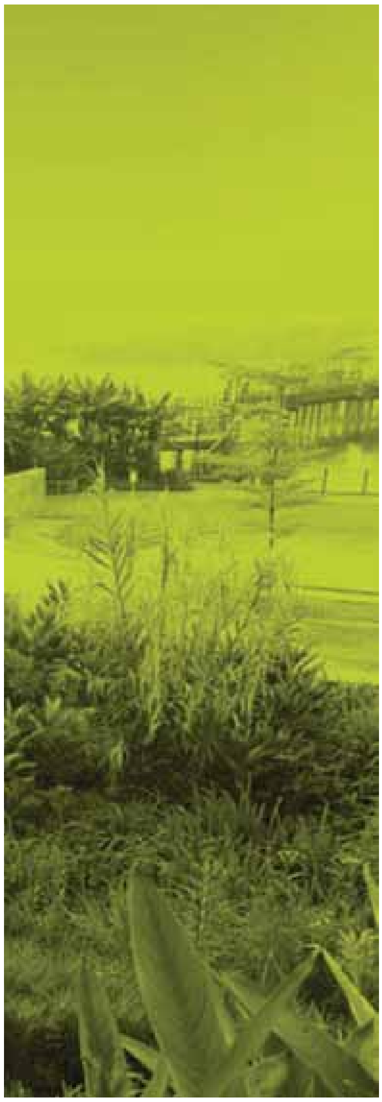
Water for All: Conserve, Value, Enjoy

Managing Urban Runoff

DRAINAGE HANDBOOK

Managing Urban Runoff

DRAINAGE HANDBOOK

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This handbook is jointly produced by PUB, the national water agency and The Institution of Engineers Singapore (IES).

Foreword

With our abundant rainfall and relatively low-lying land, flood management is an ongoing challenge in Singapore. Over the last 30 years, the Government has invested more than $2 billion to upgrade Singapore's drainage infrastructure. These measures have been effective in relieving Singapore of widespread and prolonged floods, with significant reduction in flood prone areas today.

Moving forth, with the challenges of increasing urbanisation and climate change effects, we will adopt a holistic and catchment-wide approach in drainage management. A diverse range of interventions – covering every spectrum of the drainage system from the source, pathways and receptors – will help us manage flood risks more effectively.

This handbook explains the concepts behind the Source-Pathway-Receptor approach in drainage management. It also highlights innovative "Source" and "Receptor" measures that developments can implement to reduce peak flows, while creating aesthetic value and benefits from these measures. The contents of this handbook will be continually refreshed to showcase more 'best practices' and innovative ideas from the development and engineering communities.

I would like to take this opportunity to thank the public agencies and organisations who have contributed to the development of the handbook. This collective effort is a critical step to improving Singapore's flood resilience and creating a more sustainable environment.

Chew Men Leong
Chief Executive
PUB

Engineering plays a key role in building Singapore's resilience against the impact of climate change.

In the face of intensifying rainfall and growing flood threats, The Institution of Engineers, Singapore (IES), as the national society for engineers, will build upon our long-standing relationship with PUB, as well as various government agencies to increase protection against floods for Singapore in two major ways.

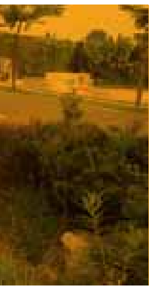
Firstly, we will continue to represent the engineering community at large to provide feedback on professional engineering matters to the government and relevant authorities. Secondly, IES will keep our members and the engineering community abreast of the latest technological developments in the industry and policy requirements from government agencies through courses, seminars and talks.

IES fully supports PUB's holistic 'source-pathway-receptor' stormwater management approach, as it provides a comprehensive set of measures to enhance our drainage systems. We believe that the Handbook on Managing Urban Runoff will become a vital reference on PUB's approach when engineers seek to create and implement engineering solutions to deal with the increasingly challenging environment.

The fight against climate change is long-term. IES is committed to work in partnership with PUB, government agencies, the industry, our members and the engineering community to develop innovative, sustainable and cost effective strategies and solutions to achieve desired levels of flood protection for Singapore in the long run.

Chou Siaw Kiang
President
The Institution of Engineers Singapore

Contents



Introduction

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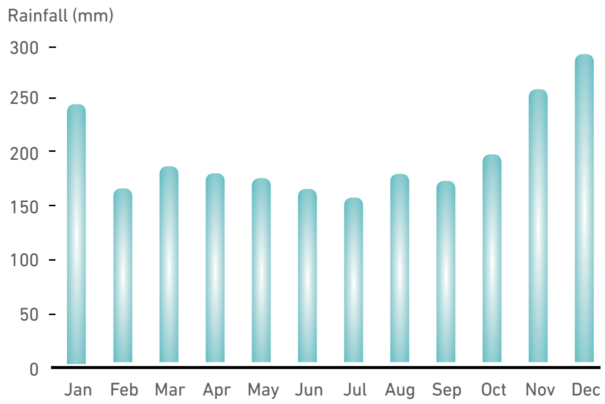


Figure 1.1 Mean monthly rainfall in Singapore.

1.1 Background

As a tropical island located 1.5° north of the Equator, Singapore experiences a hot and wet climate, with about 2400 millimetres of precipitation annually. Storms come in the form of monsoon surges, Sumatra Squalls and sea breeze-induced thunderstorms. December is usually the wettest month of the year in Singapore (Figure 1.1).

Singapore is relatively flat, with pockets of low-lying areas located along the southern and eastern coastal fronts, and some further inland (Figure 1.2). These areas face higher flood risks, especially when heavy rains coincide with high tides.

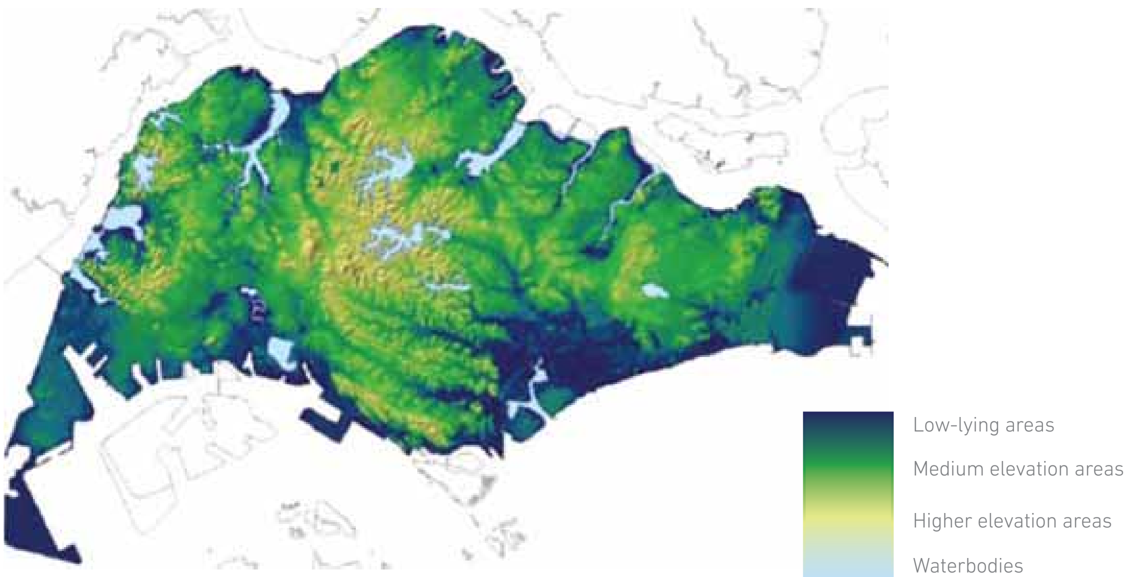


Figure 1.2 Topography of Singapore.

Figure 1.3 View of the Marina Reservoir, Singapore's first reservoir in the heart of the city. With a catchment area of 10,000 hectares, or one-sixth the size of Singapore, the Marina catchment is the island's largest and most urbanised catchment.

At the same time, like many other Asian cities, Singapore has undergone rapid urbanisation over the last few decades, with the population increasing from 1.6 million people in 1960 to 5.31 million people in 2012[1]. Over time, the development of high-density satellite towns, residential and commercial developments, has resulted in an increase in paved (impervious) areas and a reduction in green spaces. During a storm event, this results in an increase in peak flows where more runoff is generated and flows faster into the drainage system over a shorter period of time instead of being regulated by infiltration into the soil and through evapotranspiration (Figure 1.4).

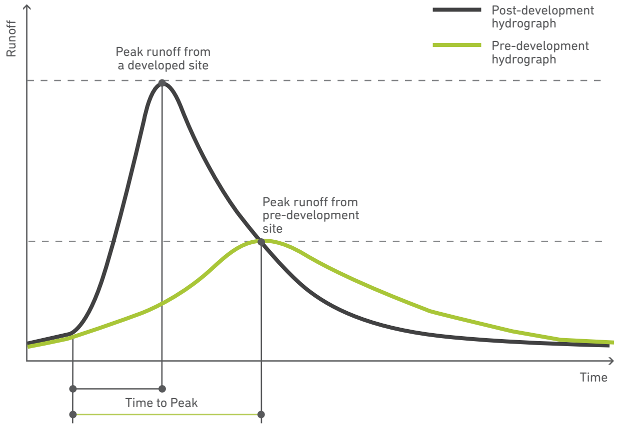


Figure 1.4 Storm hydrograph showing the difference in peak runoff between an urbanised area and a pre-development, or greenfield site. The greater the degree of urbanisation, the higher the peak runoff over a shorter period of time.

1.2 PUB's Stormwater Management Strategies

PUB manages flood risks in the following ways:

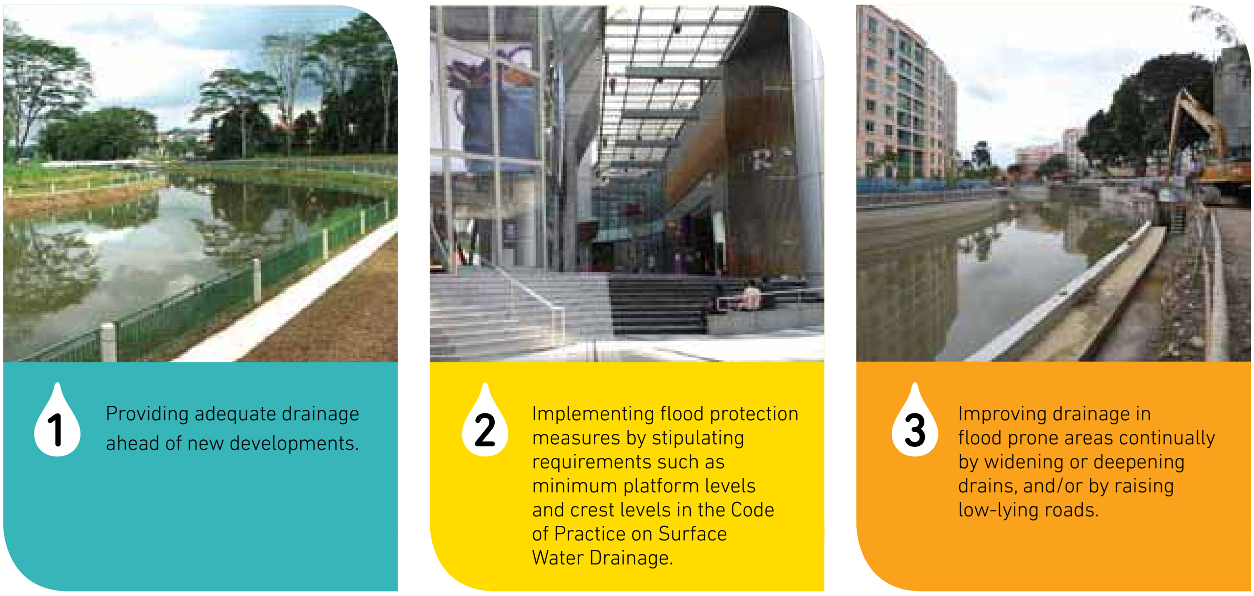


Figure 1.5 Summary of PUB's stormwater management strategies.

These strategies have been effective in reducing the extent and duration of floods in Singapore such that floods experienced today mostly occur in a small locality and subside within an hour.

Note

1 Data from Department of Statistics, Singapore.

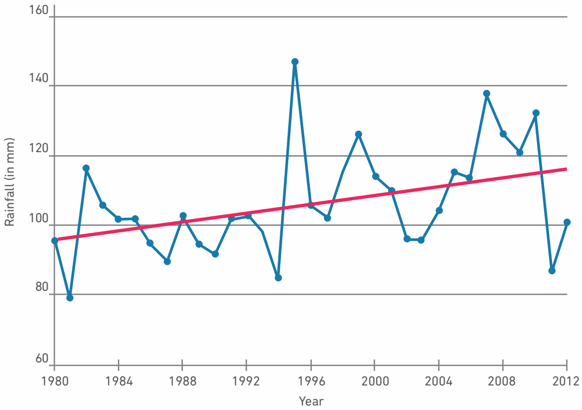


Figure 1.6 Annual maximum hourly rainfall intensities in Singapore (based on records from 28 stations, from 1980 to 2012).

1.3 The Need for Holistic Stormwater Management

Rainfall data from 1980 to 2012 has shown a trend towards higher rainfall intensities (Figure 1.6) and an increasing frequency of high intensity rain events. In addition, climate change effects of sea level rise and increases in rainfall intensities make it necessary for drainage infrastructure to be upgraded and drainage requirements to be raised in order to protect developments from flood risks.

However, widening drains to increase drainage capacity is challenging in land-scarce Singapore. Rapid urbanisation over the last few decades due to population and economic growth has resulted in competing land uses and limited land available for expanding our drainage systems.

A wider range of interventions is thus necessary to help Singapore secure a more adequate drainage system for the future. This includes implementing higher drainage design standards and holistic solutions, building new capabilities and working with stakeholders to improve preparedness.

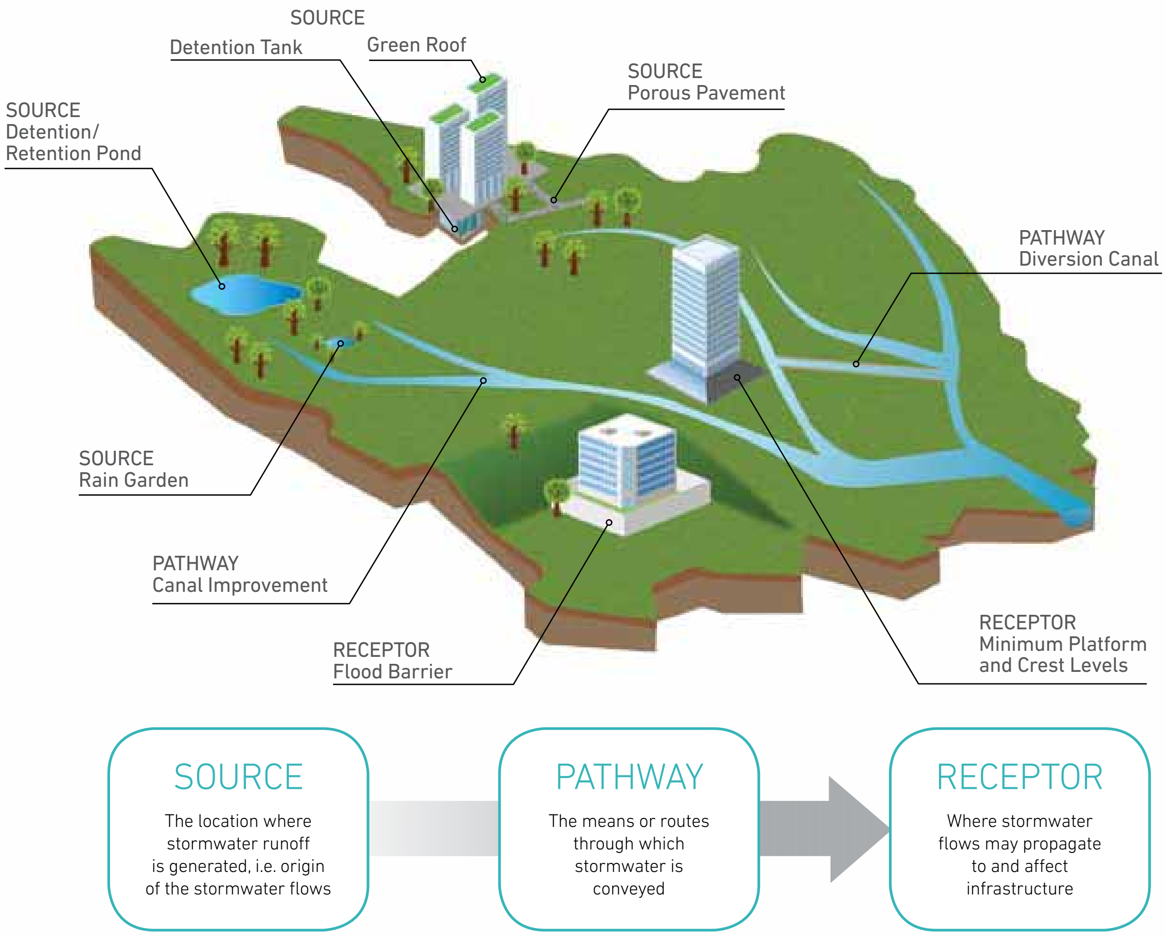


Figure 1.7 Examples of Source, Pathway and Receptor solutions to slow down and reduce peak runoff and to protect developments (receptors) from flood hazards.

Recognising that expanding canals and drains will not be sufficient, especially for areas that are more developed and have site constraints, PUB will go beyond implementing ***pathway*** solutions (e.g. drain capacity improvements, diversion canals, centralised detention tanks and ponds, etc.) to working with developers to put in place ***source*** solutions (e.g. decentralised detention tanks and ponds, green roofs, rain gardens, porous pavements, etc.) to better manage stormwater runoff, and ***receptor*** solutions (e.g. urban flood plains, raised platform levels, flood barriers, etc.) to protect developments from floods. By implementing a range of appropriate measures that covers every spectrum of the drainage system, flood risks can be more significantly reduced and effectively managed (Refer to Figure 1.7)[2].

Figure 1.8 Acting both as a pathway and source solution along Kallang River, Bishan-Ang Mo Kio Park is an integrated multi-functional space that provides active recreational spaces for park users during dry conditions, but morphs into a floodplain during rain events, providing additional drainage capacity for the waterway.

1.4 Benefits of Holistic Stormwater Management

The benefits of holistic stormwater management are manifold. They include:

- Contributing to community safety and financial risk management by reducing the risk of urban flooding.
- Providing social benefits and improved/enhanced liveability.
    - Stormwater detention and conveyance elements of high aesthetic value like green roofs, bioretention swales, rain gardens and constructed wetlands can be integrated within the development. Beyond slowing down runoff and improving stormwater quality, these multi-functional spaces can also present recreational and educational opportunities by providing a fun and creative platform for people to interact and learn about water.

Note

2 One of the key recommendations from the Expert Panel Report on Drainage Design and Flood Protection Measures, released by MEWR in January, 2012.

- Supporting environmental sustainability.
  - Developers and building owners can demonstrate their commitment to the environment by incorporating sustainable features and environmental best practices which are aligned with nationwide schemes like the Building and Construction Authority's (BCA) Green Mark Scheme and PUB's Active, Beautiful, Clean Waters (ABC Waters) Certification Programme.
  - Stormwater stored on-site can be used for a wide range of non-potable uses such as irrigation, general washing, etc. thereby reducing potable water consumption. As part of PUB's effort towards water conservation, developments are encouraged to incorporate water reuse strategies for non-potable uses.

1.5 Goals of the Handbook

This handbook aims to provide guidance to the development community and licensed professionals on the planning, design and implementation of source and receptor strategies to comply with requirements stipulated in PUB's Code of Practice on Surface Water Drainage. The handbook highlights the need for effective design of on-site stormwater management and flood protection measures. It provides information on applicable concepts and implementation strategies to facilitate a flexible approach towards the design of stormwater drainage systems to meet targeted needs of public and private developments while complying with PUB's standards and requirements for flood mitigation. The handbook also showcases innovative architectural and engineering designs that integrate flood mitigation measures within the development.

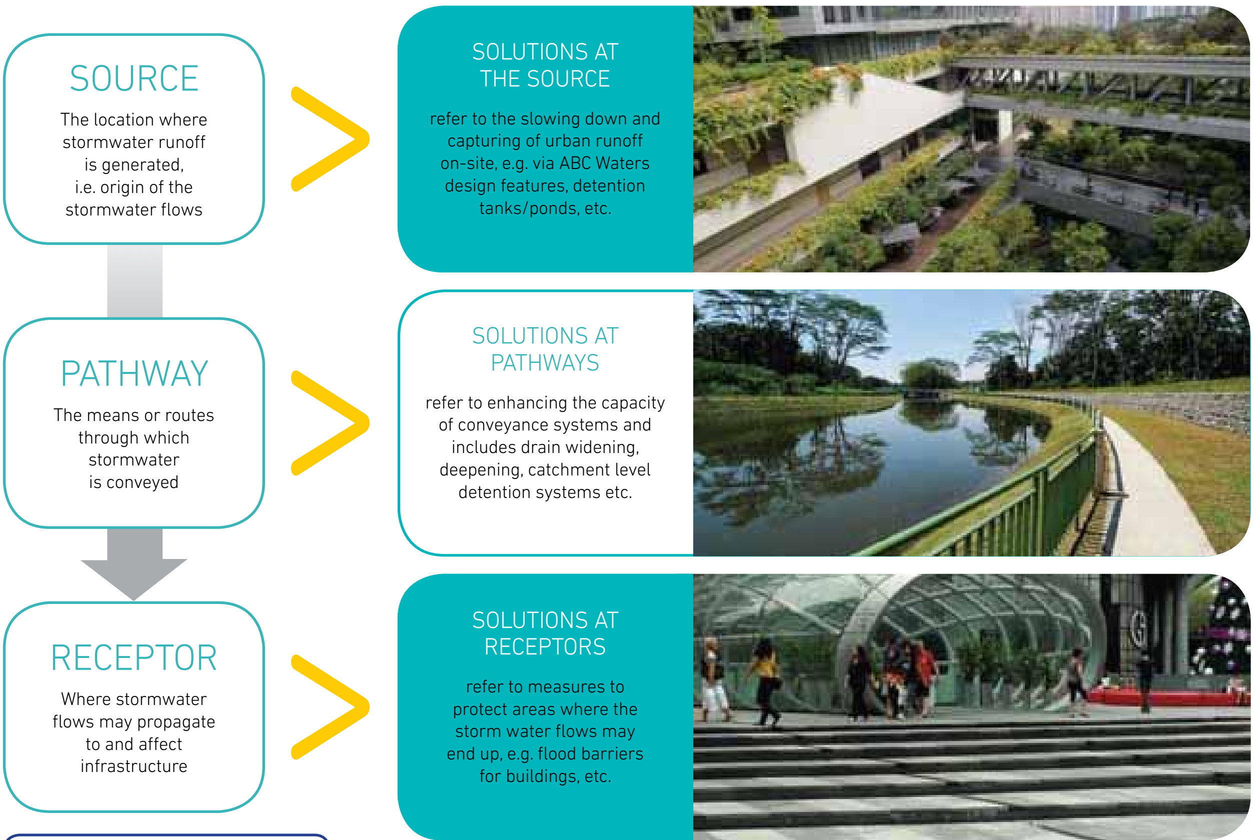


Figure 1.9 Source-Pathway-Receptor Approach.

Resources For Designing Stormwater Drainage Systems

2

2.1 Overview

In accordance with the Sewerage and Drainage Act, PUB has established a Code of Practice on Surface Water Drainage (COP) that specifies the minimum engineering requirements for the planning, design and construction of drainage systems to ensure the adequacy of drainage provisions for developments.

PUB has also developed the Active, Beautiful and Clean Waters (ABC Waters) Design Guidelines and Engineering Procedures for ABC Waters Design Features to provide developers and industry professionals with a reference on how to implement environmentally sustainable green features or ABC Waters design features in their developments.

This chapter will also briefly introduce other relevant resources pertaining to the design and implementation of stormwater drainage systems.

The list of resources and regulatory references provided in this Handbook are not exhaustive. Qualified Persons (QPs) designing these systems are responsible for verifying all other applicable agency regulations for their developments and ensuring that their designs comply with other regulatory requirements.

Figure 2.1 PUB's Code of Practice on Surface Water Drainage and ABC Waters Design Guidelines.

How does PUB's Drainage Consultation Process work?

PUB's drainage consultation process involves reviewing building plans to ensure that all necessary drainage technical requirements have been met and are consistent with the COP. The following chart shows the sequence of a typical drainage consultation:

1 Before proceeding with the design of a proposed development, Qualified Persons (QPs) will approach the Central Building Plan Department of the National Environment Agency (CBPD/NEA) to obtain drainage information related to the development site, such as the location and size of drainage reserves, minimum platform level (MPL) and land safeguarded for future drainage schemes. QPs will also verify drains on-site and MPL for effectual surface water drainage.

2 QPs submit Development Control (DC) plans for clearance with CBPD. For drainage consultations, PUB (through CBPD) will check to ensure that:

1. Proposed buildings/structures do not encroach into drainage reserves and common drains;
2. Platform level of the development complies with the MPL for effective surface water drainage;
3. Minimum crest level is provided for underground facilities and linkages; and
4. Additional drainage facilities such as pumped drainage systems and detention tanks are provided where necessary.

3 QPs submit Building Plans (BPs) and Detailed Plans (DPs) of building works as well as related building services. PUB (through CBPD) will check for compliance with the COP.

4 During Temporary Occupation Permit (TOP) clearance, QPs are required to declare that their platform and crest levels comply with the COP. This declaration shall be supported by as-built survey plans prepared by a Registered Surveyor and submitted to CBPD.

5 Upon completion of works, the QPs shall certify and submit a Certification of Inspection for Drainage Works to PUB as part of the requirements for Certificate of Statutory of Completion (CSC) stage. Drainage works to be handed over to PUB shall have a one year Defects Liability Period. The Defects Liability Period shall commence from the date PUB gives no objection to the issue of the CSC.

Note

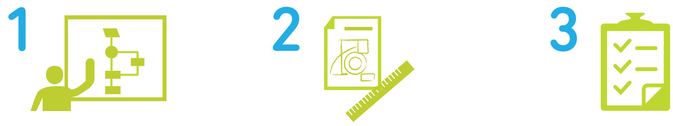
"QP" refers to a Qualified Person who is an Architect or a Professional Engineer or a suitably qualified person registered under relevant legislation (e.g. Architects Act 1991, Professional Engineers Act 1991)

The COP is available on the PUB website: **http://www.pub.gov.sg/general/code/**

2.2 The Code of Practice on Surface Water Drainage

PUB's drainage design approach is comprehensively documented in the Code of Practice (COP) on Surface Water Drainage which is available on the PUB website. The COP is issued under Section 32 of the Sewerage and Drainage Act (Chapter 294). It specifies the minimum engineering requirements for surface water drainage. Qualified Persons shall ensure that all aspects of surface water drainage are effectively taken care of in their planning, design and implementation of the development proposals.

The COP describes the following for developments:



1 **Planning requirements**

2 **Design requirements**

3 **Guidelines to ensure the integrity of stormwater drainage systems**

2.3 ABC Waters Design Guidelines

The ABC Waters programme, launched in 2006, is a strategic stormwater management strategy which aims to enhance environmental aesthetics and improve the quality of water by harnessing the full potential of our waterbodies. This is done by integrating the waterways and waterbodies with the surrounding environment to create community spaces and a sustainable living environment.

The ABC Waters design guidelines were developed based on the following principles:

a) Mitigating the impact of urbanisation by retention and/or detention of runoff and minimising impervious areas through the implementation of ABC Waters design features.

Figure 2.2 ABC Waters project at Punggol Reservoir – Sengkang Floating Wetland.

b) Improving runoff water quality from the development site into the receiving environment.

c) Integrating stormwater treatment into the landscape by incorporating multiple-use corridors that maximise the aesthetics and recreational amenities of developments.

d) Protecting and enhancing natural water systems within the development site.

The ABC Waters Design Guidelines are available on the PUB website: **http://www.pub.gov.sg/abcwaters/**

In its inception phase, the ABC Waters programme focused on public areas where blue and green elements could be woven into the urban fabric. In this Handbook, the initiative is now extended to private development parcels where stormwater begins its course. Source solutions can utilise the ABC Waters concept by detaining stormwater and treating it closer to the source before it is discharged into public waterways.

When adopted holistically as part of drainage systems design, ABC Waters design features would help to introduce additional flexibility within the system to cope with intense rainfall that exceeds the design storm. In particular, ABC Waters design features could be coupled with other stormwater detention systems (i.e. tanks, surface ponds, etc.) to shave off the peak flows generated by intense rainfall, thereby reducing flood risks to the development and the larger catchment as well.

2.3.1 ABC WATERS CERTIFICATION

ABC Waters Certification is a scheme designed to provide recognition to public agencies and private developers who embrace the ABC Waters concept and incorporate ABC Waters design features in their developments. Besides providing recognition, the scheme also aims to ensure that the design features incorporated within the developments achieve a minimum design standard.

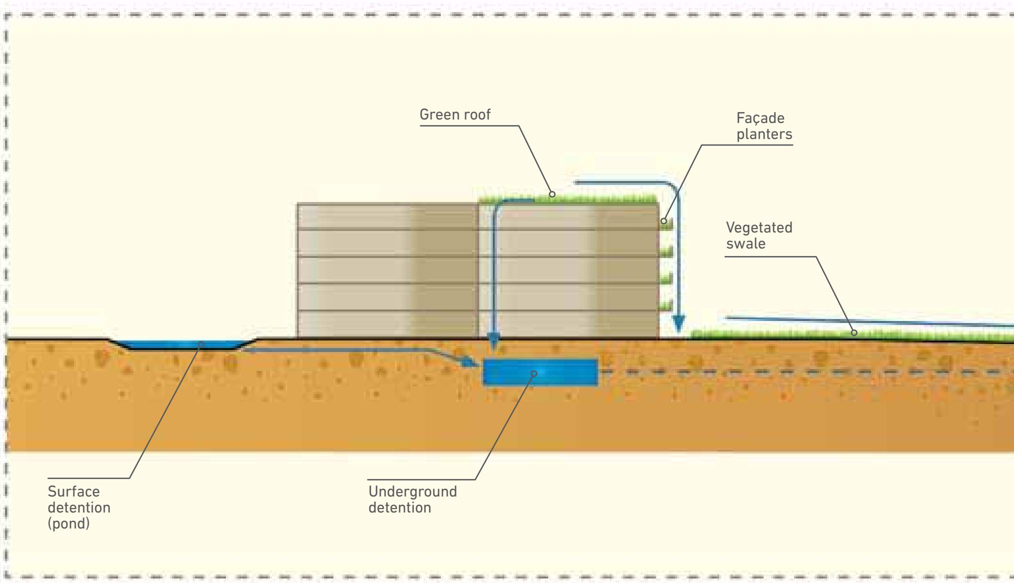


Figure 2.3 An example of how ABC Waters design features can be integrated within a building development to reduce runoff and peak flow.

2.4 Other Resources

2.4.1 CODE OF PRACTICE ON ENVIRONMENTAL HEALTH

Certain stormwater drainage features such as bioretention swales, detention or retention ponds may be subject to the *Code of Practice on Environmental Health (COPEH)*, published by the Environmental Health Department of the National Environment Agency (NEA). The COPEH provides guidelines on environmental health concerns, such as mosquito control, lists the objectives to be met and stipulates the minimum basic design criteria.

The COPEH is available on the NEA website: **http://cms.nea.gov.sg/codeofpractice.aspx**

2.4.2 CODE FOR ENVIRONMENTAL SUSTAINABILITY AND BCA'S GREEN MARK SCHEME

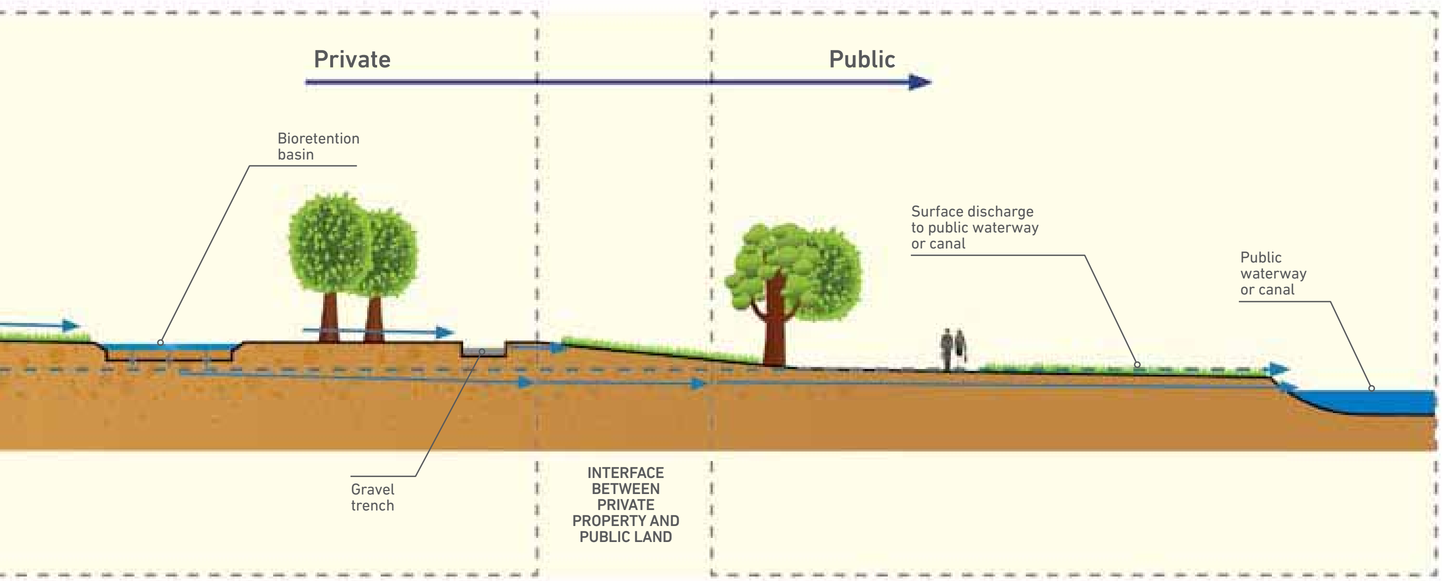
The *Code for Environmental Sustainability of Buildings* describes the minimum environmental sustainability standard for buildings and apply to:

All new building works which involve a:

- Gross floor area of 2000 square metres or more;
- Additions or extensions to existing buildings which involve increasing the gross floor area of the existing buildings by 2000 square metres or more; or
- Building works which involve major retrofitting to existing buildings with existing gross floor area of 2000 square metres or more;

The BCA Green Mark Scheme is an initiative that aims to drive Singapore's construction industry towards more environmentally friendly buildings. It is intended to promote sustainability in the built environment and raise environmental awareness among developers, designers and builders when they start project conceptualisation and design, as well as during construction. Under this scheme, stormwater management within development sites can be considered for potential Green Mark points under Building Control (Environmental Sustainability) Regulations 2008, RB 3-6, NRB 3-7 Stormwater Management; RB 2-3 Irrigation System and Landscape.

The Code for Environment Sustainability of Buildings and information on the Green Mark Scheme is available on the BCA website: **http://www.bca.gov.sg**



Source Solutions to Manage Stormwater On-site

Figure 3.1 Example of Source (park and nearby developments) which contributes runoff to the Pathway (waterway) in Bishan-Ang Mo Kio Park.

3.1 Where is the Source?

In the Source-Pathway-Receptor approach, the Source is defined as the location where stormwater runoff is generated through precipitation that lands on the development site (Figure 3.1). It is where on-site stormwater controls can be strategically implemented to mitigate the impact of increased runoff rates associated with urbanisation.

3.2 The Need for Managing Runoff at Source

In a highly urbanised environment like Singapore, many developments are largely made up of impervious surfaces such as roofs, parking lots, streets and sidewalks that do not allow rainwater to infiltrate into the ground, generating increased runoff that enters the stormwater drainage system. As a result, during intense storms, peak runoff from the urbanised catchment may exceed the design capacity of public drains, resulting in flash floods.

Source solutions provide temporary storage of stormwater on-site and release it at a controlled rate to the downstream drainage system. Retention and/or detention features, coupled with effective conveyance systems, can reduce peak runoff rates from development sites, thereby reducing the risk of excessive flows in the downstream drainage system which can cause flooding. These solutions build in additional flexibility into the drainage system to cope with increased weather uncertainties and higher intensity storms, while contributing to water quality improvement and ecological enhancement in downstream receiving waters.

What is Pre-Development and Post-Development Runoff?

Pre-development runoff is a measure of how runoff behaves in a site prior to introducing hardscape like buildings, roads and other land uses. Without development, a site typically exhibits low runoff values, which means that during a rain event, most of the rainfall is intercepted by vegetation and infiltrates into the soil, with a small portion being transformed into runoff.

Post-development runoff is a measure of how runoff behaves in a site after urbanisation, which involves the conversion of green areas into impervious areas (e.g. roads and pavements). These impervious surfaces prevent rainwater from infiltrating into the ground, and as a result, most of the rain that falls within the site is converted into runoff at a much faster rate and higher volume than the naturally occurring rate (pre-development runoff rate).

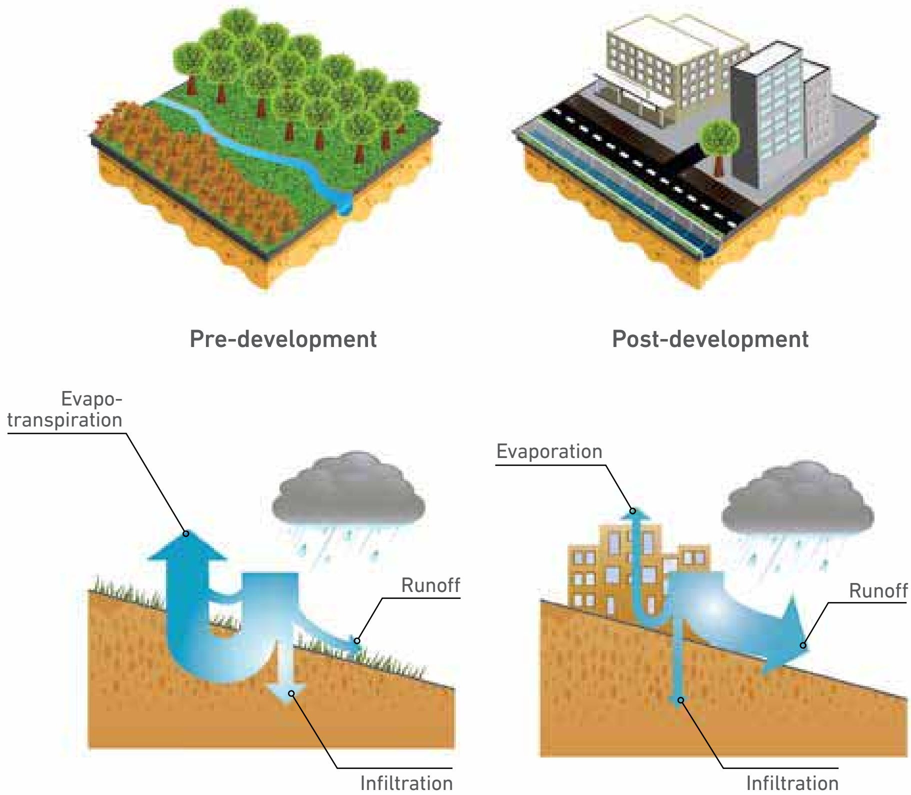


Figure 3.2 Comparison of runoff behaviour under pre-development and post-development conditions.

3.3 Strategies for Planning, Designing and Implementing Source Solutions

The following sections provide guidance on the main steps for planning, designing and implementing stormwater detention facilities and features. Although the process is presented as a series of steps, in practice it should be iterative.

Step 1: Determine the catchment area served by the drainage system

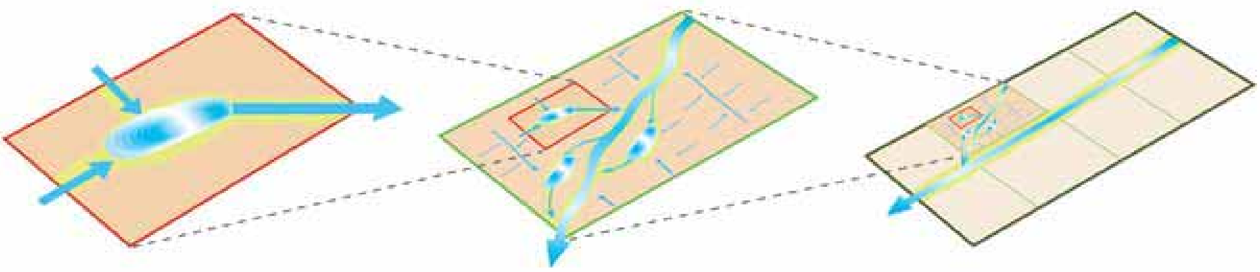
Step 2: Calculate developed runoff coefficients and peak runoff rates

Step 3: Determine maximum allowable peak discharge

Step 4: Determine and design conveyance, detention and/or retention strategies and discharge outlet

Step 1: Determine the catchment area served by the drainage system

A catchment refers to the area which contributes runoff to a defined drainage system and discharge point. For developments where runoff from the site is discharged into the public drainage system through a single discharge point, the catchment area served by the development's drainage system is the size of the development lot. A development can also be made up of different sub-catchments, depending on the topography and layout of the drainage systems.



Individual development parcels should implement on-site detention and conveyance measures to reduce discharge rates from the development.

Larger developments can use a wider range of detention strategies (e.g. centralised detention) to slow down and reduce peak runoff.

Peak flow attenuation at different scales of development ensures controlled releases to the public drainage system.

Figure 3.3 Varying scales of stormwater detention measures implemented on-site help to attenuate peak runoff in the public drainage system.

Rational Method Equation

$$Q = \frac{1}{360} CIA$$

where

Q = Peak runoff at the point of design (m^3/s)

C = Runoff coefficient

I = Rainfall intensity (mm/hr)

A = Catchment area (hectares)

Step 2: Calculate developed runoff coefficients and peak runoff rates

The Rational Method is used to compute the peak runoff from the catchment that the drainage system should cater for to reduce flood risks within the development. Depending on the proposed land use types, the overall runoff coefficient for a developed area can range between 0.45, for parks with lush greenery and ponds, and close to 1, for developments consisting almost solely of impervious surfaces like airports and commercial developments in highly urbanised areas.

Step 3: Determine maximum allowable peak discharge

New developments can do their part to reduce the impact of urbanisation on peak flows in the drainage systems by implementing measures to reduce their post-development runoff rates. To this end, PUB has imposed a mandatory requirement in the Code of Practice on Surface Water Drainage (Clause 7.1.5) for new developments and redevelopments to control peak runoff from the development sites into the public drainage system.

Step 4: Determine and design conveyance, detention and/or retention strategies and discharge outlet

Peak runoff reduction can be achieved through the implementation of ABC Waters design features and structural detention and retention features. *The Engineering Procedures for ABC Waters Design Features* provides specific guidance on the selection, sizing, construction and maintenance of ABC Waters design features, and should be referred to for the design of such features. Conveyance systems within the site should also be designed to effectively transport runoff from one location to the other and finally to the public drainage system. As PUB regulates the maximum allowable peak discharge from the site, the design of the discharge point from the development site to the public drain is crucial. Discharge by gravity flow is preferred since it reduces operational costs. However, discharge via other structures like pumps, orifices and overflow weirs can also be considered, depending on the design of the stormwater drainage system used on-site.

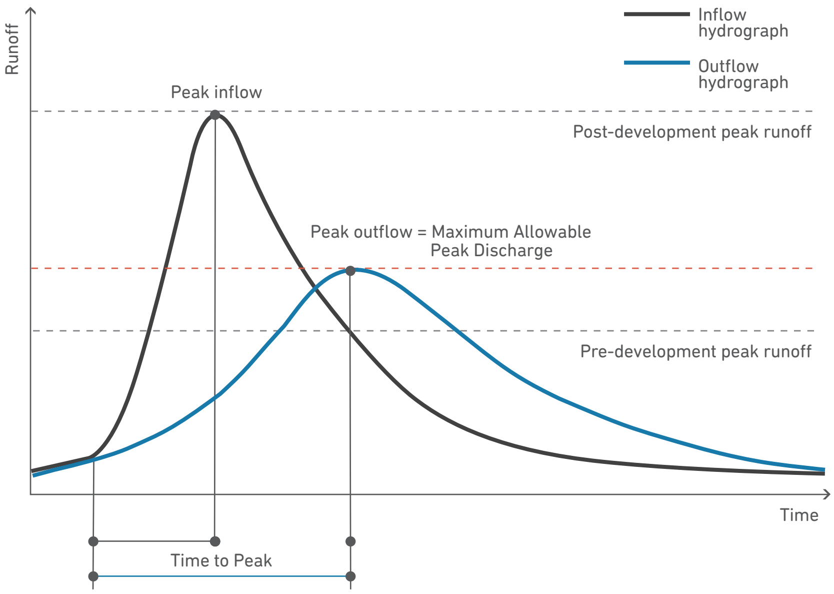


Figure 3.4 The inflow hydrograph depicts post-development runoff without runoff control. The outflow hydrograph is determined by the design of the outflow structure. The red line indicates the maximum allowable peak discharge to the public drains.

What is the Difference between Detention and Retention?

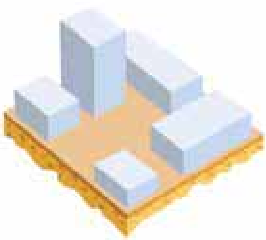
The main difference between a detention and retention basin is whether or not it has a permanent pool of water. Detention basins are also known as "dry" basins where the water is drained out in between storms, while retention basins usually retain a certain amount of water for aesthetic or water quality treatment objectives. Both detention and retention basins are important for storing and slowing (attenuating) the peak runoff from impervious surfaces.

Figure 3.5 Detention pond in the Arkadien Winnenden residential development in Germany.

Figure 3.6 Yishun Pond, a stormwater retention pond adjoining Khoo Teck Puat Hospital.

3.4 General Design Considerations for Stormwater Detention and Retention

Other than determining the volume of runoff to be detained or retained on-site to meet the requirements stipulated in the COP, designing a stormwater drainage system requires careful analysis of the space availability, topography, site obstructions as well as other considerations like maintenance and safety (which will be covered in Chapter 5).



Programmatic constraints

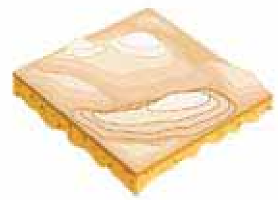
3.4.1 SPACE AVAILABILITY FOR STORMWATER DETENTION ELEMENTS

If open space for detention or retention on the ground level is limited, space-efficient alternatives such as green roofs, planter boxes and other façade conveyance systems can be used. Another viable alternative to surface detention is underground detention. Surface runoff can be channelled to an underground tank or tanks, to detain and reduce peak runoff from the site. Underground detention tanks are ideal for sites with larger proportions of impermeable surfaces. This is because runoff that is quickly generated from pavement and other impermeable surfaces can be effectively channelled and stored in underground detention tanks.

The space available within a development parcel will also determine the type of conveyance system that is most appropriate. If there is adequate open space between buildings within a development site, surface detention systems like vegetated swales or bioretention swales can be implemented as alternatives to conventional drains. Where space permits, these systems can be linked to each other to form a treatment train for water quality improvement functions.

3.4.2 TOPOGRAPHY

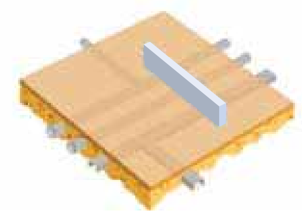
Topography determines how fast water moves from Point A to Point B. On steep topography, runoff will have higher flow rates compared with runoff on a gentle slope. Topography also determines how runoff will travel within and eventually out of the site. Runoff will naturally travel towards indentations in the terrain. As such, site topography can be adjusted to create favourable zones for conveyance and detention of runoff. For example, topographical adjustments can be made to direct runoff to a central location such as a detention or retention pond, or an indentation in the land can be a site for a swale that will transport water from Point A to Point B.



Topographical characteristics

3.4.3 SITE OBSTRUCTIONS

The design of the stormwater drainage system needs to take into consideration obstructions and constructed givens on-site, which may be above ground or below ground. Underground obstructions like pipes and services could create potential space constraints for the implementation of subsurface detention elements. If these obstructions create space constraints, they can be relocated and/or re-designed so that a balance can be achieved. If not, the stormwater drainage system would have to work around these barriers, making the most of the available space to effectively convey runoff from the site, whilst reducing peak flows.



Site obstructions

If the site has existing stormwater drains, they can be retrofitted or substituted with more naturalised conveyance elements like vegetated swales or bioretention swales. If the site constraints are too significant, other detention or retention options can be introduced or intensified. **Stormwater management is a composite system and a combination of elements can be developed to address the opportunities and constraints of each site.**

3.5 Options for Detention and Retention within the Development Site

The detention concept is most often employed in urban stormwater discharge systems to limit peak flow rates from the development site by the temporary and gradual release of stormwater runoff. Detention elements can be connected in a series to form a stormwater treatment train. A treatment train is a series of stormwater management features that work together to slow down water by reducing peak flows and/or improve water quality through a natural cleansing process.

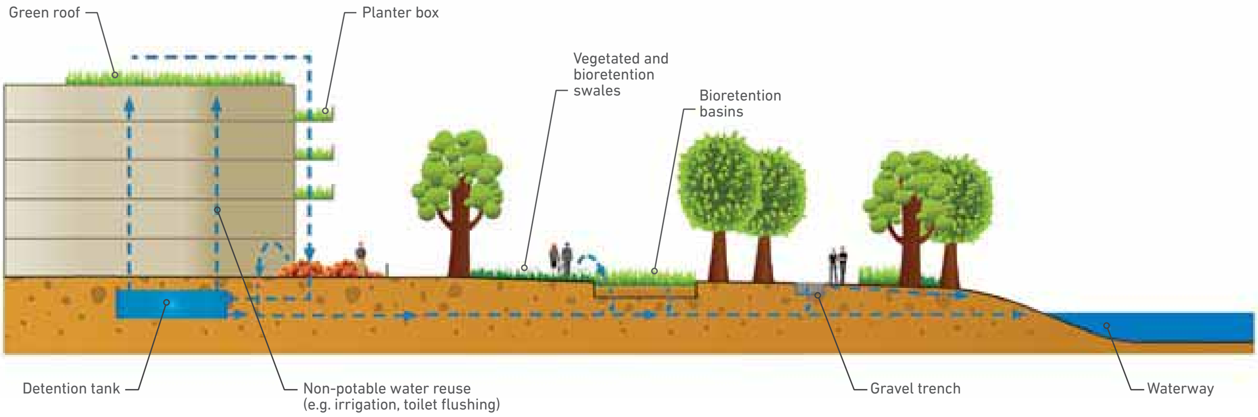


Figure 3.7 Options for on-site detention and retention of stormwater runoff within the development site.

Detention and retention elements can be sited on buildings, on ground level or even underground (Figure 3.7). When determining the size and types of detention and retention options to use, factors like the availability of space, site characteristics (e.g. topography and existing structures), the type and amount of maintenance required, and costs (e.g. capital, operational and maintenance costs) have to be considered.

3.5.1 ON BUILDINGS

Figure 3.8 Landscaped green roof and rooftop garden area on top of Orchard Central Mall.

GREEN ROOFS

The rooftop is where rainwater usually lands first and begins its journey towards the public waterways. Rooftop systems allow for maximised building footprints and are an ideal place to harvest rainwater for reuse. Green roofs are typically constructed with a waterproof membrane, drainage material, a lightweight layer of soil and a cover of plants. The rooftop vegetation captures rainwater allowing evaporation and evapotranspiration processes to reduce the amount of runoff entering downstream systems, effectively reducing stormwater runoff volumes and attenuating peak flows. The amount of storage provided by green roofs is limited by the drainage layers and the controlling weir elevation of the roof drain.

ROOF GARDENS

A roof garden (refer to Figure 3.9) is usually designed to be accessible and utilised as a communal rooftop space, with other features such as pathways, lighting and benches. The soil layer in roof gardens can be deeper to support a diverse range of vegetation, which serve the same functions as a green roof. However, it is important to check the loading capacity of the rooftop to ensure that it can cater to the heavier loads. The main difference between a rooftop garden and a green roof system is the former's more substantial thickness of the substrate and media layer.

Figure 3.9 Roof garden at Central Horizon HDB development in Toa Payoh.

PLANTER BOXES

Planter boxes (Figure 3.10) can also be implemented on building façades or roofs as additional surface area for stormwater management. Apart from being space-efficient systems that can help reduce peak runoff from the building during rain events, stormwater treatment benefits can also be achieved by incorporating a cleansing biotope or bioretention system into the planter boxes.

Figure 3.10 Planter boxes on the sides of the building and along pedestrian bridges at Khoo Teck Puat Hospital.

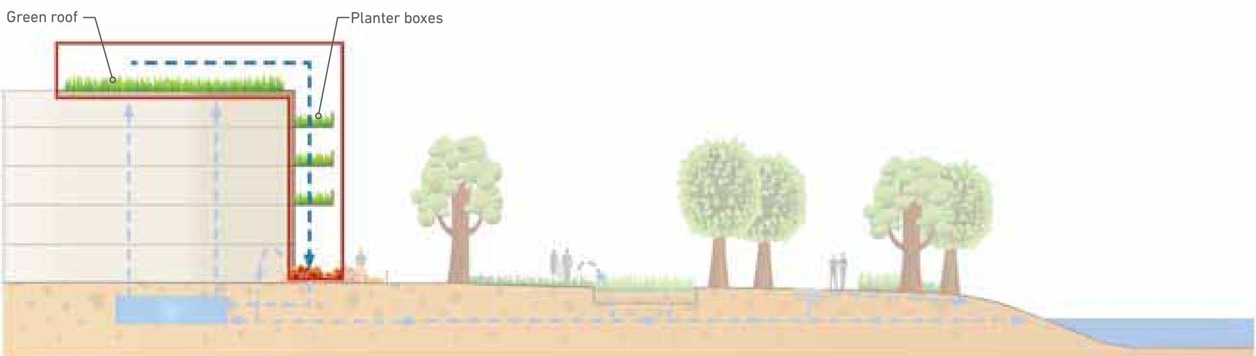


Figure 3.11 On-site stormwater detention and retention options on buildings.

3.5.2 ON GROUND LEVEL

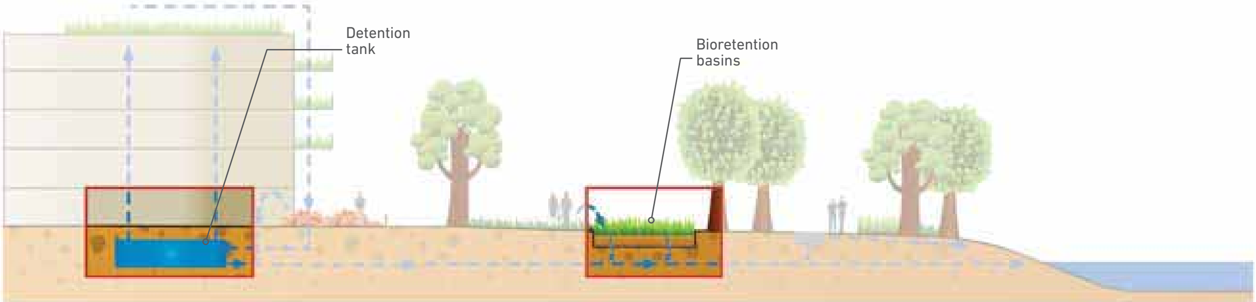


Figure 3.12 On-site stormwater detention and retention options on ground level.

STORMWATER DETENTION OR RETENTION BASINS (PONDS)

Providing storage at source via detention or retention basins can be an effective means of slowing down peak flows for short, high intensity rainstorms. Detention ponds are systems that temporarily store stormwater runoff during the rain event and release it later at a controlled rate to the drainage system. Retention ponds (which hold a permanent pool of water) can also be designed for both peak runoff control and pre-treatment as part of a treatment train with downstream ABC Waters design features. Detention or retention basins can be configured to capture *overflows* from the internal conveyance system (i.e. off-line storage) or *inflows* from the conveyance system (i.e. on-line storage).

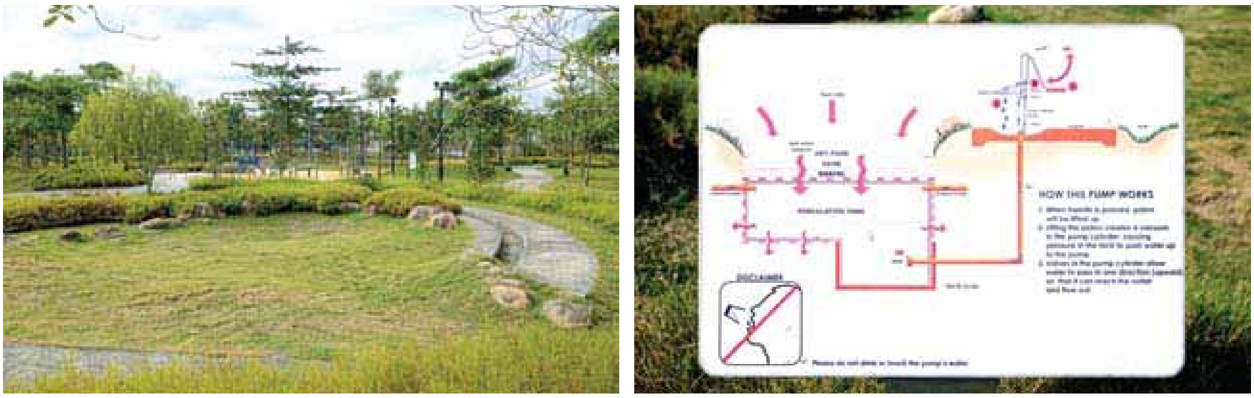


Figure 3.13 Dry pond at Greenwood Sanctuary - During rain events, stormwater runoff flows from the surrounding ground to the dry pond and filters to underground percolation tanks encased in a permeable membrane layer. During dry weather, the lawn area in the dry pond can also be used for recreational activities.

BIORETENTION BASINS OR RAIN GARDENS

Bioretention basins are vegetated land depressions designed to detain and treat stormwater runoff. The runoff is first filtered through densely planted surface vegetation and then through an engineered filter media (soil layer). A perforated pipe within the drainage layer collects and transports the filtered runoff to a downstream detention system or to a designated discharge point.

To allow for maximum runoff reduction, bioretention basins can be integrated with underground storage in the form of gravel layers or detention tanks, whereby excess runoff beyond the surface detention volume of the bioretention basin can be channelled directly into the underground storage detention via an overflow pit. Developments looking to harvest stormwater runoff for reuse may also install an underground detention tank where the filtered stormwater can be stored for reuse.

Figure 3.14 A bioretention basin at Balam Estate with an overflow pit.

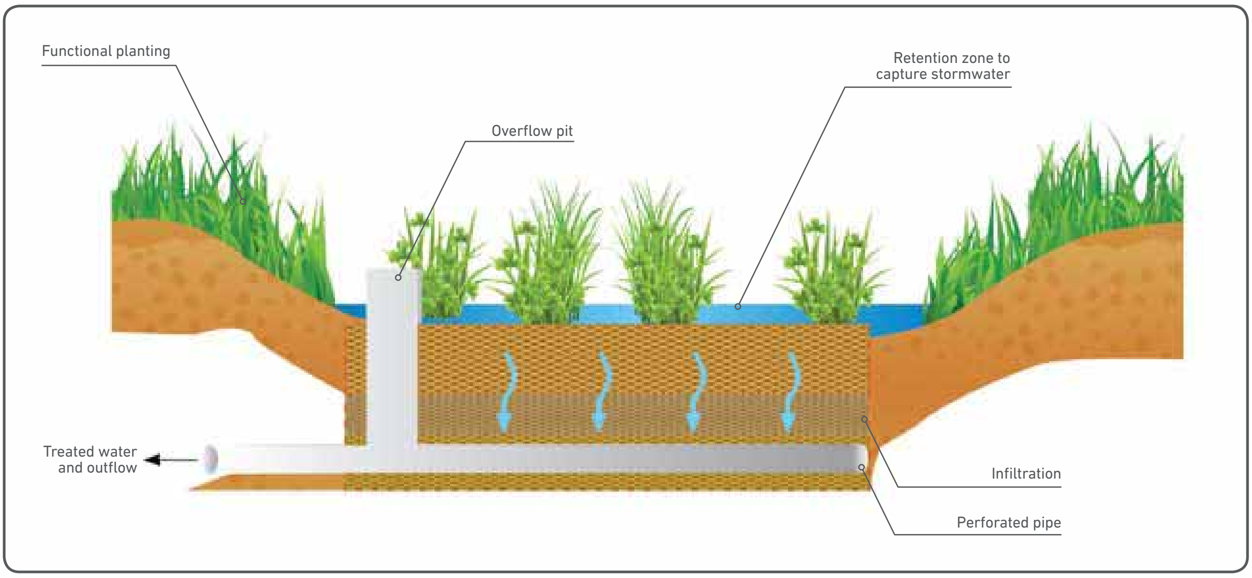


Figure 3.15 A typical section of a bioretention basin.

CONVEYANCE FEATURES THAT PROVIDE DETENTION AND RETENTION

Conveyance systems serve two fundamental functions within a catchment: firstly, to collect runoff and deliver it to detention areas and secondly to channel water from detention areas towards discharge points. They are the most commonly used tools to manage runoff in urban areas as they can be designed to slow down and reduce peak flows. A well-designed stormwater management system could utilise conveyance elements that are linked to detention and retention zones in order to achieve the required targets for peak flow reduction.

SIZING CONVEYANCE SYSTEMS

In addition to catering for flows within the catchment, the size of conveyance elements also depends on the secondary system(s) they are connected to. This means that if a conveyance swale receives water from a surface detention system, it needs to be sized so that it can receive or discharge the desired flows without creating problems upstream or downstream. The regulation of flow volumes can be achieved by understanding the operating rules of the detention system and designing the appropriate conveyance element to support its drainage.

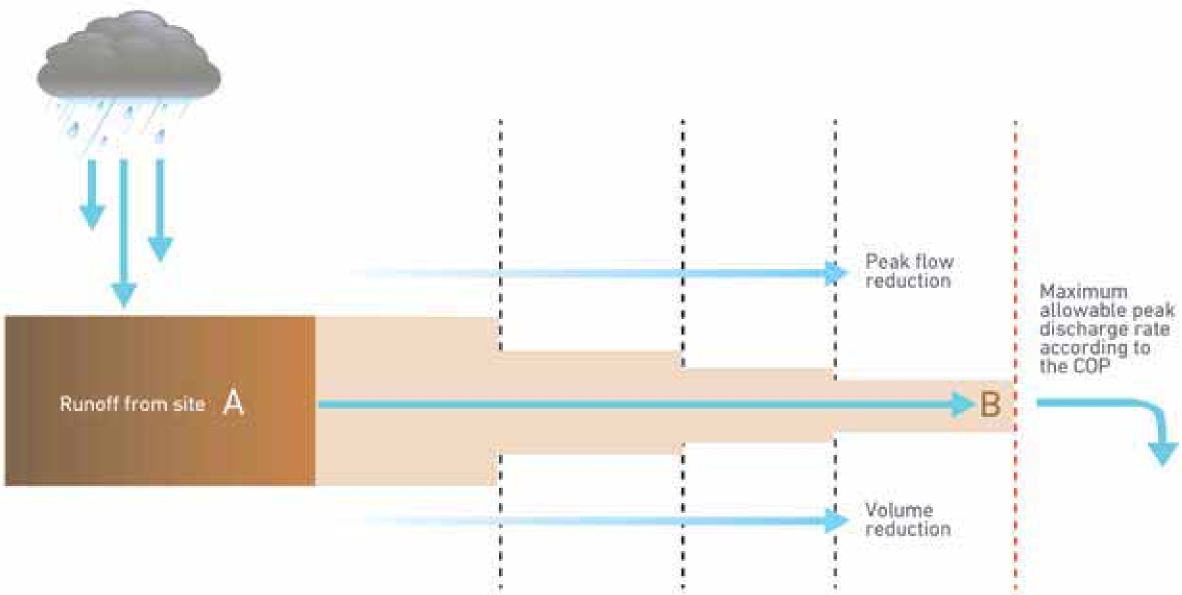


Figure 3.16 Illustration showing the reduction in peak flows and flow volumes as runoff flows through a conveyance system that connects detention and retention features.

VEGETATED AND BIORETENTION SWALES

Vegetated swales are open conveyance channels that are designed to convey stormwater via overland flow while providing green space amenities for a development. As stormwater runoff flows through a vegetated swale, the vegetation in the swale slows down the stormwater flow, promoting the settling of sediments and other pollutants. Swales can reduce the number and cost of storm drains and piping required within the development site and can look like a typical landscaped area. Vegetated swales alone cannot provide sufficient stormwater treatment to meet water quality objectives, but are particularly good at removing coarse sediments and can provide the necessary pre-treatment when combined with downstream treatment such as bioretention systems.

Figure 3.17 Bioretention swales along Margaret Drive.

Bioretention swales provide additional stormwater quality improvements via infiltration through a filter media, with the cleansed runoff being collected via a subsoil perforated pipe. By providing temporary surface detention of runoff, bioretention swales also help to reduce peak flows from the development.

Figure 3.18 Example of a gravel trench serving as a conveyance channel for stormwater runoff.

GRAVEL TRENCHES

A gravel trench (Figure 3.18) is a non-vegetated trench usually filled with stone to create an underground reservoir for stormwater runoff. The runoff volume gradually exfiltrates through the bottom and sides of the trench into the subsoil. The gravel trench is usually part of a conveyance network and is designed with an overflow pipe so that excess flows can be conveyed through the pipe to the drainage system if the detention capacity of the trench is reached. Gravel trenches are not intended to trap sediment and should be designed with a sediment forebay and grass channel or filter strip or other appropriate pre-treatment measures to prevent clogging and failure.

3.5.3 UNDERGROUND SYSTEMS

In addition to surface ponds, detention tanks (refer to Figure 3.19) can also be placed underground to capture runoff and reduce peak flows into the drainage system. Underground detention systems can be valuable stormwater management tools when properly sized, sited and maintained. The design of underground detention systems depends on several factors, such as available space. Detention tanks can be constructed from pre-cast concrete structures, pre-fabricated systems from vendors, or cast-in-place concrete.

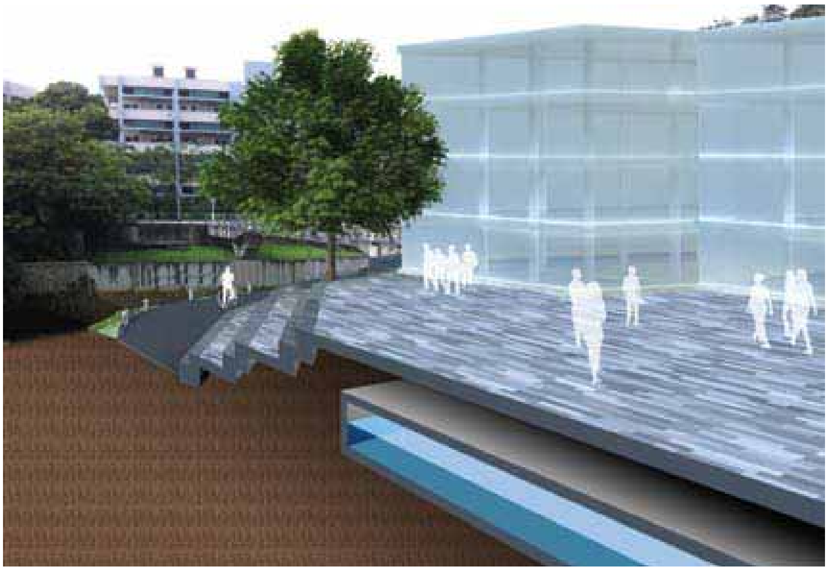


Figure 3.19 Schematic of an underground detention tank.

In addition to reducing peak runoff, a detention tank can also be combined with a rainwater harvesting system to provide storage for non-potable reuse. Developments have the flexibility to design and optimize combination systems to the extent that they do not compromise the maximum allowable peak runoff requirement. In order for the detention tank to be effective in reducing peak runoff from the development site, the runoff that is detained has to be removed within the period stipulated in the COP to ensure sufficient capacity for the next storm. Additional capacity would have to be set aside to store the volume required for reuse.

3.6 Interfacing between Source Elements and Public Drains

The interface between the stormwater drainage system within the development site and the public drainage system is crucial because it is the point where the discharge of runoff from the site has to comply with the maximum discharge rate required by the COP. Outlet configurations should be designed in relation to surrounding levels of the external drainage to determine the discharge method (i.e. by gravity or pumped drainage).

Conveyance elements like swales are typically connected to public drains via outflow channels that discharge runoff at a controlled rate. They should be designed to ensure that the discharge of peak runoff from the site does not exceed the maximum allowable rate.

Similarly, detention systems hold back water only to be released slowly after the rain subsides. The outlet structure must be designed to allow for a release rate that does not exceed the maximum allowable peak flow. Detention zones should also be equipped with emergency overflow outlets that can release water in a controlled way to the public drains.

All remaining ABC Waters elements such as green roofs, façade planters and other detention or retention systems sited on buildings must be connected to public drains via drainage downpipes that transport water to designated outflow channels.

Receptor Solutions to Protect Developments from Floods

4

4.1 Where is the Receptor?

Receptors are where stormwater flows may propagate to and affect infrastructure (e.g. basements or underground parking areas).

4.2 The Need for Implementing Receptor Solutions

While PUB continues to improve overall flood resilience by implementing pathway solutions such as providing adequate drainage ahead of new developments and upgrading existing drainage infrastructure, flooding can still occur. This can be due to more intense rainfall than what the drainage system is designed to cater for, or localised issues such as depressions in topography. Thus, in view of increasing rainfall intensities and weather uncertainties, both existing and new developments – especially those in areas that remain more susceptible to flooding – must do their part to protect their premises from flooding. Developments will need to implement receptor solutions that include appropriate building design and on-site flood protection measures to minimise flood risk to people and property.

4.3 Planning Receptor Solutions

Receptor solutions come in two broad categories, structural and non-structural measures. Structural measures include platform levels for the ground levels of developments, crest levels for entrances to basements, and mechanical flood protection measures like manual or automatic flood barriers. Non-structural measures include pre-emptive flood monitoring such as subscribing to SMS alerts and getting updates on water levels in the waterways.

Figure 4.1 Minimum platform levels for developments and crest levels for entrances to basements are some examples of structural receptor solutions.

The following sections provide guidance on the main planning considerations for the successful implementation of receptor solutions.

4.3.1 EVALUATING FLOOD RISK

As part of the development design process, designers or building owners need to evaluate the flood risk for the development site. This involves understanding the surrounding topography of the site, the site's flood history, and the potential impact to users of the site.

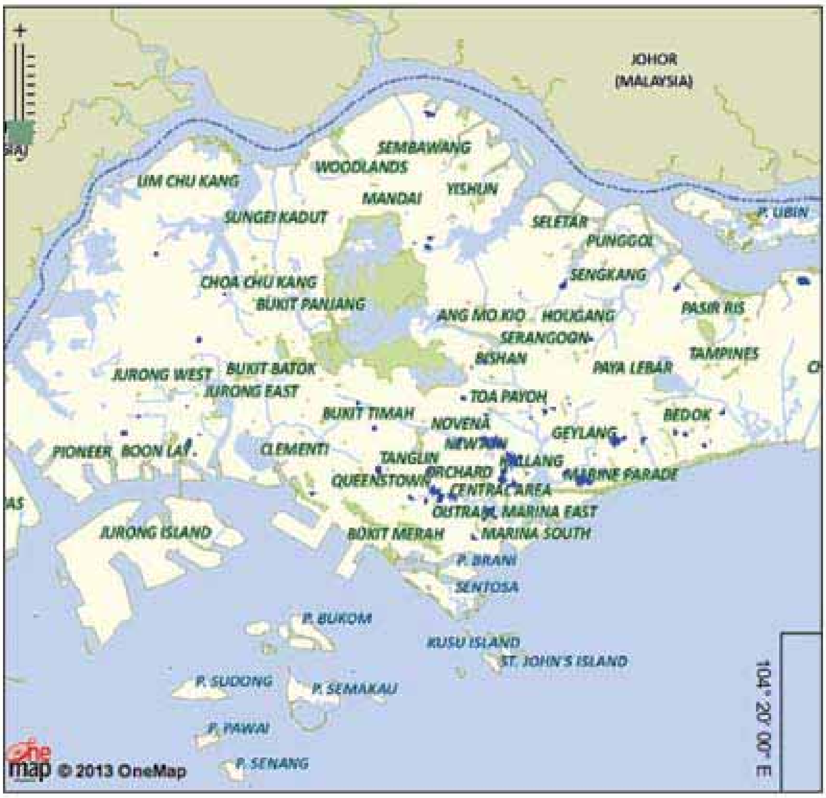


Figure 4.2 Map of flood prone areas in Singapore.

PUB's website provides a map (Figure 4.2) and table showing flood prone areas and hotspots in Singapore.

PUB's website provides a map and table showing flood prone areas and hotspots in Singapore: **http://www.pub.gov.sg/managingflashfloods**

4.3.2 UNDERSTANDING MINIMUM PLATFORM LEVELS AND MINIMUM CREST LEVELS

The COP describes requirements for structural flood protection measures, i.e. minimum platform levels and crest levels. The minimum platform level of a development site is the required minimum ground level of the proposed development. For developments with underground facilities like underpasses or basements, an additional minimum crest level is required for any entrance, exit or opening to the basement or underground structure (e.g. tunnel, underground facility, etc.) (refer to Figure 4.3).

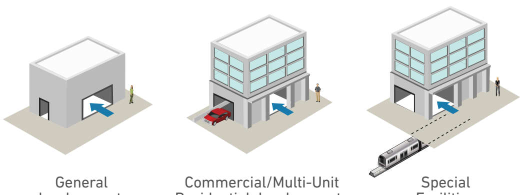
MINIMUM PLATFORM LEVELS

The minimum platform level is derived from a combination of factors:

1. Location (Northern or Southern coast);
2. Type of development;
3. Flood history; and
4. Adjacent road/ground levels

The highest level of the four will determine the minimum platform level of the development.

Figure 4.3 Steps and ramps are some of options to achieve the minimum platform levels for developments with entrances to underground facilities.

FACTOR		MINIMUM PLATFORM LEVEL REQUIREMENTS FOR:
location		Developments in catchments discharging to the: • **Northern Coast:** 104.5 mRL • **Southern Coast:** 104.0 mRL
development typology		• **General developments:** 300 mm above the adjacent road/ground level • **Commercial/Multi-Unit Residential developments with basements:** 600 mm above the adjacent road/ground level • **Special facilities and developments with linkages to special underground facilities:** 1 m above the adjacent road/ground level
flood history		<u>**Areas with Flood History**</u> • **General developments:** 600 mm above the highest recorded flood level • **Commercial/Multi-Unit Residential developments with basements:** 600 mm above the highest recorded flood level • **Special facilities and developments with linkages to special underground facilities:** 1 m above the highest recorded flood level

MINIMUM CREST LEVELS

Figure 4.4 Additional crest protection levels are required for developments with underground linkages to MRT stations (e.g. Ion Orchard Link) and for all openings to basement facilities, including ventilation ducts (e.g. Wisma Atria)

For developments with basements or underground facilities, additional crest protection has to be provided. Crest protection can be in the form of steps, ramps, humps as well as flood barriers. The minimum crest level is at least 150 mm above the minimum platform level for general developments, and 300 mm above the minimum platform level for commercial, multi-unit residential developments and special underground facilities including Mass Rapid Transit (MRT) stations and developments with direct or indirect links to special underground facilities. This requirement applies to all openings to basement facilities, including ventilation ducts and windows.

4.4 Designing Structural Solutions

There are many creative design solutions to achieve minimum platform and crest level requirements without compromising the attractiveness of the development. In order to develop effective structural receptor solutions for flood protection, designers need to:

1. Understand the proposed building typologies for the site and the amount of space available between minimum platform requirements and adjacent road/ground levels;

2. Review the design options suitable for migitating level differences, taking into consideration requirements from various government agencies concerning slope gradients, barrier-free accessibility, pedestrian access, etc.; and

3. Determine the type of tools to be used for minimum platform and crest level requirements to be met through structural means, which could include raising the platform level of the development site, adding ramps or stairs, or by installing mechanical flood barriers.

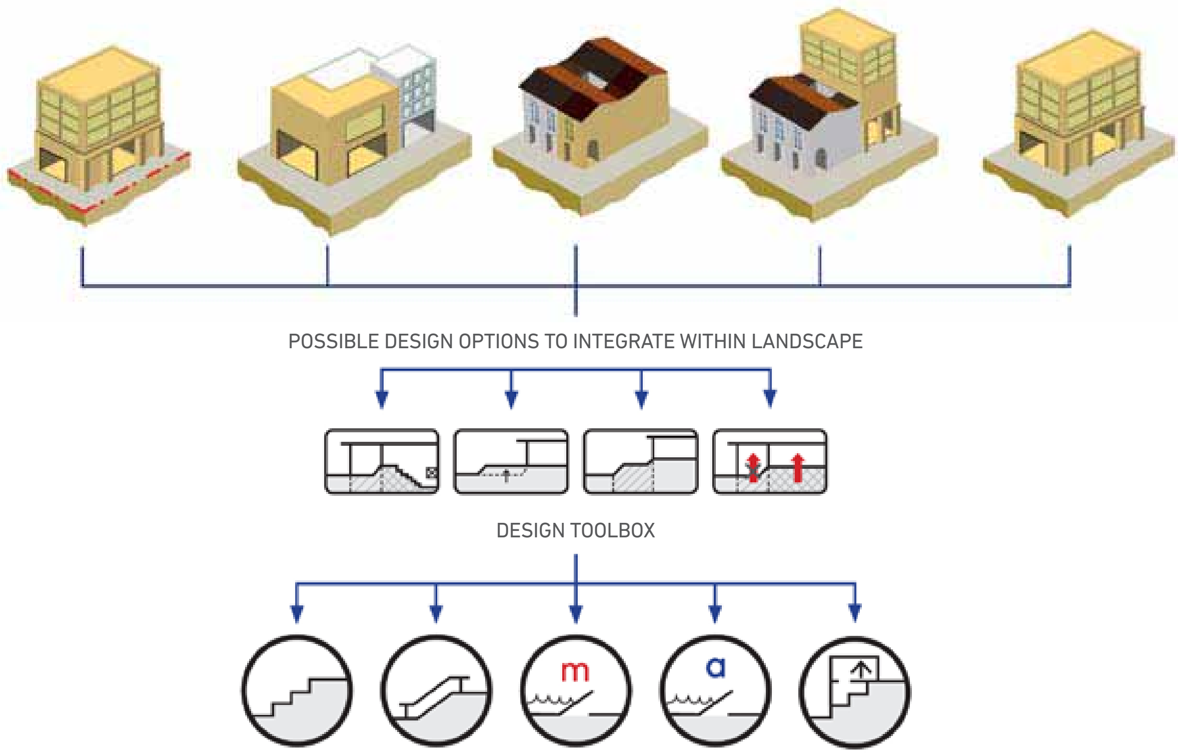
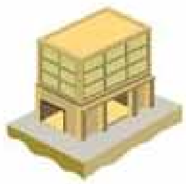
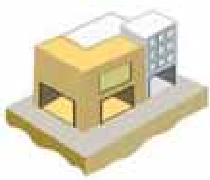


Figure 4.5 There are various design options for different building types to meet minimum platform and crest levels.

4.4.1 DEVELOPMENT SCENARIOS

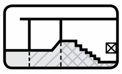
The different development parameters for each site affects the method of mitigating between adjacent levels and required minimum platform levels. The following table characterises the general building types in Singapore and the challenges and opportunities for integrating the required platform level of the new development with existing adjacent levels.

	**Standalone development with setback from boundary line** (e.g. most condominiums, schools, bungalows) • The setback within the development can be used to mitigate between level differences.
	**Standalone development with no setback** (e.g. some commercial developments in densely built up areas) • As the boundary line is adjacent to the public access way, there may be limited space within the side table to mitigate level differences.
	**Development with common setback and common access way** (e.g. shophouses with five-foot way, shop units, terraces) • The common access way limits the space available for mitigating level differences.

	**Restored conservation buildings** (e.g. conservation shophouses, heritage buildings) • There is limited space available for mitigating level differences as the façade and floor levels of the conserved building cannot be altered.
	**New rear extension behind conservation building** (e.g. building extension behind conserved main building) • Although there is a common access way and façade for the frontage, it is possible to mitigate level differences internally.

4.4.2 DESIGN OPTIONS FOR FLOOD PROTECTION

The following examples show different design options that provide flood protection for the building while maintaining connectivity to the street and adjacent buildings.



SEGREGATING THE DEVELOPMENT PARCEL BASED ON DIFFERENT MINIMUM PLATFORM AND CREST LEVEL REQUIREMENTS

If the development has direct or indirect links to special underground facilities such as underground MRT stations, higher minimum platform and crest level

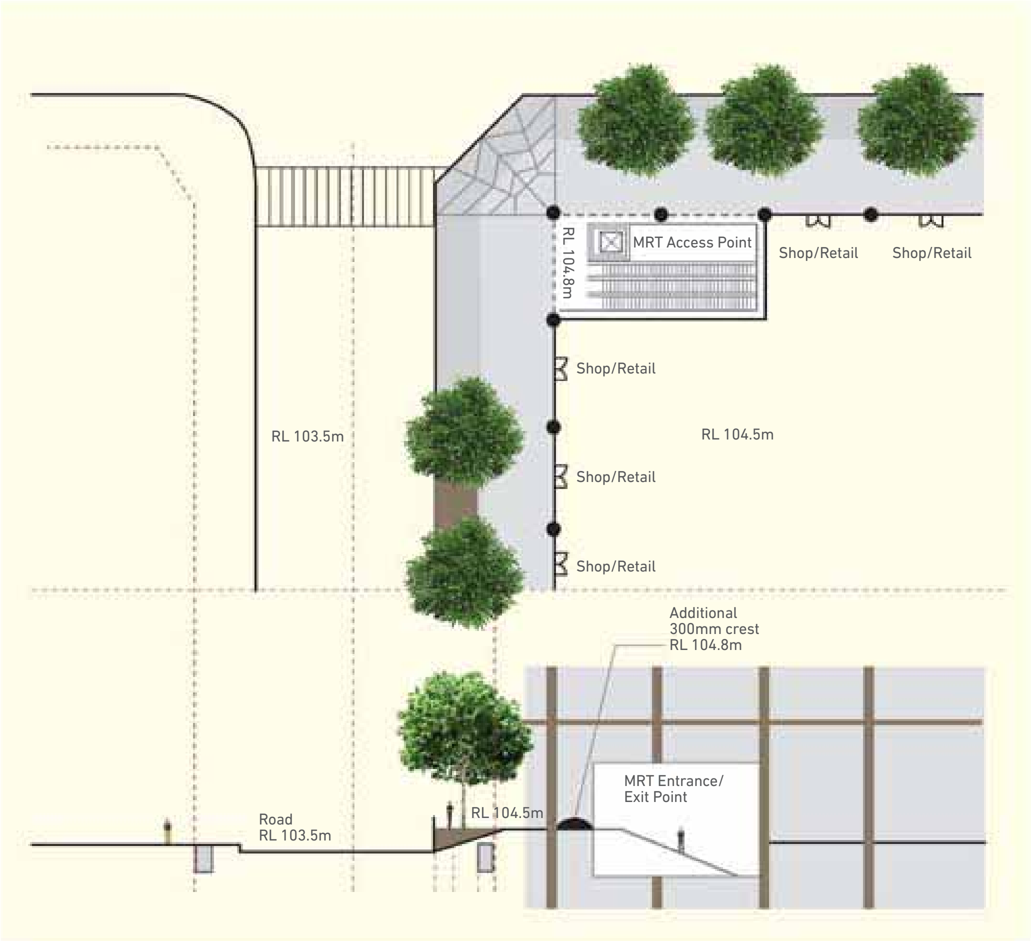
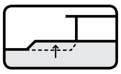


Figure 4.6
Example illustration of how a development can be partitioned to provide for an additional crest level of 300 mm for the entrance to a MRT station while the rest of the site is subject to an MPL of 104.5 mRL.

requirements must be met to ensure that floodwaters does not enter these facilities through their connecting basements or ground level entrances, exits and openings. The development may have different platform and crest levels based on the locations of points of access to the different parts of the building i.e. ground level or basement entrances (refer to Figure 4.6).



CHANGING LEVELS ON COMMON ACCESS WAYS

In cases where the building shares a common access way with other buildings, it may be possible to design the access level for the building entrance to match adjacent levels by changing the entrance level and providing stairs or ramps to connect with pedestrian sidewalks (Figure 4.7).

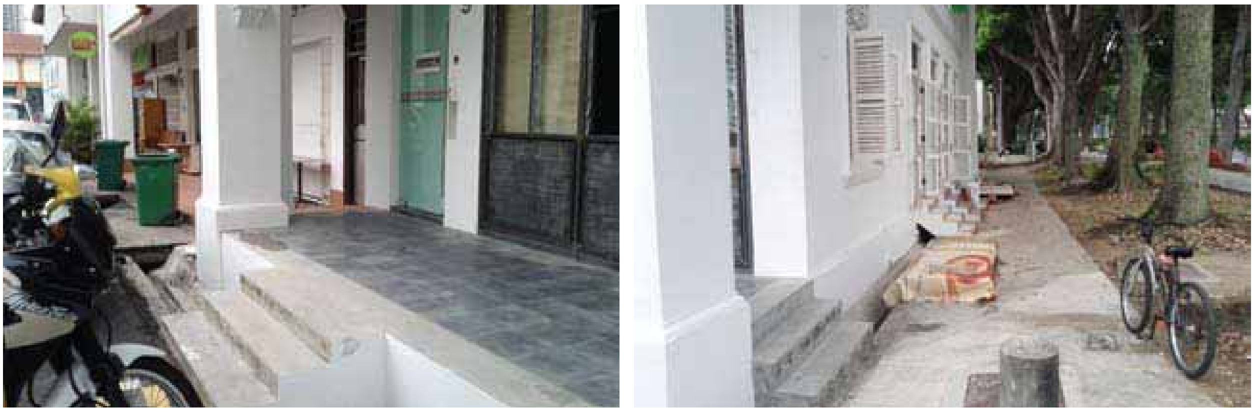
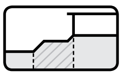


Figure 4.7 For this corner unit shophouse, the five-foot way was raised to match entrance levels. Steps were created to lead down to the road and common sidewalk area for the side entrances.



USE OF ANCILLARY AREAS

For developments in low-lying areas that may have significant differences between the minimum platform levels and adjacent road or ground levels, ancillary areas could be designed as an intermediate transition zone to tie-in with the adjacent low-lying road/ground levels, or to satisfy other planning considerations. Using ancillary spaces such as those listed below provides more opportunities to mitigate the differences between platform levels (Figure 4.8).

UNDER THE CODE OF PRACTICE, ANCILLARY AREAS INCLUDE:

i. entrance driveways;
ii. bin centres;
iii. turfed compound areas;
iv. car porches for single unit developments; and
v. other areas as may be approved by PUB.

Figure 4.8 The ancillary area outside this development is used to showcase street art, adding vibrancy to the entrance of the building.

ALIGNMENT OF ENTRANCE LOCATIONS

On development sites that are sloped, it may be easier to align entrances and access on the higher elevation side of the slope compared to the lower elevation side so as to mitigate between the minimum platform level requirements and adjacent levels (Figure 4.9).

Figure 4.9 The development incorporates an urban park with a sloped access to act as an intermediary area to mitigate the level difference between the road and the platform level of the development, where the entrances are located.

4.4.3 DESIGN TOOLS

This section presents the benefits, constraints, and applications of various tools that could facilitate the implementation of design options that would either meet the minimum platform and/or crest levels required for the development site, or would achieve at least the same level of flood protection that the minimum platform and/or crest levels would provide for the building.

STAIRCASES AND RAMPS

Staircases and ramps may be used to mitigate differences between the ground level and the development's platform level. In space-constrained developments, stairs may be a space-efficient means of providing accessibility from the street level to the building. However, tall staircases could potentially create visual barriers to the landscape. Designers should take into consideration the various uses of access points into the building and determine the locations where these features would be appropriate.

Figure 4.10 Two examples of staircases and ramps used to bridge the level differences between ground levels and the development's platform level.

Benefits

- Easily implementable if there is adequate setback area.
- Minimal maintenance.
- Can be integrated as a permanent feature in the development.

Constraints

- Stair structures that are used to mitigate significant differences in the ground level and the building's platform level may become a visual barrier depending on the location of the stairway.
- Ramps may require long areas of passage to mitigate between levels (e.g. ramps typically need to maintain a certain slope to meet safety and handicap access requirements).

Applications

- All development types.

MECHANICAL LIFTS

In developments with space constraints, platform lifts, stair-lifts, passenger and car lifts can be used together with stairs and ramps to mitigate level differences and provide additional access into the building. However it is important to note that the mechanical and electrical systems located below the lifts may be subject to the ingress of floodwater, so it is vital to have an additional crest protection for these systems by providing a ramp up to the lift or by installing flood barriers.

Figure 4.11 Examples of different types of mechanical lifts. Top – Platform lift for handicap access. Bottom – Car lift that is integrated into the building.

Benefits

- Offers an alternative option in addition to ramps and staircases to mitigate level differences.
- Provides barrier-free accessibility for access from a lower level to a higher level.

Constraints

- Electrical equipment that is located below the platform level may be subject to flooding (requires a ramp or mechanical flood barrier to prevent water from short circuiting the electrical system).

Applications

- Can be retrofitted into existing developments.
- Underground parking entrances.
- All development types.

FLOOD BARRIERS

Flood barriers are mechanical barrier systems that are installed to prevent water from flooding the protected area behind the barrier. These barriers are typically installed at the ground level of a development and at entrances and exits of basements. Flood barrier systems can be automated or manually operated. Apart from ensuring that flood protection levels are met, tests for watertightness are necessary to ensure that the flood barriers remain watertight when the floodwaters are below the top edge of the barriers.

For developments that are unable to meet the minimum platform and crest levels through structural design tools alone, flood barriers could be implemented on-site to achieve an equivalent level of flood protection. However, it must be emphasised that **the platform and crest levels should be raised to the highest possible levels before considering the implementation of flood barriers.** Flood barrier systems should be combined with other structural measures to ensure that the development is adequately protected from flooding. These flood protection measures are cost-effective solutions compared with the potential economic costs of flood damages and inconvenience caused to building users.

KEY CONSIDERATIONS FOR SELECTION OF FLOOD BARRIER SYSTEMS

When selecting the type of flood barrier systems to implement, a designer should consider the following:

1. **Response Time:** the time from the issue of the flood alarm to the onset of flooding and the readiness and availability of personnel;

2. **Deployment Time:** the time taken to activate the barriers, including appropriate locations to store detachable barriers; and

3. **Maintenance of Mechanical Flood Barriers:** the amount of maintenance required (e.g. maintenance of mechanical components) and the required testing frequency.

Figure 4.12 Maintenance staff checking and testing a flip-up flood barrier.

Type of Flood Barriers	Manual Slot-in	Manual Swing	Manual Pivot	Manual Watertight Door	Manual/Automatic Flip-up	Manual/Automatic Sliding	Automatic Drop-down (Shuttle door)
Description	Piece(s) that are manually deployed prior to a flood event. Slots must be installed to guide installation of barrier(s).	Barrier that operates on a "swing door" concept.	Flood barrier is lowered into place using a pivot system.	Watertight version of doors.	Flood barrier is recessed in the ground and raised into position during flooding conditions.	Flood barrier that slides across an opening into position.	Flood barrier that is kept in a raised position under normal conditions and is lowered during flood event.
Benefits	• Lightweight and easy to mobilise. • Can be stored away until needed for deployment and therefore less prone to wear and tear. • Surface mounted for easy post-construction installation. • Economical cost.	• Installed in place, reducing deployment time. • Minimal personnel required to deploy system.	• Installed in place, reducing deployment time. • Minimal personnel required to deploy system.	• Installed in place, reducing deployment time. • Useful in unmanned areas for doors that are kept closed at all times, as no human intervention is needed to activate the system.	• Flush with the ground surface, reducing visual obstruction. • Installed in place, reducing deployment time. • Certain models can be activated with the lifting power of floodwater, without the need for electricity.	• Installed in place, reducing deployment time. • Minimal/no personnel required to deploy system.	• Installed in place, reducing deployment time. • Requires minimum installation space. • Can be used for large openings.
Constraints	• Longer response time needed to manually deploy flood barrier system.	• Permanently visible structure. • May be prone to wear and tear. • May require vanity covers to conceal the barriers for aesthetics.	• Permanently visible structure. • May be prone to wear and tear. • May require vanity covers to conceal the barriers for aesthetics.	• If the door is constantly being used for access into the building, it may be more prone to wear and tear.	• Needs to be customised to site conditions. • May be prone to wear and tear if integrated with roads or pavements.	• Best to be integrated during construction.	• Permanently visible structure.

MANUAL FLOOD BARRIERS

Manual flood barriers are barriers that have to be physically installed or operated in the event of a flood. These barriers can be pre-installed, such as swing-type systems that can remain open during normal times, or "slot-in" barriers that are put in place only when necessary. Manual systems require time and manpower to install and activate, which are important considerations as flooding situations require quick response.

Figure 4.13 Manually installed slot-in barrier system.

Figure 4.14 Manually operated swing-type barrier system.

Figure 4.15 Sliding mechanical flood barrier system.

Benefits	Constraints	Applications
• Wide variety of systems with many possible configurations. • Manual systems usually come with flexible components, making them easier to install. • Demountable barriers can be removed when not required and are usually made of lightweight material for portability. • Typically requires low maintenance.	• Requires more manpower to activate the barriers manually, therefore may result in longer response and deployment time during flood events. • Mechanical hinges and slot components associated with manual systems may not integrate well with the overall aesthetics of the building. • If the flood barrier is not removable and is located in a public area, it may be more prone to wear and tear.	• Can be retrofitted into existing developments. • Suitable for developments that have a maintenance crew on-site for deployment of flood barriers.

There are also more permanent options available, such as building low flood walls along the perimeter of the development site with provisions (e.g. gaps or slots) for flood barrier systems. Gaps between the walls would provide pedestrian access during normal conditions. During flood situations, flood barriers would be installed or activated to close the gaps and ensure that the areas around the building are fully watertight. Flood barriers can also be integrated into the design of entrance gates (Figure 4.16).

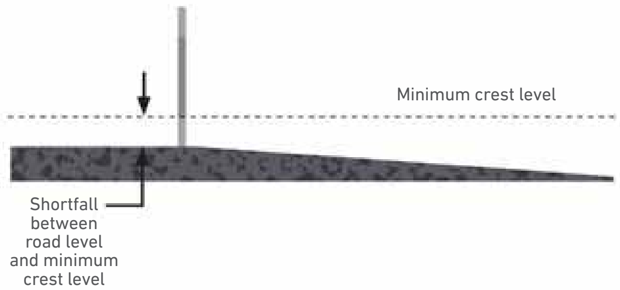


Figure 4.16 The entrance gate of this development leading directly to the basement car park was designed with a solid bottom section, with openings (for aesthetics) starting at the level above the required minimum crest level. A cross-section schematic of the gate is shown on the right.

Figure 4.17 Automatic flood barrier system at Lucky Plaza.

AUTOMATIC FLOOD BARRIERS

Automatic flood barriers are permanently installed in place and can be activated very quickly compared with manual flood barriers (Figure 4.17). There are several types of automatic barriers, including automatic flip-up, self-closing or drop-down systems. The normal position of these automatic flood barriers is flush with the pavement, road surface or side walls, providing seamless pedestrian or vehicular access. When activated, the barrier will be raised, lowered or closed to protect the premises from flooding. When the floodwaters recede, the barrier will return to its original location allowing for vehicle and pedestrian passage.

Benefits

- Fully automatic, no manual deployment needed.
- Can be activated quickly at any time of the day.
- Can be linked to water level sensors or alarm systems for faster activation.
- Well-integrated into the environment with minimal interference with building aesthetics.

Constraints

- As the barrier is part of pedestrian or vehicular access, it may be prone to damage or wear and tear.

Applications

- Public areas.
- Can be integrated into new developments for round-the-clock, unmanned activation.

4.5. Non-Structural Receptor Solutions

PUB has installed more than 150 sensors in waterways around Singapore to monitor water levels. CCTVs have also been installed in highly-urbanised areas like Orchard Road, the Central Business District, Bukit Timah, Upper Thomson, Ang Mo Kio, Little India and Commonwealth to provide up-to-date images of conditions at these locations. Information from the water level sensors and CCTVs are available on PUB's website (refer to Figure 4.18) and PUB's mobile app, MyWaters. PUB also provides flood alerts and updates to the public via various channels such as Facebook, Twitter, PUB's website (http://www.pub.gov.sg/managingflashfloods/) and the MyWaters mobile app.

PUB's "MyWaters" is a free mobile app that is available via Apple's App Store and Android's Marketplace.

Building operations and maintenance staff and occupants can prepare themselves for potential flood risks through updates from these channels or by subscribing to the Heavy Rain Warning SMS alert service provided by the Meteorological Service Singapore (MSS). Subscribers of the MSS service will receive alerts via SMS when heavy rain is expected over any of the five sectors (north, south, east, west, central) across Singapore.

The Heavy Rain Warning SMS alert service is part of the Integrated Heavy Rain and Water Level Alert Service jointly operated by the MSS and PUB. Members of the public can subscribe to either one or both alerts through NEA's MyENV mobile app or PUB's MyWaters mobile app, or via the PUB website.

SMS alerts received can be used to trigger standard operating procedures or flood contingency plans for the operation of flood protection measures and activation of alert or warning systems so as to reduce the risk of flood damage to property or safety hazards to occupants and members of the public.

The Heavy Rain Warning information is available on PUB's website:
http://www.pub.gov.sg
and NEA's website:
http://app2.nea.gov.sg

Figure 4.18 Location of water level sensors and CCTVs for flood monitoring in Singapore, available on the PUB website and MyWaters mobile app.

Safety, Operations and Maintenance Considerations

5

Figure 5.1 A crossing installed across a grass conveyance swale ensures a smooth transition between the two walkways, and also protects the soil beneath from being compacted by pedestrians, which would otherwise reduce the infiltration capacity of the swale.

When designing source and receptor solutions, it is important to keep in mind the safety, operations and maintenance aspects of the proposed solutions. By considering these aspects right from the design stage, innovative and cost-effective source and receptor solutions that not only meet public agencies' requirements, but are well integrated into the development to create a safe and beautiful environment for users can be implemented.

5.1 Safety Considerations

A risk and safety assessment can be conducted to identify potential safety hazards that might occur after the completion and implementation of stormwater management measures. It is paramount to put public safety as the most important consideration and is the responsibility of the developer and/or Qualified Person (QP) to ensure that all applicable safety standards are met and that a system of safety checks is set up and continues to be in place after the development project is completed.

Some key considerations for designing for public safety are listed below (not an exhaustive list):

1. BCA requirements for safety;
2. Safety and maintenance considerations in ABC Waters Design Guidelines (if there are ABC Waters design features);
3. NEA requirements for public health (e.g. mosquito breeding prevention);
4. NParks requirements for tree conservation and tree planting provisions within developments;
5. Safe access for maintenance of the stormwater management features; and
6. Public awareness and education to inform people of potential hazards and restricting access to areas with potential flood risk during storm events (e.g. dry ponds or plazas that are designed to store stormwater).

5.1.1 RISK ASSESSMENT FORMS

A Risk Assessment Form (Figure 5.2) can be used to assist designers in identifying and addressing potential hazards associated with various features on-site.

RISK ASSESSMENT FORM

Company		Conducted by (Name, Signature)
Job scope/Location		
Project		Approved by (Name, Designation, Signature)

Item	Hazards	Potential Consequence(s)	Current Risk Control Measures	Severity	Likelihood	Risk	Additional Risk Control Measures	Action by
Design Considerations	Areas designed to be accessed directly by users that have a waterbody/ waterbodies of varying depth and velocity.	Slowly fluctuating water depth of approx. 0.1 m during extreme storm events creates potential injury/drowning hazard.	Water safety signage/hazard warning will be placed at a strategic location to promote public awareness of the potential dangers and proper use of facilities.	Moderate	Occasional	Medium	• Designated entry points • Low wheel stops or raised kerbs for areas of circulation between 500mm - 1000mm • Railings or planted edges to be provided where level difference is 1000mm and above	
	Water edges that are hard to discern at night.	Park users may inadvertently wander or fall into the water during or just after rain events.	Higher intensity lighting to be provided at hotspot activity areas, lighting along pathways, uplighting of trees will also illuminate water surface and edge.	Moderate	Occasional	Medium	At some locations with steeper banks or higher flow volumes, softscape will be used to shield the user from the water edge.	
Operations & Maintenance and Monitoring	Stagnant water that could possibly be a mosquito breeding site.	Risk of mosquito-related diseases.	Checks to be carried out twice a week for stagnant water and mosquito larvae.	Minor	Frequent	Low	<u>Detention facilities:</u> • Check for chokages and stagnant water <u>Retention facilities with permanent water body:</u> • Ensure constant water circulation • Introduce wildlife which would eat larvae or introduce anti mosquito agent (eg BTI)	
	Interim detention facilities or other detention facilities where people are encouraged to enter and play in.	Poor water quality affecting public health.	Users are informed on water quality of facilities and proper use of facilities.	Minor	Occasional	Low	Where necessary (eg if used for play area for children), create wash point.	

Received by ______________________ Date ______________

Risk (R) Matrix

Likelihood (L) / Severity (S)	Remote	Occasional	Frequent
Major	Medium	High	High
Moderate	Low	Medium	High
Minor	Low	Low	Medium

Acceptability of Risk: Low risk (Acceptable); Medium Risk (Moderately acceptable); High Risk (Not acceptable)

Figure 5.2 Example of a Risk Assessment Form.

Figure 5.3 Using a combination of gradual slopes and clear signage, this dry pond allows users to move out of the area safely and easily during a rain event.

5.1.2 SAFETY ISSUES FOR SOURCE SOLUTIONS SITED ALONG PUBLIC ACCESS

Source solutions, such as surface detention and conveyance elements that are open and sited along public access, or that serve dual functions as recreational areas during dry weather and stormwater detention ponds during wet weather are subject to higher safety requirements. For such features with multiple functions, it is important to understand and address the associated risks accordingly.

For retention elements which have a permanent pool of water (e.g wetlands), barriers such as railings should be provided to prevent people from falling in.

Figure 5.4 A low seat wall, together with clear signage, can be used to limit access into the bioretention feature.

5.2 Operations and Maintenance Considerations

Operations and maintenance decisions and actions pertain to the control and upkeep of property and equipment. They include, but are not limited to:

1. Scheduling, work procedures, systems control and optimisation; and
2. Routine, preventive, predictive, scheduled and unscheduled maintenance actions aimed at preventing equipment failure or decline, with the goal of maintaining system performance.

5.2.1 OPERATIONS AND MAINTENANCE CHECKLISTS

Similar to the Risk Assessment Form, an Operations and Maintenance Checklist should be developed to identify actions which need to be carried out on a frequent basis, a less frequent basis, or periodically (e.g. after a heavy storm event). Maintenance encompasses visual inspections and equipment checks, cleaning as well as caring for greenery (landscaped areas and ABC Waters design features which include vegetation). Frequent visual inspection and maintenance of not just singular elements but the entire stormwater drainage system for the development is essential to ensure that the performance of the stormwater drainage system continues to function according to design. Regular and thorough visual inspections of the system elements take little time and aid in identifying preventive maintenance needs.

Examples of Operations and Maintenance Checklists for ABC Waters design features can be found in the Engineering Procedures on PUB's website: **http://www.pub.gov.sg/abcwaters/**

5.2.2 OPERATIONS AND MAINTENANCE ISSUES FOR SOURCE SOLUTIONS

Maintenance can be categorised into aesthetic maintenance and functional maintenance. Functional maintenance aims to ensure performance of the stormwater system, its environmental benefits as well as public safety, while aesthetic maintenance aims to satisfy the aesthetic needs of the users.

The following two key points should be noted:

1. Before the commissioning of the stormwater drainage system, an overall comprehensive check of all components is essential. All parts of the stormwater drainage system must be free of any construction waste to ensure that runoff from the source can be effectively conveyed to the public drains.
2. All components of the stormwater drainage system must be monitored on a regular basis and the frequencies of maintenance should be adjusted to the site-specific conditions and customised according to the experience gained from operating and maintaining the stormwater drainage system and records kept. These should be reviewed periodically.

Figure 5.5 Erosion in grass swales can be minimised by planting more resilient or water-tolerant species in areas that experience higher flow velocities or are frequently submerged (e.g. depression areas).

Figure 5.6 Sedimentation and excessive vegetation have grown inside the swale, obstructing flow and reducing conveyance capacity during rain events. This could also potentially be a breeding ground for mosquitoes when stagnant water is trapped in the swale. Regular maintenance of the swale is required to ensure its functionality.

DETENTION SYSTEMS

Detention systems which discharge stored water to the public drains are only allowed to do so when water levels in the public drains have dropped below 75%. Water levels in the public drains will be monitored via a water level sensor. It is important to understand how the system of storing and discharging runoff works, so that the operations and maintenance plan for the detention system can be developed accordingly.

If the detention system is a tank, maintenance of the tank may include:

- Regular desilting to ensure that the storage capacity of the tank is maintained.
- Checking that the discharge system continues to function effectively.
  - For discharge via gravity flow, maintenance is required to ensure that the outlet does not get clogged.
  - For discharge via pumped drainage, maintenance of the electrical systems and pumps is required.

5.2.3 OPERATIONS AND MAINTENANCE ISSUES FOR RECEPTOR SOLUTIONS

During a flood situation, floodwaters will naturally flow towards the lowest points in the terrain. As such, it is imperative that building owners and management take steps to ensure that receptor solutions continue to be in place and function effectively so as to minimise potential damage to property and other safety hazards. This would involve regular checks and maintenance, and is especially important for flood barriers which are located in public areas that may be subject to wear and tear which may affect their operational effectiveness.

Designers and operators should also refer to Chapter 13 of the COP, which contains clauses on maintaining the integrity of the stormwater drainage system, including flood protection measures.

Figure 5.7 Regular tests and inspections of flood barrier systems are necessary to ensure that the system can be reliably activated during flood events.

FLOOD OPERATIONS PLAN

When supplementing structural receptor solutions like platform levels with mechanical receptor solutions like flood barriers, it is also important to note that the development's flood protection is only as good as the response time to activate the flood barriers. A Flood Operations Plan, or a flood standard operating procedure, is developed with the aim of ensuring the safety of people and minimising damage to property in the event of a flood.

The Flood Operations Plan details actions that take place before, during and after the storm event and defines a chain of command to initiate operations. Elements of a Flood Operations Plan would include situation monitoring, flood threat identification, alert response, dissemination of information, emergency response actions and post-flood recovery and management (Figure 5.8).

PUB's website also provides advisory information on how members of the public can exercise caution during flash floods: **http://www.pub.gov.sg/managingflashfloods/**

Before	During	After
Identify Potential Risk/Source • Establish Action and Emergency Response Plan including chain of command and responsibility • Equipment operation and maintenance of flood safety equipment (e.g. flood barriers, sand bags, etc. if any) • Planning and conducting flood drill exercises in implementation of flood barriers (if any) • Planning and conducting flood drill exercises in public evacuation	**Flood Warning/Monitoring** • Determine flood threat and monitoring of flood **Action and Emergency Response Action** • Alert response • Dissemination of information and warnings • Deployment/activation of flood protection measures or safety equipment (if any) • Routing the public to areas of safety and away from potential dangers	**Termination and Recovery** • Transitioning from emergency phase into recovery phase • Removal of debris, inspecting property damage, condition of development • Post-mortem of Flood Action and Emergency Response

Figure 5.8 Elements of a Flood Operations Plan.

Subscribe to SMS Alerts:
http://www.pub.gov.sg managingflashfloods/
or download the 'MyWaters' mobile app to receive heavy rain or water level alerts.

FLOOD MONITORING

Owners and operations and maintenance personnel of developments located in low-lying or flood prone areas can improve their readiness in activating flood protection systems through close monitoring of weather forecasts and water level information, available on the NEA and PUB websites respectively. In addition to monitoring websites, building owners, occupants and building management can also subscribe to the SMS alert systems for Heavy Rain Warning and water level alerts, so as to determine which actions they need to take to protect themselves and their premises from flood risks.

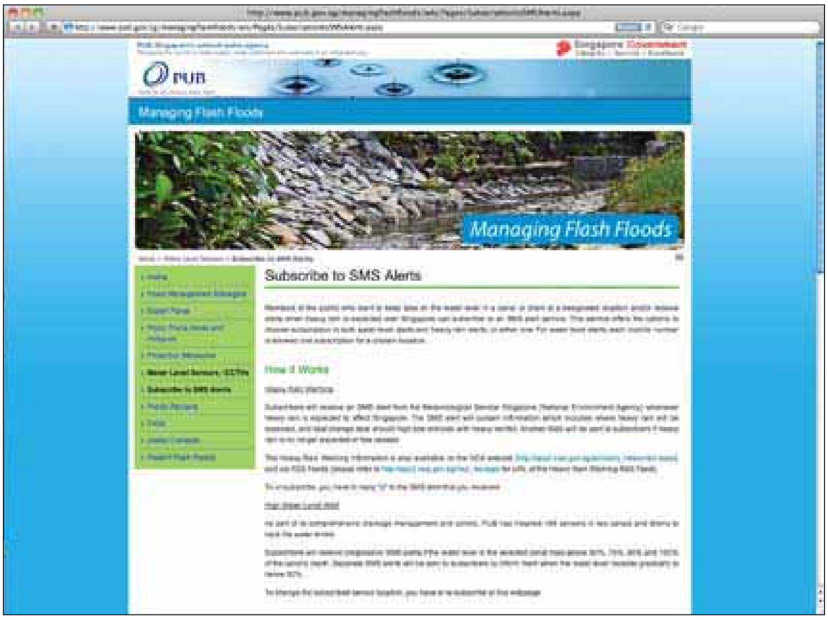


Figure 5.9 Members of the public can subscribe to free heavy rain warning and water level SMS alerts through PUB's website.

Case Studies

6

6.1 Waterway Ridges, Singapore

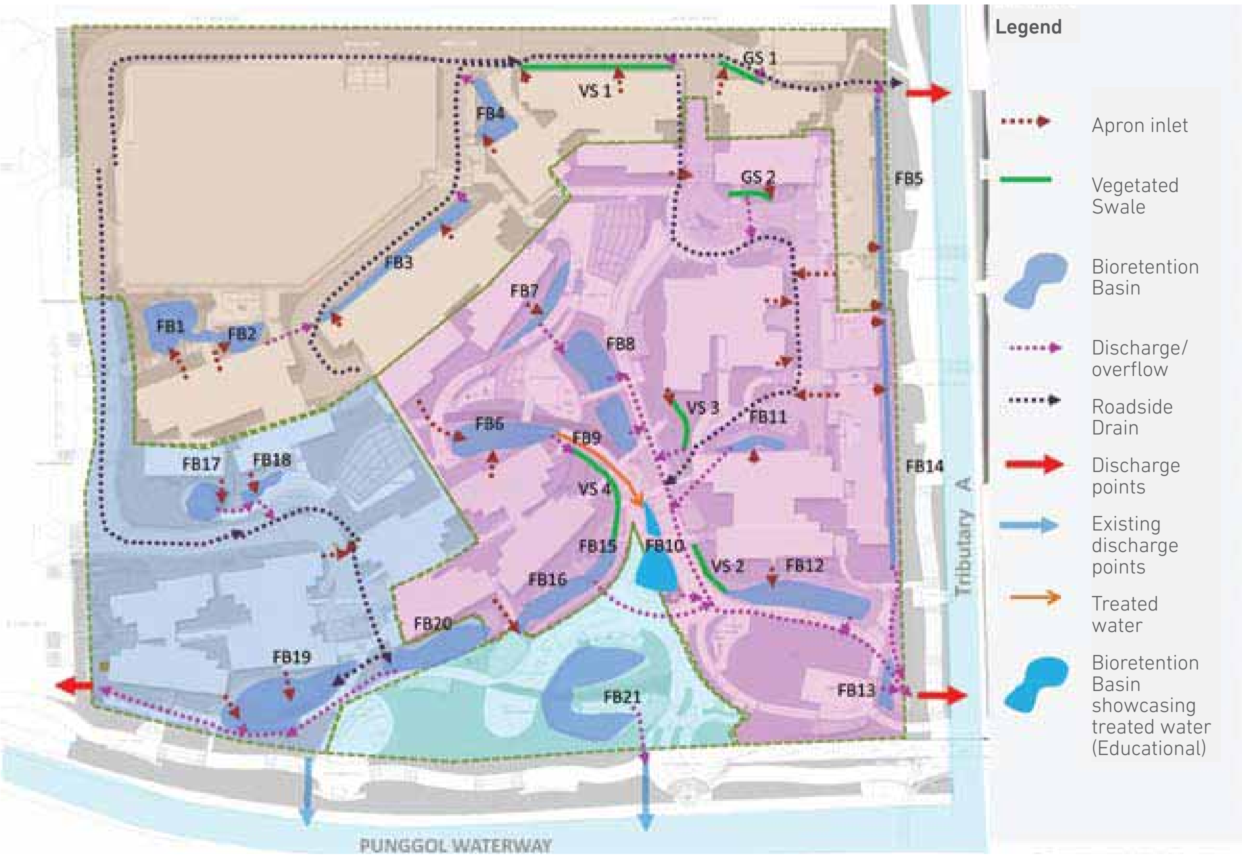


Figure 6.1.1 Indicative drainage flow paths in Waterway Ridges. Stormwater runoff is conveyed, detained and treated through a series of bioretention basins and vegetated swales before being discharged from the development into the roadside drains, Punggol Waterway and Tributary A.

6.1.1 BACKGROUND

Waterway Ridges in Punggol is a 3.98 hectare public housing project that demonstrates how the collection, detention, treatment and conveyance of stormwater runoff can be integrated with a residential development at a precinct level. While maintaining the pre-development hydrology of the site for all storm events up to a 10 year return period, the holistic integration of ABC Waters design features into residential spaces also brings additional benefits to the community and the environment in terms of improving runoff quality, creating multi-functional spaces, enhancing aesthetics and promoting biodiversity.

The main challenge of Waterway Ridges was to design a stormwater drainage system that could regulate the runoff rate from the precinct as well as improve runoff water quality. ABC Waters design features are located at both the Common Green and Waterway Ridges precinct, slowing down flows collectively to maintain the pre-development peak runoff rate (up to a 10 year return period) and cleansing stormwater to improve water quality.

6.1.2 INTEGRATED STORMWATER MANAGEMENT SOLUTIONS

Due to site constraints, runoff from about 70% of the total site runoff would be channelled through a comprehensive train of rain gardens and vegetated swales meandering through the development. Normally dry, these aesthetically pleasing gardens and swales would be filled with stormwater runoff during rainy weather, acting as temporary detention basins and treatment features before being discharged into the public drains.

Figure 6.1.2 Bioretention basin during dry weather (left). During a rain event (right), stormwater is directed into the swale, reducing the velocity and volume of runoff into the drainage system.

As space at the ground level had to be set aside for public amenities (e.g. playgrounds, lawns, etc.), the amount of space available for surface detention was limited. Thus, underground detention space was implemented in addition to surface detention. This was done through the use of gravel storage layers, with depths ranging from 400 to 850 mm, which were located within or below the bioretention basins and integrated with the drainage layer (refer to Figures 6.1.2 and 6.1.3).

Overflow system design

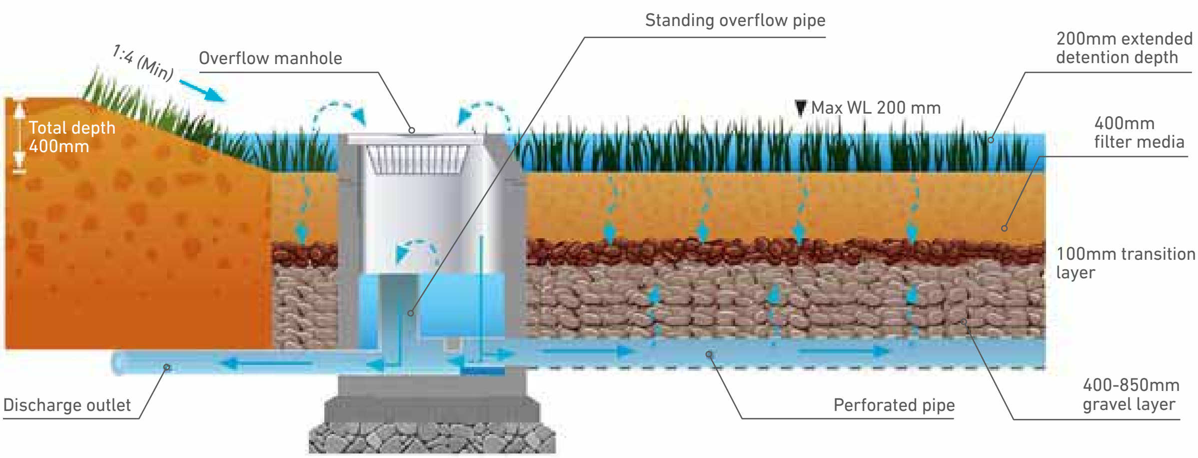


Figure 6.1.3 Typical cross-section of a bioretention basin implemented at Waterway Ridges.

Sized to cater to runoff from a storm with a return period of 10 years, runoff from the sub-catchment flows into the basin, and water is allowed to pond up to a maximum detention depth of 200 mm. Above that, runoff will overflow into the manhole and be directed into the underground gravel layer for detention through the perforated pipes. Meanwhile the amount of overflow entering the discharge overflow pipe will be regulated through the reduced outlet, the opening size of which was predetermined through calculations to maintain the pre-development peak flow. When the underground gravel layer is full, the water level in the manhole rises to the standing overflow pipe and is discharged via the discharge outlet that connects to the roadside drains.

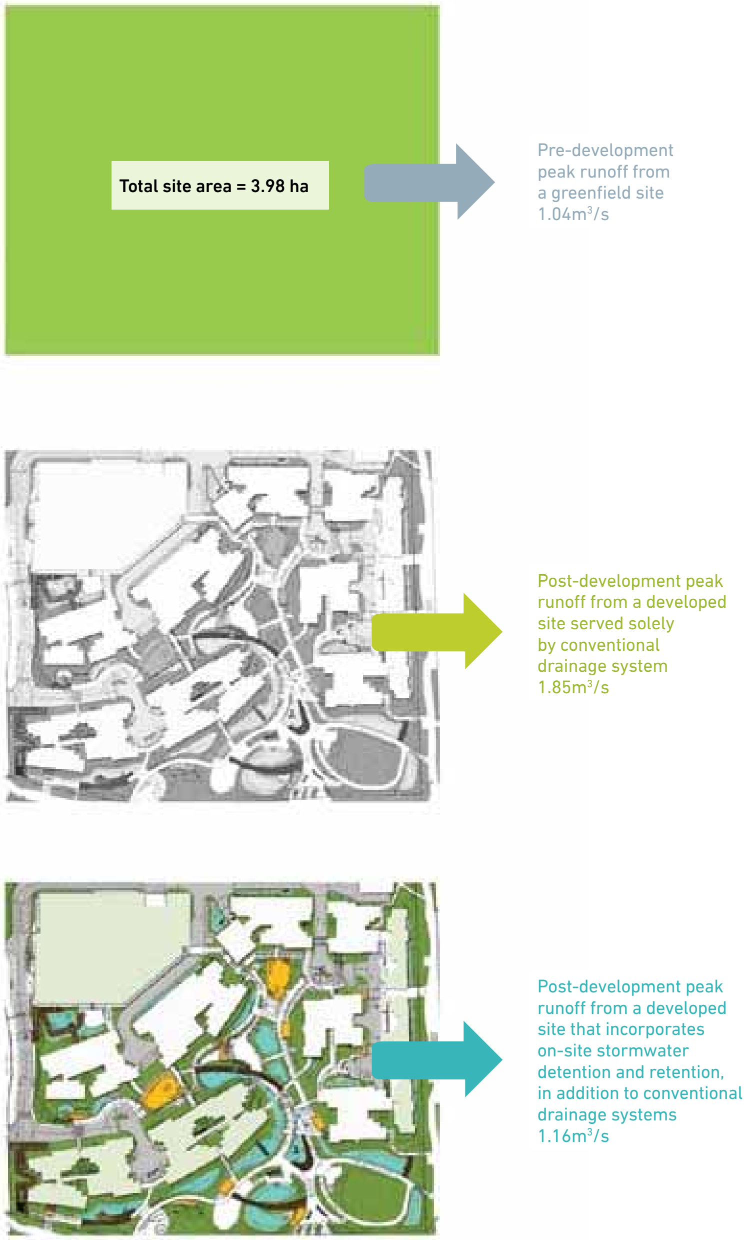


Figure 6.1.4 Comparison of the different peak runoff rates for different drainage systems adopted for the precinct.

Besides detaining stormwater runoff, the ABC Waters design features in the precinct also function as natural filters which remove fine to colloidal particles and dissolved pollutants in water with the following treatment objectives:

For 90% of all storm events:

TSS (Total suspended solids):	80% removal or less than 10 ppm (parts per million)
TP (Total phosphorus):	45% removal or less than 0.08 ppm
TN (Total nitrogen):	45 % removal or less than 1.2 ppm

Since aesthetics and public amenities on the ground level are important for such a development, plants of high aesthetic value and which encourage biodiversity were incorporated into the design of the ABC Waters design features for conveyance and detention. The ABC Waters design features were also designed as multi-functional spaces, able to be used during dry weather as public amenities. For example, selected bioretention basins would serve as communal lawns, where residents can enjoy recreational activities during dry weather. As such, through holistic planning, peak runoff reduction and runoff water quality improvement can be achieved, while creating a beautiful environment rich in biodiversity for residents to enjoy.

Figure 6.1.5 Bioretention basin serving as a multi-purpose lawn during dry weather. During a rain event, it acts as a temporary detention feature for stormwater runoff.

6.2 Tanglin Mall, Singapore

Figure 6.2.1 Tanglin Mall, located at the junction of Tanglin Road and Grange Road.

6.2.1 BACKGROUND

Tanglin Mall is a 0.57 hectare commercial development located at the junction of Tanglin Road and Grange Road. Completed in 1994, Tanglin Mall complied with the minimum platform level requirement imposed by PUB. Notwithstanding this, in light of changes in the surroundings and weather patterns, Tanglin Mall has taken further measures to meet the higher flood protection requirements specified by PUB in the COP (revised in December 2011).

Due to its strategic location at the junction of two major roads, Tanglin Mall has at least ten entrances, including a basement car park. This makes it challenging as no single type of flood protection measure can be implemented across the entire frontage of the building without compromising pedestrian or vehicular access. Additionally, the new flood protection requirement stipulated in the COP (6th Edition) was 0.7 metres above the existing platform level. As such, a combination of flood protection measures had to be designed and implemented to meet PUB's revised requirements as well as those imposed by other agencies such as the need for seamless connectivity at pedestrian access areas.

A thorough examination of the vulnerabilities of the building was carried out followed by consultation with agencies, so as to devise a holistic solution that would not only increase Tanglin Mall's level of flood protection, but also preserve its attractiveness as a lifestyle mall at the gateway of the Orchard Road shopping district.

Figure 6.2.2 Flip-up barrier at the front of Tanglin Mall, in closed (left) and open (right) positions. This barrier was chosen to achieve seamless connectivity for pedestrians crossing the junction of Tanglin and Grange Road to Tanglin Mall.

Figure 6.2.3 A flip-up barrier at the entrance to the basement carpark in closed (left) and open (right) positions.

Figure 6.2.4 A multi-slot barrier at the front of Tanglin Mall before (left) and after (right) installation. These barriers have to be installed manually.

Figure 6.2.5 Swing-type flood barrier in open (top) and closed (bottom) positions at access to loading/unloading areas.

6.2.2 FLOOD PROTECTION MEASURES IMPLEMENTED

Tanglin Mall implemented a combination of flood barriers and raised platform levels at the building's access areas. For covered walkways, to minimise disruption to pedestrian movement and visual porosity to the building, flip-up barriers were implemented at key locations such as the entrance to the building at the junction of Tanglin Road and Grange Road (Figure 6.2.2). Similarly, at areas where vehicular access should not be obstructed such as the entrance to the service driveway, flip-up barriers were also used (Figure 6.2.3).

At other areas where there are technical constraints to install flip-up barriers due to the existing structure of the building, low walls, slot-in barriers or swing-type flood barriers were used (Figure 6.2.4 and 6.2.5).

In addition to implementing on-site flood protection measures, the building management subscribed to the SMS alert service for both Heavy Rain Warnings and water level alerts, and developed a Standard Operating Procedure (SOP) for flood barriers to be installed and activated in the event of a flash flood along Grange Road or Tanglin Road.

6.3 Wisma Atria, Singapore

Figure 6.3.1 Wisma Atria, located along Orchard Road.

6.3.1 BACKGROUND

Opened in 1986, Wisma Atria is an established shopping mall situated along Orchard Road. This 0.62 hectare development also provides access to the Orchard MRT station via an underground link.

Wisma Atria has been innovative in incorporating various architectural and engineering designs to enhance its level of flood protection without compromising its attractiveness to retailers and consumers. This ensures that the building and the adjoining underground MRT station are protected from flood risks.

Figure 6.3.2 Using steps to create a 1 metre high crest protection for the basement shops.

6.3.2 FLOOD PROTECTION MEASURES IMPLEMENTED

In 2001, modifications to allow direct access to shops located in Basement 1 of Wisma Atria from the pedestrian walkway along Orchard Road were made. This meant that crest protection had to be provided at entrances to the basement to reduce the risk of floodwaters entering the basement levels of the building as well as Orchard MRT station. To address this risk, the building management of Wisma Atria worked with PUB and LTA to implement the following flood protection measures:

1. At areas with direct entry to the basement levels from the pedestrian walkways, a 1m high crest was created using steps. Pedestrians would have to first climb a flight of steps before descending to the basement.

2. In 2008, a 5m long, 0.9m high sliding mechanical flood barrier was installed along a short stretch of the pedestrian walkway. During dry days, the flood barrier would be left open, allowing pedestrians to enter the basement level of Wisma Atria from the pedestrian walkway along Orchard Road.

Figure 6.3.3 A sliding mechanical flood barrier protects the basement shops from floodwaters.

Wisma Atria also developed a set of Standard Operating Procedures (SOP) to guide its staff on the steps and measures to take in the event of an intense rainstorm. For example, the sliding mechanical flood barrier would be closed after business hours and during rainstorm events when water level in the Stamford Canal was high. To serve as an early warning system for the activation of the flood barrier, a water level sensor was installed in the Stamford Canal at the section near the building.

Figure 6.3.4 Sliding mechanical flood barrier to provide crest protection.

6.3.3 FURTHER IMPROVEMENTS TO WISMA ATRIA

More recently in 2012, Wisma Atria has undergone a more extensive transformation to provide new retail experiences along the Orchard Road shopping belt.

The steps leading to the shops at the basement and the mechanical flood barrier were replaced by a raised platform, integrated with accessibility ramps that are linked to the second level of Wisma Atria. This continuous raised platform has further enhanced the level of flood protection for the development and eliminated the risk of floodwaters entering the building due to mechanical failure of the flood barrier. In addition to enhancing Wisma Atria's flood protection levels, this transformation complies with BCA's barrier free access, while taking advantage of URA's Façade Articulation Guidelines to refresh their façade.

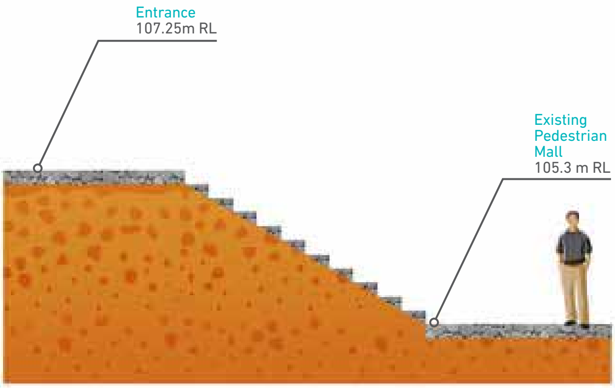


Figure 6.3.5 Wisma Atria's continuous raised platform (left) and section view (right).

Figure 6.3.6 Wisma Atria's continuous raised platform next to the main pedestrian walkway.

Figure 6.3.7 Raised platform at entrance to the Orchard MRT station.

6.4 The Prisma, Germany

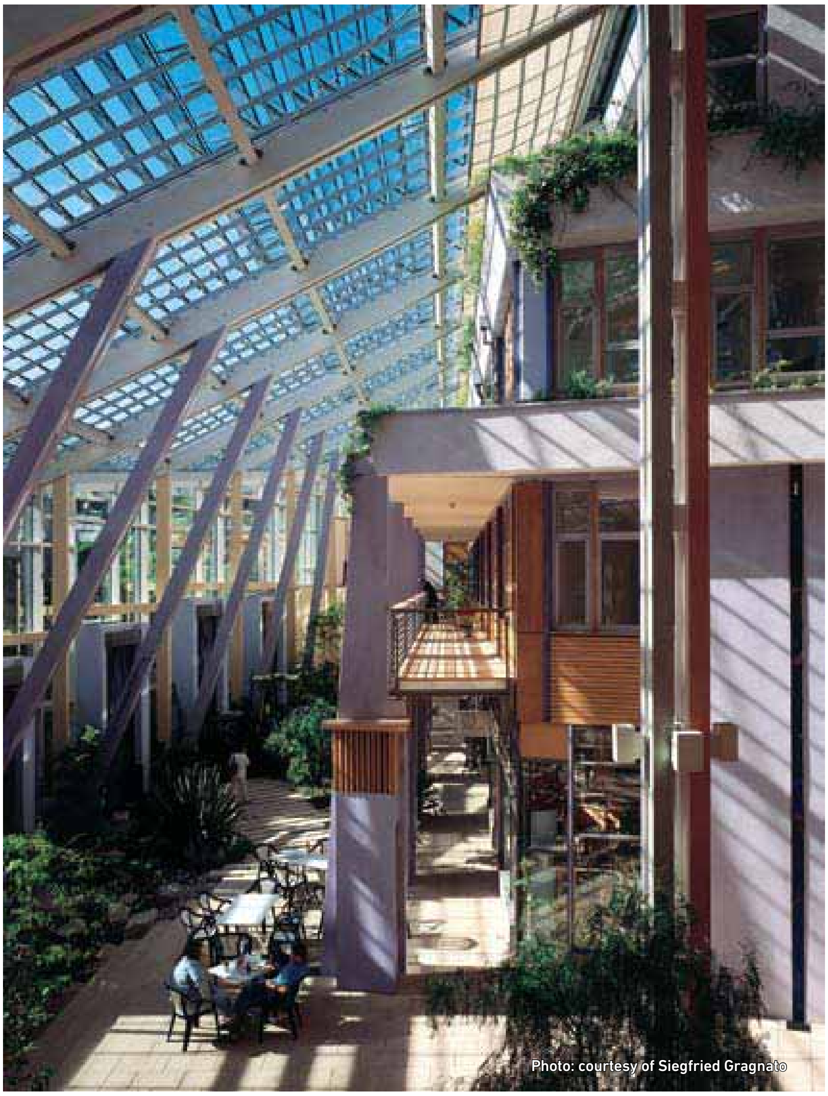


Figure 6.4.1 Stormwater management integrated within the development. Water walls and luxuriant vegetation work together with the building to create a healthy atmosphere.

6.4.1 BACKGROUND

The Prisma is a 1.7 hectare mixed-use building complex located in Nuremberg, Germany, comprising 61 residential units, 32 office spaces, 9 retail stores, a cafe and a public kindergarten. Rainwater that falls within the development is collected and reused. Surplus stormwater is allowed to infiltrate into the ground. At the same time, stormwater that is collected within the site is used to regulate air quality and the climate within the building, as well as provide visual and acoustic aesthetics to the development. By integrating these features into the development, water has become the central theme of the development, creating an oasis in the heart of the city.

6.4.2 STORMWATER CONCEPT – COLLECTION, STORAGE, PURIFICATION & INFILTRATION

During a storm, all the rainwater that falls on the roofs within the development is channelled to a series of vegetated planters on the upper floors. As it flows downwards towards the ponds and then into a cistern (with storage capacity of approximately 300 m^3), the stormwater is cleansed as nutrients and suspended solids are removed through the vegetated filter systems.

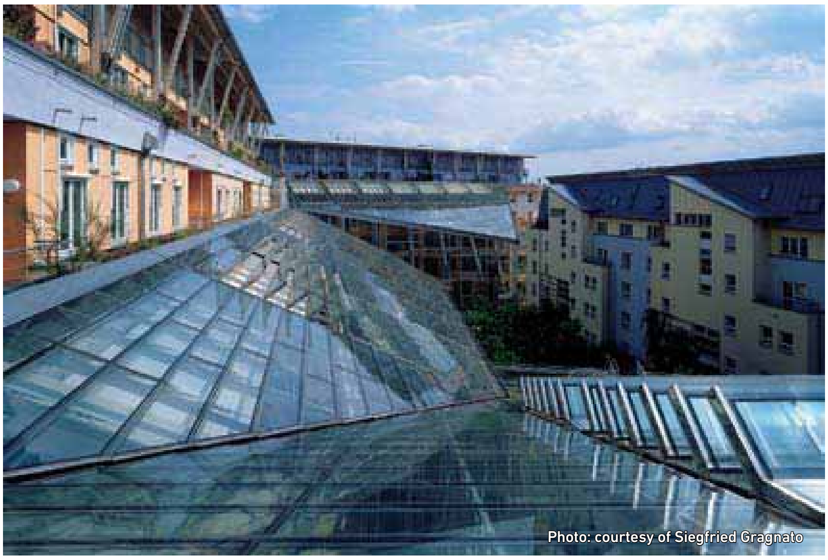


Figure 6.4.2 Rainwater from the entire roof area (approximately 4000 m^2) is collected and channelled into the cistern. Approximately 70% of the cistern serves as stormwater detention storage, 17% of the storage is used for emergency purposes (fire-fighting), and 13% is used to circulate rainwater throughout the building as "natural air-conditioning".

Stormwater that is stored in the cistern is then redistributed throughout the development via three circulation systems – one for irrigation, one for fire-fighting in the fire sprinkler system and the other for "natural air-conditioning". With a runoff detention capacity of 200 m^3, any surplus stormwater flows out of the cistern and recharges the groundwater through an infiltration system located below the buildings' foundations.

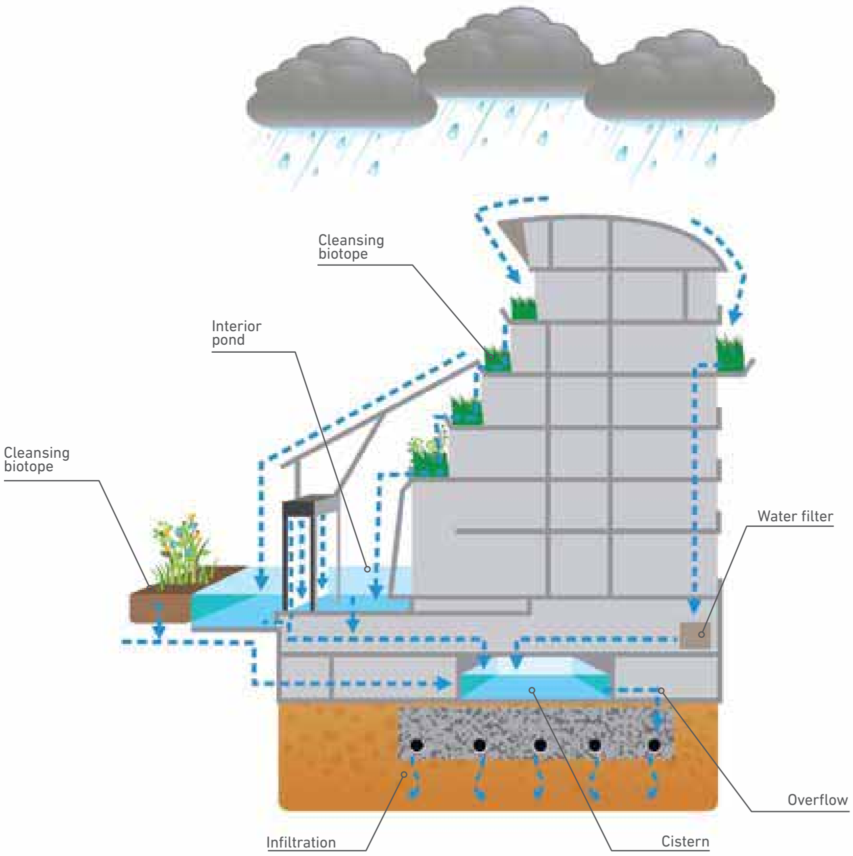


Figure 6.4.3 Sized to cater to storms of a 10 year return period, stormwater is collected, stored, cleansed and reused. Excess water is released into the groundwater via infiltration.

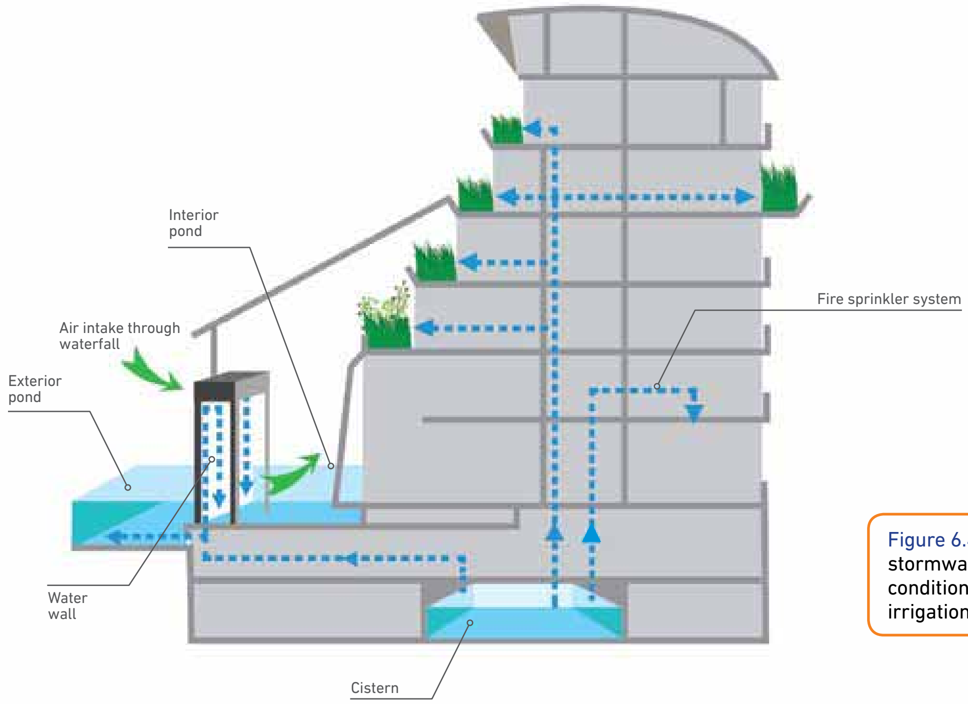


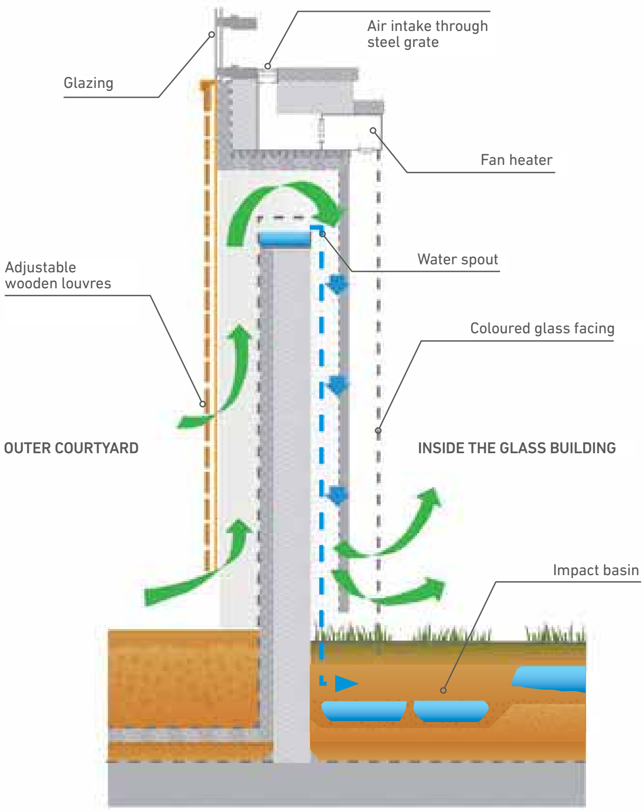
Figure 6.4.4 Using collected stormwater for natural air-conditioning, fire-fighting and irrigation.

6.4.3 STORMWATER FOR NATURAL AIR-CONDITIONING

As part of the "natural air-conditioning" system, water is circulated to six water walls within the development. The effect of the water walls is similar to that of waterfalls since the water walls make use of the hydro-physical process of water pulling air down as it falls, creating a light wind. As water falls between two walls each 5 metres high, the stream of water pulls air through a slit in the wall. This results in a cooling effect in summer. In winter, the warmer water (set at a minimum of 18 degrees Celsius) warms up the cool air from outside, creating a comfortable atmosphere indoors. The circulation of fresh air is clearly noticeable later as the water moves through whirlpools, streams and finally flows into a central pond surrounding the cafe patio before returning to the cistern.

By integrating various source solutions and water features within the development, the Prisma has demonstrated how stormwater can be harnessed as an asset to enhance the living environment, reduce the development's potable water usage and reduce the impact of urbanisation on peak flows downstream.

Figure 6.4.5 (Top) Exterior vents supply the water wall with fresh air which is drawn down the falling water and blown out at a wind speed of 3 metres per second. This system helps to regulate the microclimate by cooling the building in summer and warming it in winter, as well as improving air quality over a total volume of 15,000 m^3 in the glass atriums. (Bottom) Cross-sectional view of the water wall circulation system.



Frequently Asked Questions

FAQ

These are some of the commonly asked questions that PUB receives. More questions pertaining to drainage issues and their answers can be found at the PUB website: **http://www.pub.gov.sg/**.

7.1 GENERAL

What is the definition of a return period?

It is the probability that the rainfall event will be exceeded in any one year (or the inverse of the expected number of occurrences in a year). For example, 1-in-10-year return period rainfall has a 0.1 or 10% chance of being exceeded in any one year and a 50-year return period rainfall has a 0.02 or 2% chance of being exceeded in any one year.

Since PUB will be requiring new and re-developments to reduce the post-development peak runoff from the development site, does it mean that PUB will no longer continue to upgrade the drains to cater for increased urbanisation and higher rainfall intensities?

No, PUB will continue to upgrade the drains under its ongoing Drainage Improvement Programme. However widening drains to increase drainage capacity is challenging in land-scarce Singapore. Therefore there is a need to go beyond pathway solutions to on-site solutions (source solutions) to provide flexibility and adaptability to cater for the impacts of climate change.

7.2 SOURCE SOLUTIONS: TOOLS TO MANAGE STORMWATER ON-SITE

As part of stormwater management, is it possible to combine stormwater detention with stormwater collection (i.e. rainwater harvesting)? Can my client build ornamental ponds or ponds to collect rainwater for gardening and washing of the building premises?

Runoff that is collected using detention systems can be used for non-potable uses. However, it is important to ensure that the storage tank capacity can accommodate volumes necessary for both retention purposes (i.e. for non-potable use) as well as detention purposes (i.e. temporary storage of runoff). The detention volume must be kept empty so that the system will be effective in reducing peak flows from the next storm event.

Can PUB allow for a change of the existing drainage discharge points within the development site?

PUB may allow the change of the existing drainage discharge points within the development site provided that the proposal does not significantly alter the existing drainage overland flow pattern of the site and give rise to flooding problems. The applicant has to submit the proposal to PUB for technical comments and clearance. The QP has to avoid diverting flow from one catchment to another as this may overload an existing drainage system, which may result in flooding.

Frequently Asked Questions

7.3 RECEPTOR SOLUTIONS: FLOOD PROTECTION STRATEGIES

What can owners/tenants of existing buildings do to protect their premises against higher storms?

Owners of existing buildings may approach QPs for technical advice on the appropriate flood protection measures they could adopt, if necessary. PUB also engages owners and management of older developments which have been identified to be at risk of flooding. For example, PUB engaged the owners of premises affected by flooding along Orchard Road and recommended flood protection measures such as flood barriers and humps at entrances to basements to protect their premises. Building owners are also encouraged to develop emergency plans for communication and evacuation procedures in the event of floods. They can also subscribe to the Heavy Rain and Water Level SMS alert service to get information on expected heavy rain and rising water levels in the major drains and canals. They can also receive such alerts and flash flood updates through PUB's MyWaters mobile app.

Will the new development adjacent to my site lead to increase surface runoff and eventually flood my site which is on lower ground?

PUB has put in place various measures that the QP/developer needs to comply with to ensure that a new development does not flood the adjacent site that is located on a lower platform level. As stipulated in the COP, all runoff within a development site shall be discharged into a roadside drain or outlet drain and not into adjacent premises. The development needs to have a drainage system along the site boundary (including a minimum 600mm high boundary wall) to prevent surface runoff from overflowing into the adjacent premises.

How do I comply with the minimum platform level if there are site constraints such as low-lying roads and surrounding ground levels?

The minimum platform level is necessary to protect the new development against flooding. Therefore, the building structures must be built above or at the minimum platform level. For walkways, if there is a large difference between the minimum platform level and the existing road level, the QP may study and propose a compromised walkway level that could be lower than the minimum platform level but higher than the road level to provide barrier-free access. The QP may also propose lower platform levels for other ancillary areas such as driveways to tie in with the existing road level. All these deviations from the minimum platform level are subject to PUB's approval.

I have a proposal to construct a new underpass linking an existing building to an existing MRT station. Can I seek a waiver of complying with the required crest protection level for the existing or proposed entrance, exit or opening linking the existing building to the underground MRT?

PUB does not grant waivers due to the need for a higher level of flood protection for MRT systems. All developments with underground linkages to an MRT system must comply with the minimum platform and crest levels imposed for the MRT system.

Glossary

Active, Beautiful, Clean Waters (ABC Waters) Design Features	are environmentally friendly features that detain and treat stormwater runoff using natural elements like plants and soil. The features also enhance the surroundings with biodiversity and aesthetic value.
Addition & Alteration (A&A)	Additions refer to any new construction which increases the floor area of an existing building, for example rear extensions. Alterations are physical changes to a building.
Catchment	refers to the area which drains into a stormwater drainage system.
Central Building Plan Department (CBPD)	refers to the Central Building Plan Department of the Environmental Protection Division, National Environment Agency.
Certificate of Statutory Completion (CSC)	is issued by BCA (Building and Construction Authority) when building works are completed and all agencies' requirements have been complied with.
Commercial/Multi Unit Residential Developments with Basements	refers to developments with basements such as shopping malls, large office buildings, condominiums, hotels and hospitals.
Common Drain	refers to a drain of less than 1m wide serving more than one premise and without drainage reserve.
Crest Level	refers to the bottom level of any openings (including ventilation and services openings) or summit level of a ramp or access way leading into or away from an underground or basement structure or facility, including the summit level of any exits of the underground facilities.
Drain	includes any canal, culvert, conduit, river or watercourse.
Drainage Reserve	refers to any land set aside for drainage works pursuant to development proposals approved by a competent authority.
General Developments	refers to developments other than commercial/multi-unit residential developments with basements and special facilities.
Pathway	refers to means or routes through which stormwater is conveyed (e.g. waterways such as drains and canals).
Platform Level	refers to the general ground level of a proposed development.
Qualified Person (QP)	refers to a person who is an Architect or a Professional Engineer or a suitably qualified person registered under other relevant legislation.
Receptor	is defined as where stormwater flows may propagate to and affect infrastructure, for example development sites, building premises, or other infrastructure such as courtyards, parking lots and basements.
Source	is defined as the location where stormwater runoff is generated, i.e. the origin of stormwater flows.
Stormwater Drainage System	Refers to a system of drains for the conveyance or storage of stormwater and includes a) Any weir, grating, float boom, gauge, tidegate, sump, storage pond, pumping station, maintenance access and debris interception and removal facility related to such system. b) Any structure constructed to convey, store or measure stormwater or for flood alleviation; and c) Any bridge over or railing for any such drain or any appurtenance thereof.

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Notes

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