PUB SINGAPORE'S NATIONAL WATER AGENCY

MANAGING URBAN RUNOFF

DRAINAGE HANDBOOK (2ND EDITION)

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Contents

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Introduction

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 convective 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 1.3). These areas face higher flood risks, especially when heavy rains coincide with high tides.

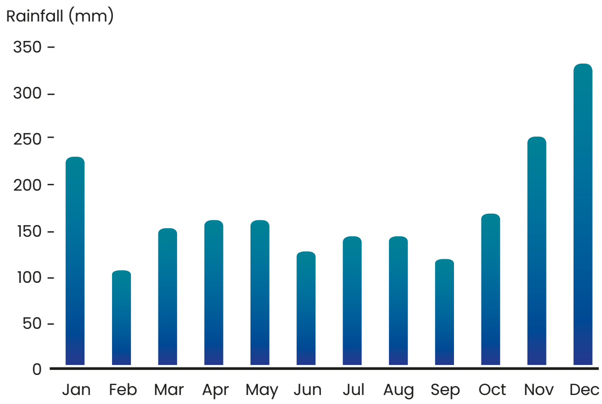


Figure 1.1 Mean monthly rainfall in Singapore.

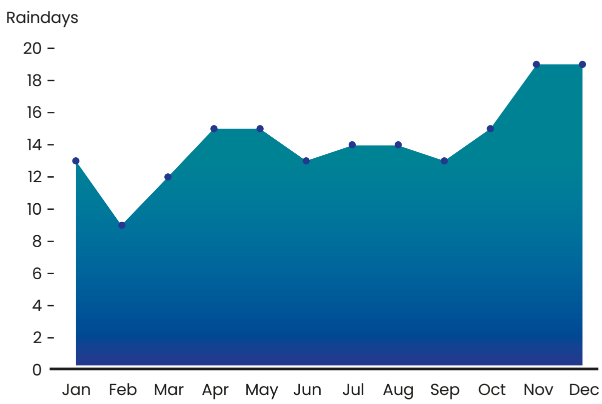


Figure 1.2 Records of Climate Station Means (Climatological Reference Period: 1991-2020).

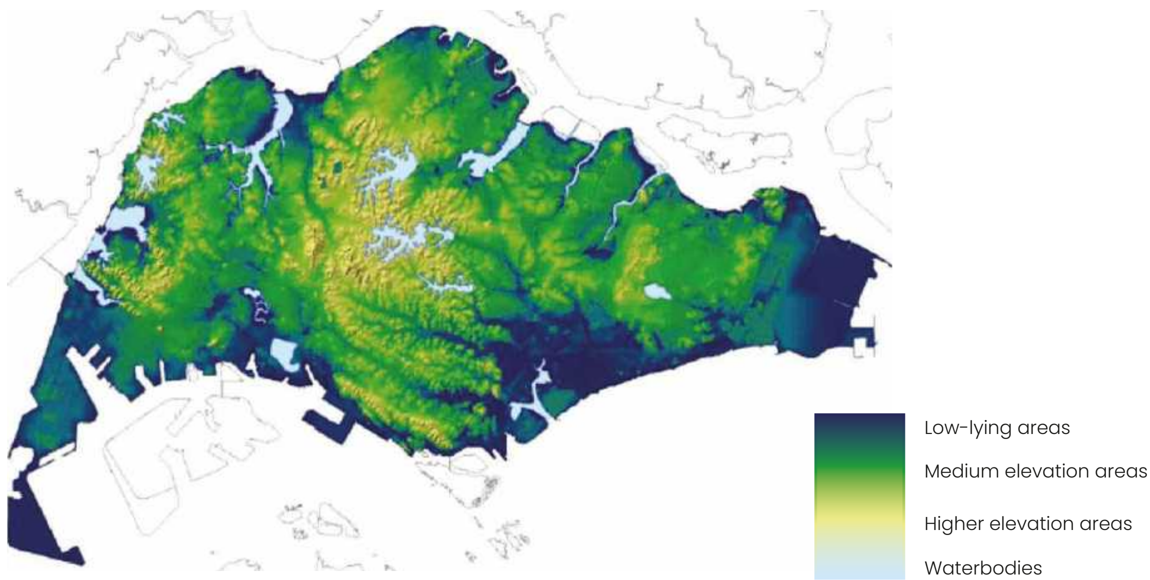


Figure 1.3 Topography of Singapore.

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 5.92 million people in 2023.

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).

Despite the growth in urban areas, flood prone areas in Singapore have reduced from 3,200ha in 1970s to less than 30ha in 2022 (Figure 1.5). This is largely due to the implementation of the island-wide drainage improvement projects over the years.

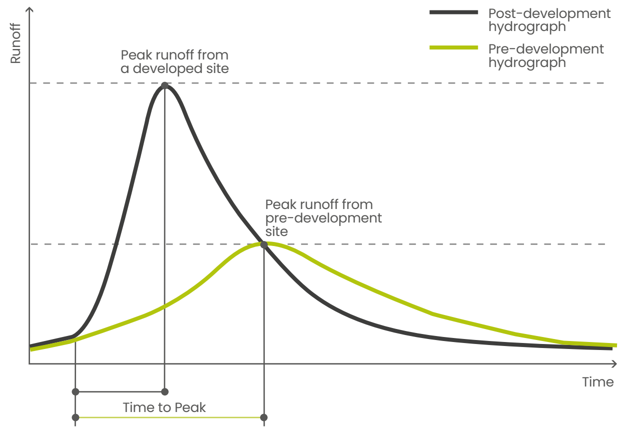


Figure 1.4 Storm hydrograph showing the difference in peak runoff between an urbanised area and a pre-development, or greenfield site. The greater the degree of urbanisation, the higher the peak runoff over a shorter period of time.

Figure 1.5 Reduction in flood prone areas between 1970s and 2022.

1.2 PUB's Stormwater Management Strategies

PUB manages flood risks in the following ways:

1 Providing adequate drainage ahead of new developments.

2 Implementing flood protection measures by stipulating requirements such as minimum platform levels and crest levels in the Code of Practice on Surface Water Drainage.

3 Improving drainage in flood prone areas continually by widening or deepening drains, and/or by raising low-lying roads.

Figure 1.6 Summary of PUB's stormwater management strategies.

PUB has an ongoing drainage improvement programme to achieve the following objectives:

1.2.1 Flood Prevention

PUB plans for adequate drainage ahead of the development of new areas. Through modelling, advance drainage planning, and consultation with other agencies, flood risks are mitigated through proper provision of drainage facilities in developments.

1.2.2 Flood Protection

PUB ensures that developments comply with flood protection requirements by providing standards in the Code of Practice on Surface Water Drainage, as well as upgrading and constructing drainage infrastructure to reduce flood risks in flood prone areas.

1.2.3 Flood Control

PUB's drainage operations team responds quickly for damage control of flood events. Through quick deployment and incidence response, the extent of flooding and its impacts are minimized.

These strategies have been effective in reducing the extent and duration of floods in Singapore over the years. However, sudden and intense storms can temporarily overwhelm our canals and drains and cause localised flash floods, which typically subside within an hour.

1.3 The Need for Holistic Stormwater Management

With climate change, Singapore can expect to experience more extreme and unpredictable weather, with more frequent and intense storm. Sea levels around Singapore are projected to rise by up to 1.15 metre by 2100. As a low-lying island surrounded by the sea, enhancing our nation's overall coastal and flood resilience is a critical long-term endeavour.

However, expanding drains to increase drainage capacity is challenging in land-scarce Singapore. Rapid urbanization over the last few decades due to population and economic growth has resulted in competing demands for the 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.

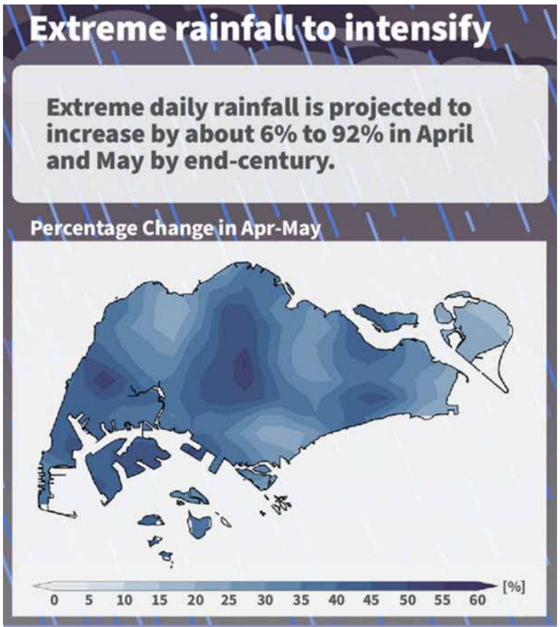


Figure 1.7 Extreme rainfall to intensify (Source: Centre for Climate Research Singapore, 2024, The Third National Climate Change Study)

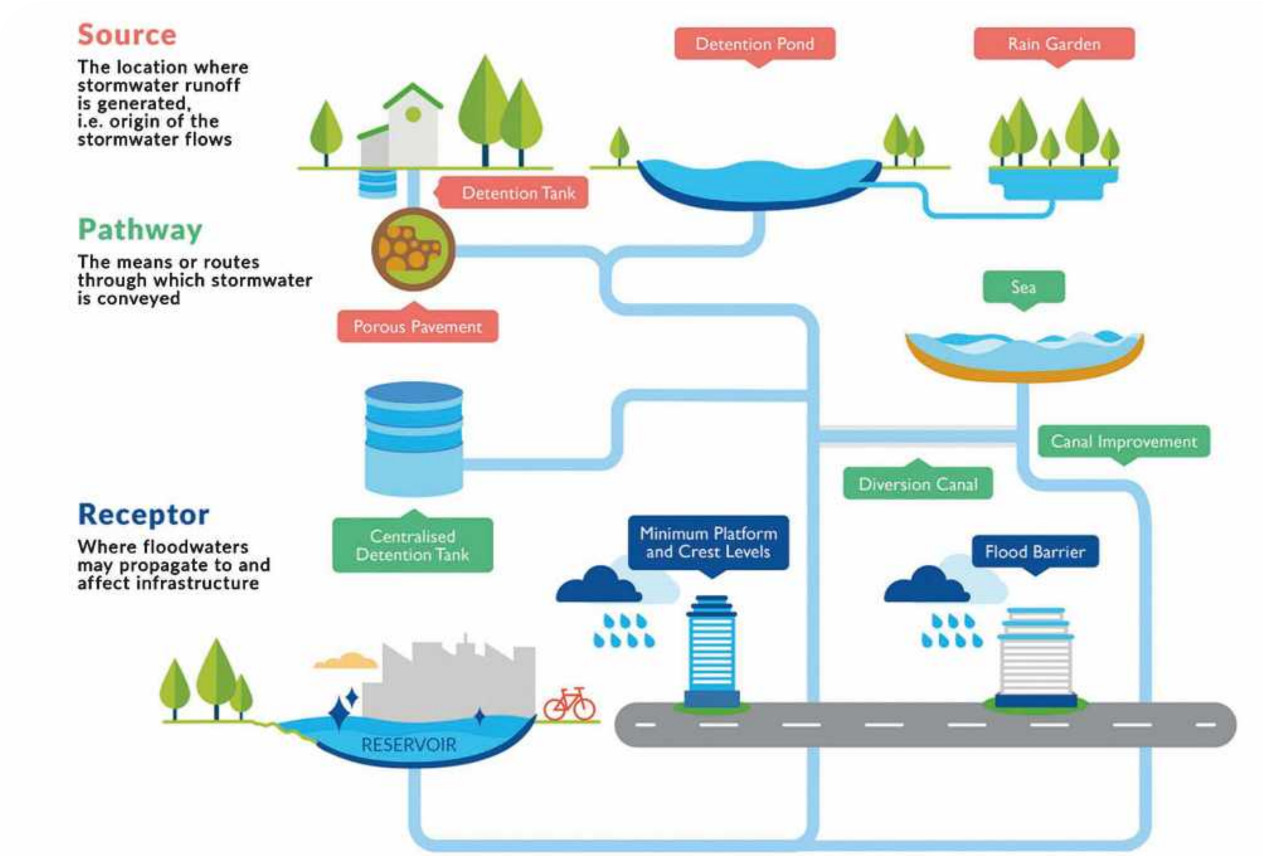


Figure 1.8 Examples of Source, Pathway and Receptor solutions to slow down and reduce peak runoff and to protect developments (receptors) from flood hazards.

SOURCE

The location where stormwater runoff is generated, i.e. origin of the stormwater flows

SOLUTIONS AT THE SOURCE

refer to the slowing down and capturing of urban runoff on-site, e.g. via ABC Waters design features, detention tanks/ponds, etc.

PATHWAY

The means or routes through which stormwater is conveyed

SOLUTIONS AT PATHWAYS

refer to enhancing the capacity of conveyance systems and includes drain widening, deepening, catchment level detention systems etc.

RECEPTOR

Where stormwater flows may propagate to and affect infrastructure

SOLUTIONS AT RECEPTORS

refer to measures to protect areas where the storm water flows may end up, e.g. flood barriers for buildings, etc.

Figure 1.9 Source-Pathway-Receptor Approach.

Recognising that expanding canals and drains will not be sufficient, especially for areas that are more developed and have site constraints, PUB has adopted the "**Source-pathway-receptor**" approach since 2012 as a more holistic stormwater management (See Figures 1.8 and 1.9).

This holistic approach introduces flexibility and adaptability to Singapore's drainage system, addressing not just the drains and canals through which the stormwater travels ("Pathway"), but also in areas generating the stormwater runoff ("Source") and areas where floods may occur ("Receptor"). 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.

Figure 1.10 Acting as a source measure, the construction of a detention tank below a rain garden, helps to retain the first flush stormwater runoff while simultaneously cleansing it. Any excess runoff will overflow into the detention tank.

Figure 1.11 Acting as a pathway measure, Sungei Tampines is partially naturalised to integrate seamlessly with the adjacent Tampines Eco Green.

1.4 Benefits of Holistic Stormwater Management

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

- Supporting environmental sustainability.
  - 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.
- 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.
- 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.

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.

2 Resources for Designing Stormwater Drainage Systems

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 blue-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.

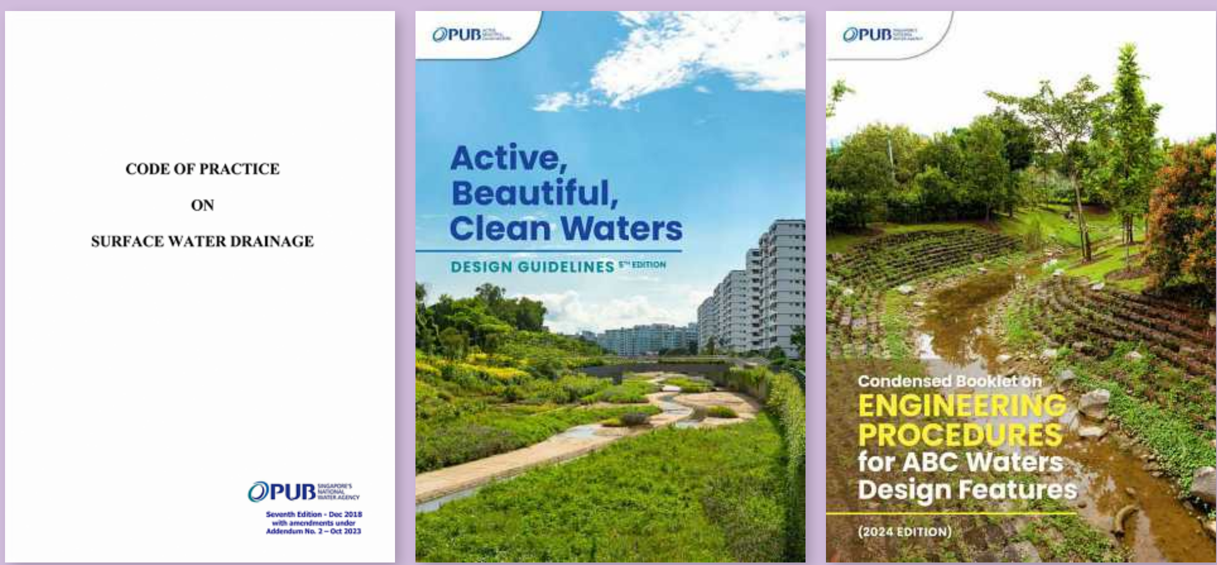


Figure 2.1 PUB's Code of Practice on Surface Water Drainage and ABC Waters Design Guidelines.

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 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. These information can be requested from PUB's Building Plan Unit (BPU) via the QP Portal available on the PUB website. QPs will also verify drains on-site and MPL for effectual surface water drainage.

2

QPs submit Development Control (DC) plans for clearance with BPU via Corenet. For drainage consultations, PUB (through BPU via Corenet) 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 BPU via Corenet) 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 BPU via Corenet.

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:
www.pub.gov.sg/Professionals/Resources/Code-of-Practices

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

The ABC Waters Design Guidelines are available on the PUB website:
www.pub.gov.sg/Professionals/Working-on-ABC-Waterways/ABC-Waters-Design-Guidelines

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.

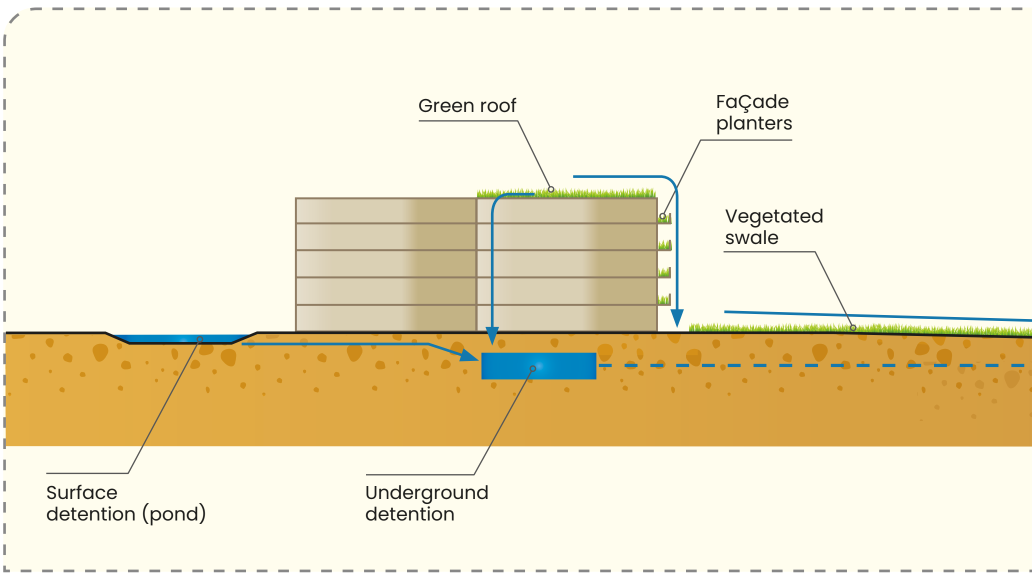


Figure 2.2 An example of how ABC Waters design features can be integrated within a building development to reduce runoff and peak flow.

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.

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

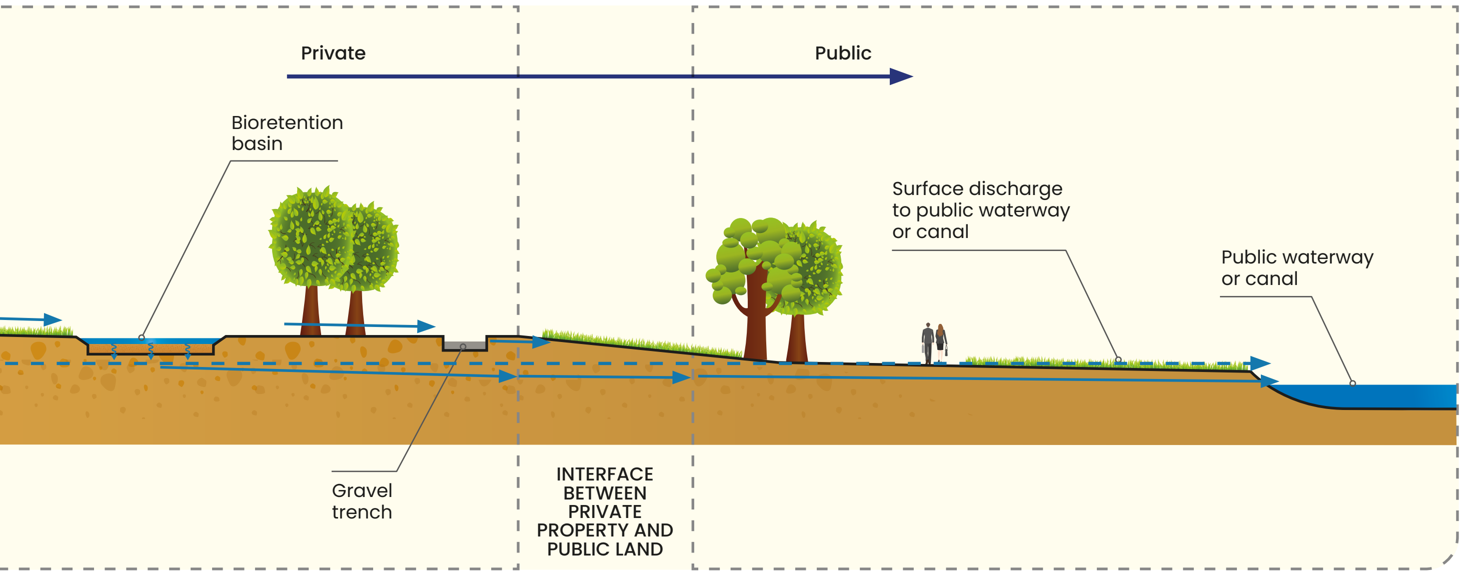
c) Integrating stormwater treatment into the landscape by incorporating multiple-use corridors that maximise the aesthetics and recreational amenities of developments.

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

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.

Figure 2.3 ABC Waters project at Sungei Ulu Pandan – A raingarden.



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.

Developers/Owners shall engage ABC Waters Professionals to design, oversee the construction of, and develop a maintenance plan for the ABC Waters design features. The design drawings and calculations for these features, endorsed by ABC Waters Professionals, shall be submitted to PUB as part of DC submission.

2.4 Other Resources

The COPEH is available on the NEA website: **https://www.nea.gov.sg/docs/default-source/resource/practices-/copeh-2021.pdf**

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 National Environment Agency (NEA). The COPEH provides guidelines on environmental health concerns, such as vector control, lists the objectives to be met and stipulates the minimum basic design criteria.

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 5000 square metres or more;
- Additions or extensions to existing buildings which involve increasing the gross floor area of the existing buildings by 5000 square metres or more; or
- Involve the provision, extension or substantial alteration of the building envelope and building services in or in connection with an existing building.

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

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.

3 Source Measures to Manage Stormwater On-site

Figure 3.1 Example of Source measure in Paya Lebar Quarters – rain garden integrated with detention cells underneath.

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, sudden and intense storms can cause a higher peak runoff which temporarily overwhelm our canals and drains, causing localised flash floods.

Source measures 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 measures build in additional flexibility into the drainage system to cope with increased weather uncertainties and higher intensity storms.

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).

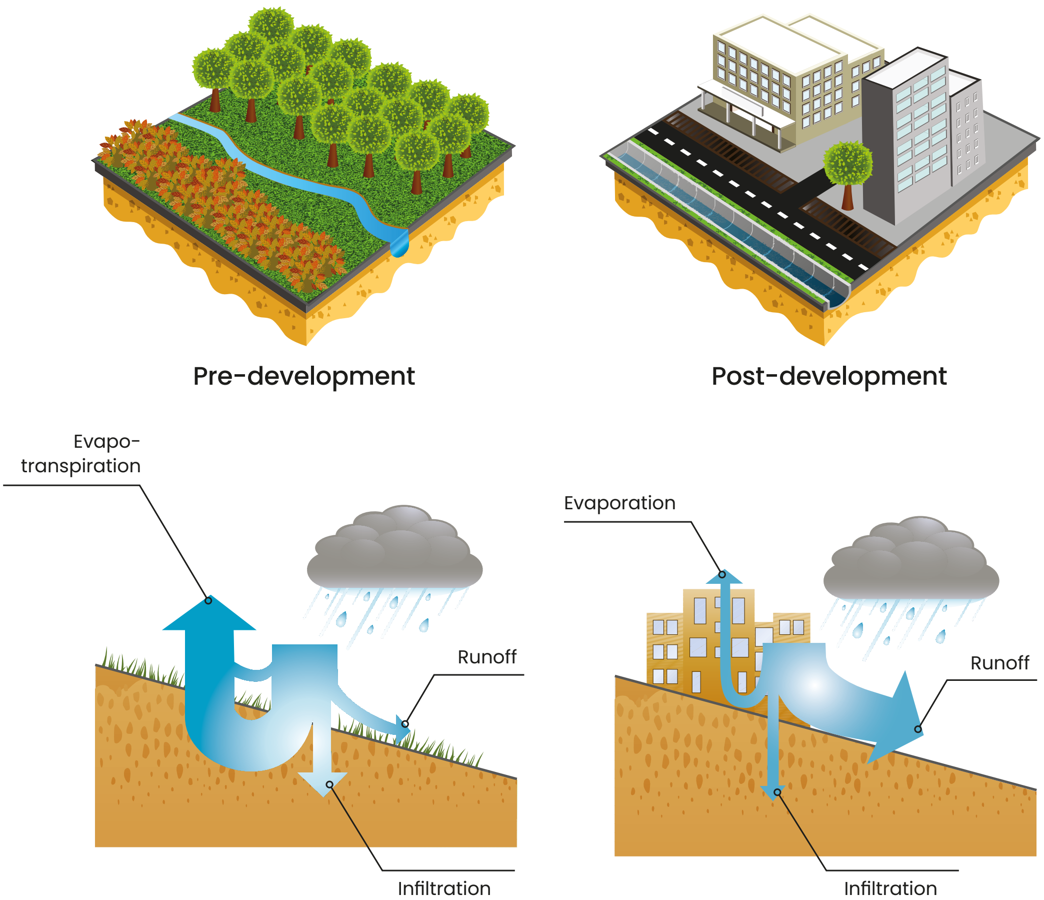


Figure 3.2 Comparison of runoff behaviour under pre-development and post-development conditions.

3.3 Strategies for Planning, Designing and Implementing Source Measures

The following sections provide guidance on the main steps for planning, designing and implementing source measures to slow down and reduce peak runoff. 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

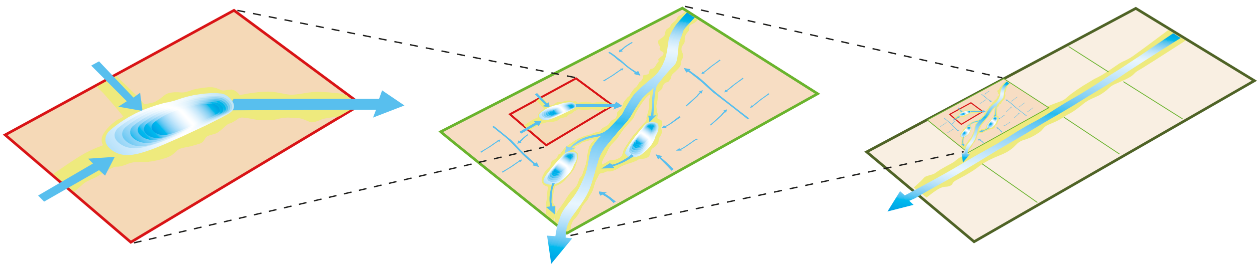
Step 2: Calculate developed runoff coefficients and peak runoff rates

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

Developers can do their part to reduce the impact of urbanisation on peak flows in the drainage systems by implementing on-site 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 detention and/or retention features, coupled with effective conveyance systems. 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.

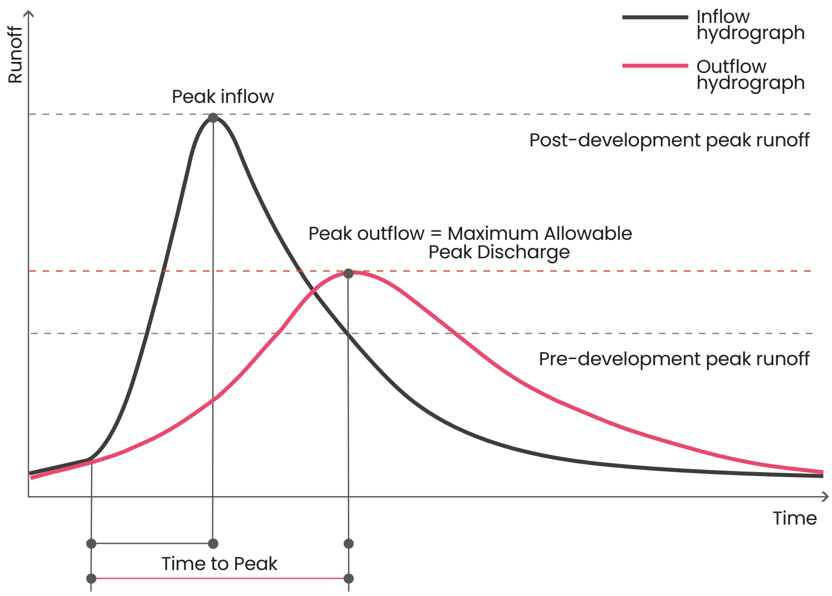


Figure 3.4 The inflow hydrograph depicts post-development runoff without runoff control. The outflow hydrograph is determined by the design of the outflow structure. The red line indicates the maximum allowable peak discharge to the public drains.

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 one of the important strategies to attenuate the peak runoff from impervious surfaces.

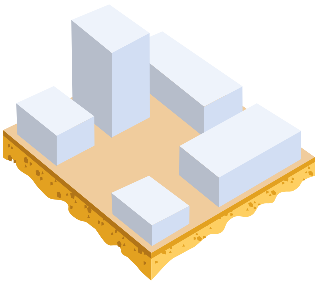
Figure 3.5 Detention Lawn in Surbana Jurong Campus.

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

3.4 General Design Considerations for Source Measures

Other than determining the maximum allowable peak discharge from the 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 6).

3.4.1 SPACE AVAILABILITY



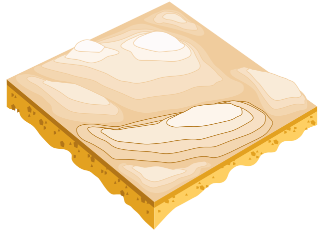
Programmatic constraints

If open space on the ground level is limited to implement surface detention or retention features, 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 underground 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 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, naturalised conveyance system, like vegetated swales or bioretention swales can be implemented as alternatives to conventional drains to slow down runoff and provide other benefits, such as increased greenery and cleansing of runoff.

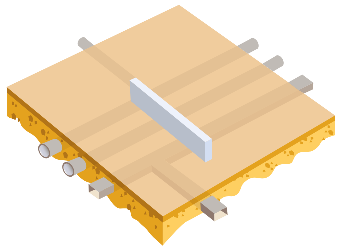
3.4.2 TOPOGRAPHY

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 drainage system would have to work around these obstructions, making the most of the available space to reduce the peak flow and convey the runoff from the site.


Site obstructions

If the site has existing stormwater drains, they can be retrofitted or substituted with naturalised conveyance systems like vegetated swales or bioretention swales. If the site constraints are too significant, other detention or retention options can be introduced. **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 Source Measures within the Development Site

Source measures can be sited on buildings, ground levels and underground. These measures can be connected in series to achieve the required target for peak flows reduction. 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. (Refer to Figure 3.7)

ABC Waters design features can also be incorporated with the source measures to provide the additional benefit of cleansing the runoff and improving the aesthetics within the development.

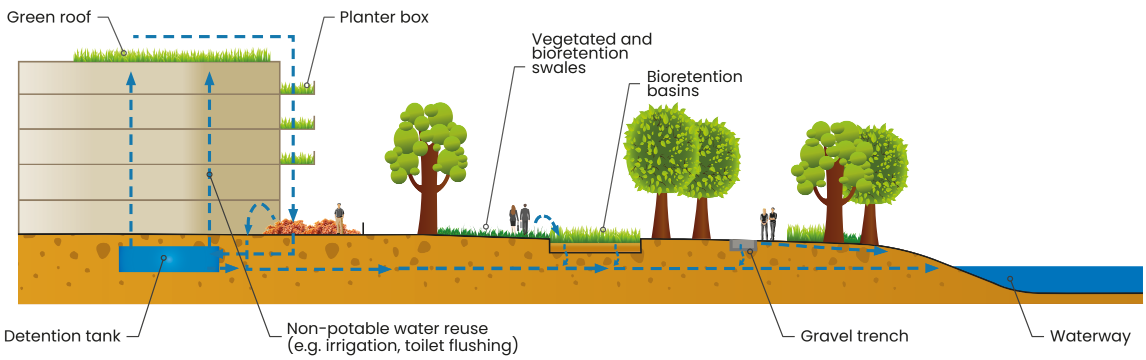


Figure 3.7 Options for on-site source measures within the development site.

ABC WATERS DESIGN FEATURES

ABC Waters design feature is a natural treatment system of plants and soil that slow down and retain the first flush of stormwater while simultaneously cleansing it.

Figure 3.8 Examples of ABC Waters design features – Rain Garden (left) & Constructed Wetland (right).

3.5.1 ON BUILDINGS

Figure 3.9 Landscaped green roof and rooftop garden area on top of Orchard Central Mall.

ROOFTOP SYSTEMS

The rooftop is where rainwater usually lands first and begins its journey towards the public waterways. The roof can be designed as a garden where the soil layers temporarily store the runoff before it is channelled into the downstream systems. The amount of storage is limited by the drainage layers and the controlling weir elevation of the roof drain. It is important to check the loading capacity of the rooftop to ensure that it can cater to the heavier loads.

Figure 3.10 Roof garden at Central Horizon HDB development in Toa Payoh.

PLANTER BOXES

Planter boxes (Figure 3.11) are space-efficient systems that can be implemented on building façades or roofs to help reduce peak runoff. ABC Waters design features, e.g. rain gardens, cleansing biotopes, can be incorporated to provide an additional benefit to cleanse the runoff before this is discharged into the public drainage system.

Figure 3.11 Planter boxes on the sides of the building and along pedestrian bridges at Khoo Teck Puat Hospital.

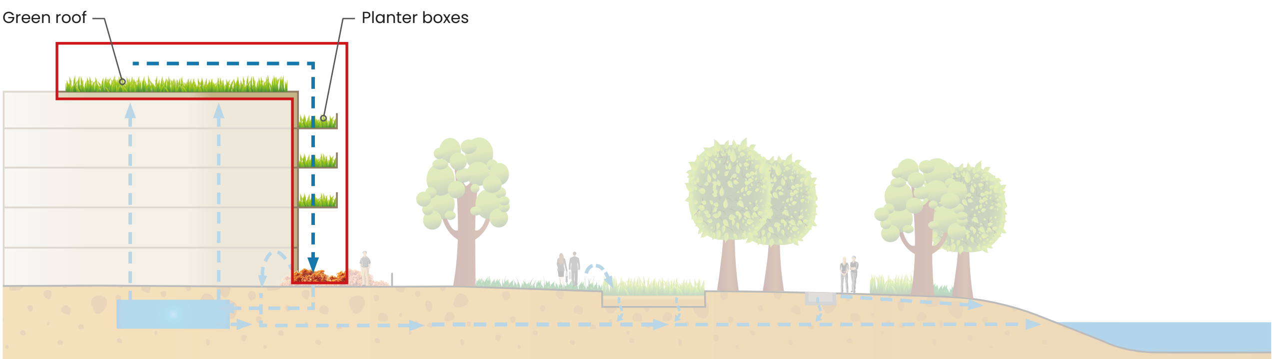


Figure 3.12 On-site stormwater detention and retention options on buildings.

3.5.2 ON GROUND LEVEL

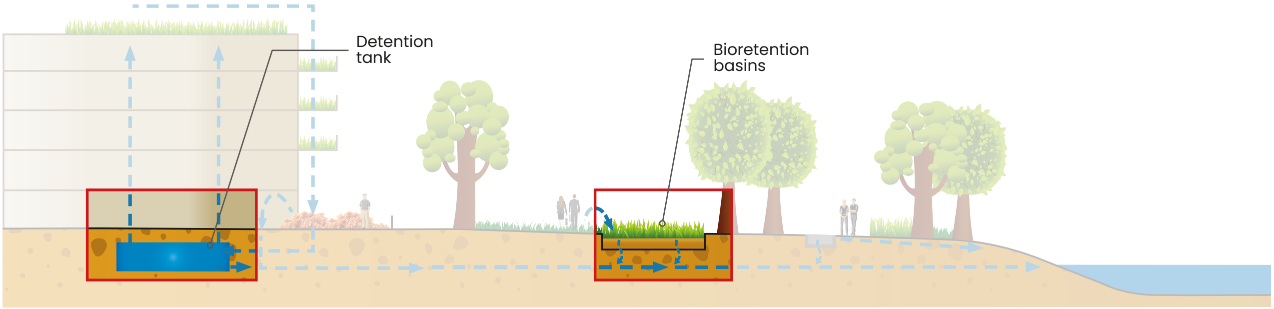


Figure 3.13 On-site stormwater detention and retention options on ground level.

STORMWATER DETENTION OR RETENTION BASINS (PONDS)

Providing storage at source via detention or retention basins can be an effective mean of slowing down peak flows for sudden and intense storms. Detention tanks/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. offline storage) or inflows from the conveyance system (i.e. on-line storage).

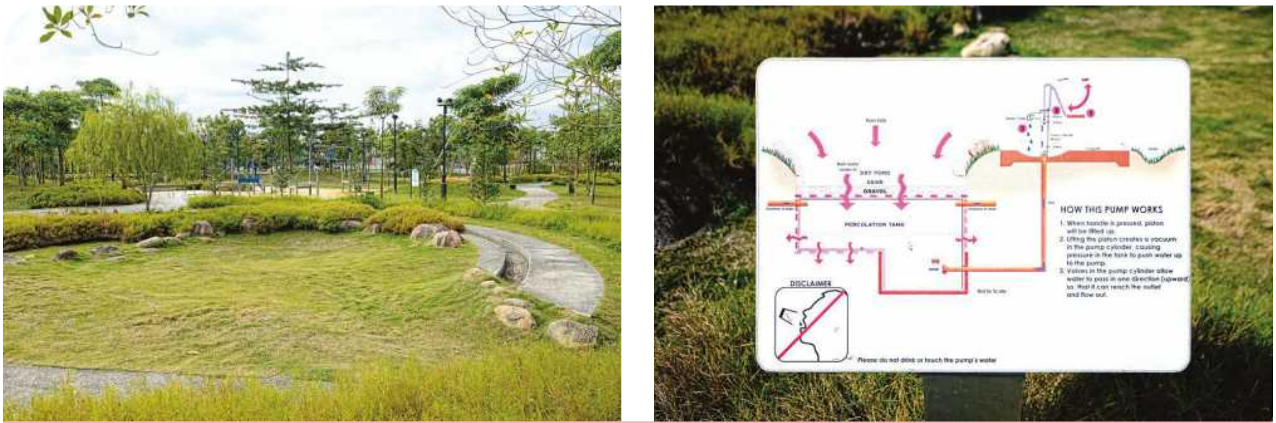


Figure 3.14 Dry pond at Greenwood Sanctuary - During rain events, stormwater runoff flows from the surrounding ground to the dry pond and filters to underground percolation tanks encased in a permeable membrane layer. During dry weather, the lawn area in the dry pond can also be used for recreational 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.

Figure 3.15 A bioretention basin at Balam Estate with an overflow pit.

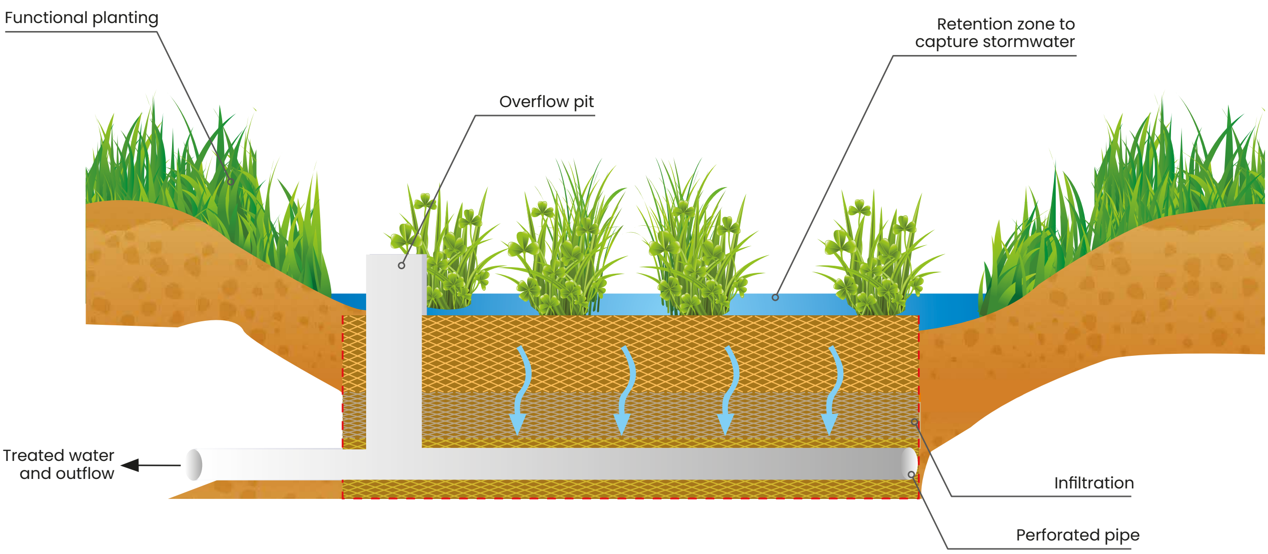


Figure 3.16 A typical section of a bioretention basin.

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 measures that are linked to detention and retention zones in order to achieve the required targets for peak flow reduction, e.g. wider drain to contain more runoff for attenuating peak flow, meandering naturalized drain to slow down runoff, etc.

SIZING CONVEYANCE SYSTEMS

In addition to catering for flows within the catchment, the size of conveyance measures 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.

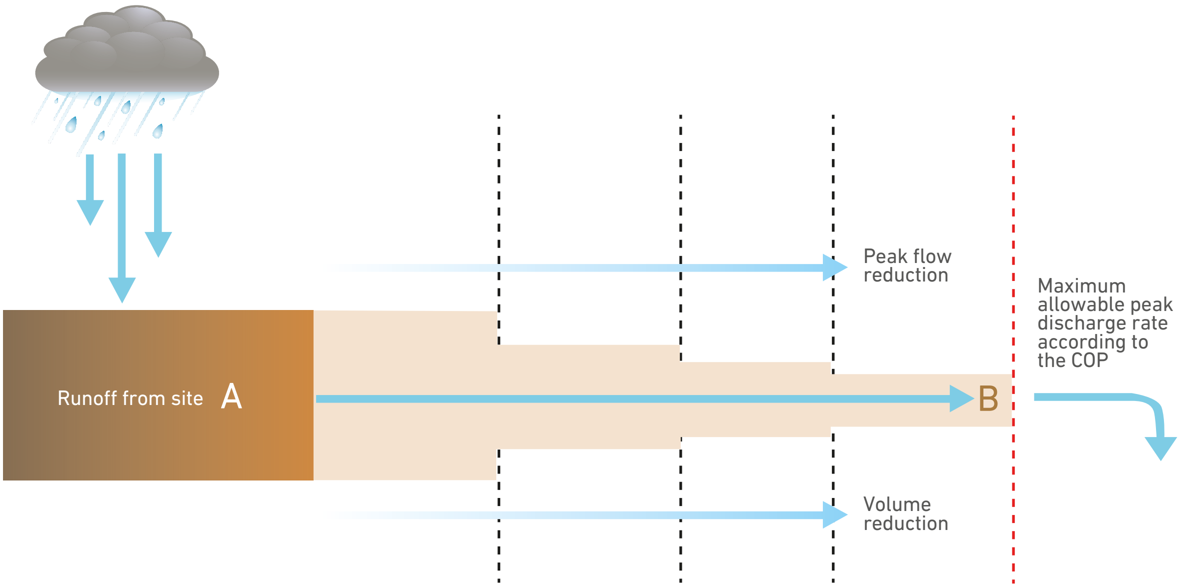


Figure 3.17 Illustration showing the reduction in peak flows and flow volumes as runoff flows through a conveyance system that connects detention and retention features.

VEGETATED AND BIORETENTION SWALES

Swales are open conveyance channels that are designed to convey stormwater via overland flow while increasing the green spaces within the development. Swales can reduce the number and cost of stormwater drain and piping required within the development site and can look like a typical landscaped area.

The vegetation in the swale helps to slow down and reduce the peak runoff, and at the same, promoting the settling of sediments and other pollutants. Bioretention swale provides additional stormwater quality improvements via infiltration through a filter media, with the cleansed runoff being collected via a subsoil perforated pipe (refer to Figure 3.18).

Figure 3.18 Bioretention swales along Margaret Drive.

Figure 3.19 Example of a gravel trench serving as a conveyance channel for stormwater runoff.

GRAVEL TRENCHES

A gravel trench (Figure 3.19) 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 pretreatment measures to prevent clogging and failure.

3.5.3 UNDERGROUND SYSTEMS

If there are limited space at the ground levels, source measures (refer to Figure 3.20) 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.

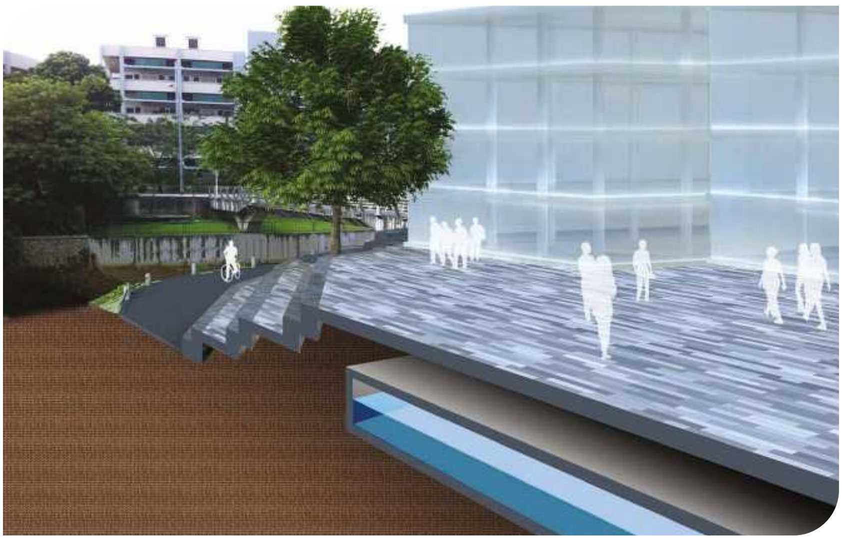


Figure 3.20 Schematic of an underground detention tank.

3.6 Sustainable Stormwater Management

3.6.1 ACTIVE, BEAUTIFUL, CLEAN WATERS (ABC WATERS) CONCEPT

ABC Waters design features can be incorporated as part of the source measures to create a treatment train to improve water quality. A treatment train is a series of stormwater management features that work together to slow down water by reducing peak flows and cleanse the runoff using a system of plants and natural materials.

Developers may refer to the ABC Waters design guidelines and engineering procedures for specific guidance on the selection, sizing, construction and maintenance of ABC Waters design features.

3.6.2 RAINWATER HARVESTING

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.

3.7 Interfacing between Source Measures 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 measures 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 measures such as rooftop system, 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.

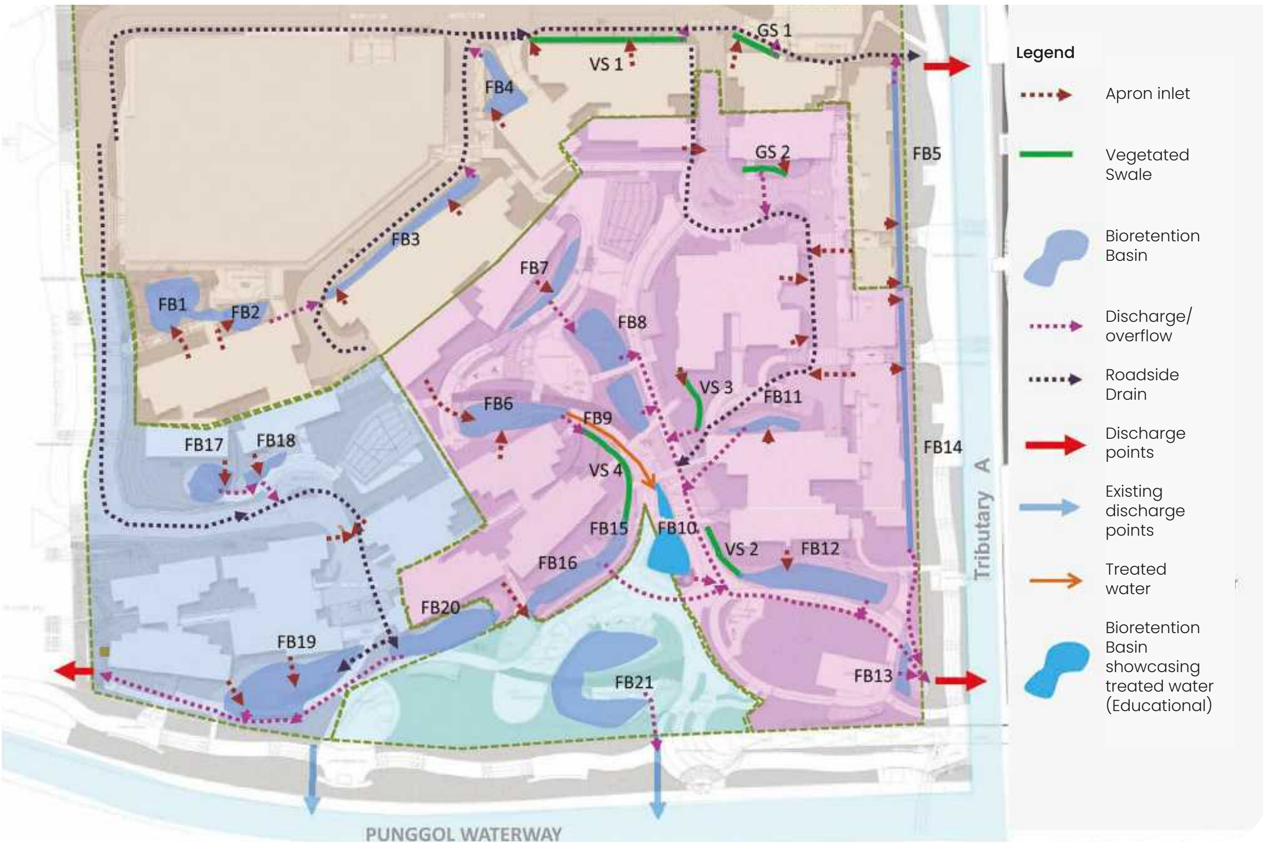


Figure 3.21 Indicative drainage flow paths in Waterway Ridges. Stormwater runoff is conveyed, detained and treated through a series of bioretention basins and vegetated swales before being discharged from the development into the roadside drains, Punggol Waterway and Tributary A.

3.8 Case Study - Waterway Ridges, Singapore

3.8.1 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 improve water quality.

3.8.2 INTEGRATED STORMWATER MANAGEMENT MEASURES

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 3.22 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 Figure 3.23).

Overflow system design

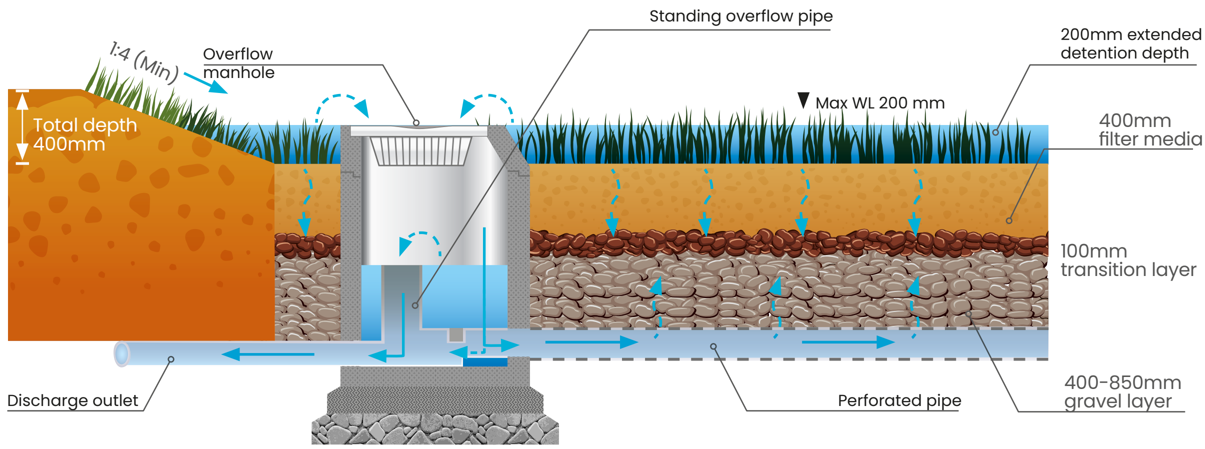


Figure 3.23 Typical cross-section of a bioretention basin implemented at Waterway Ridges.

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.

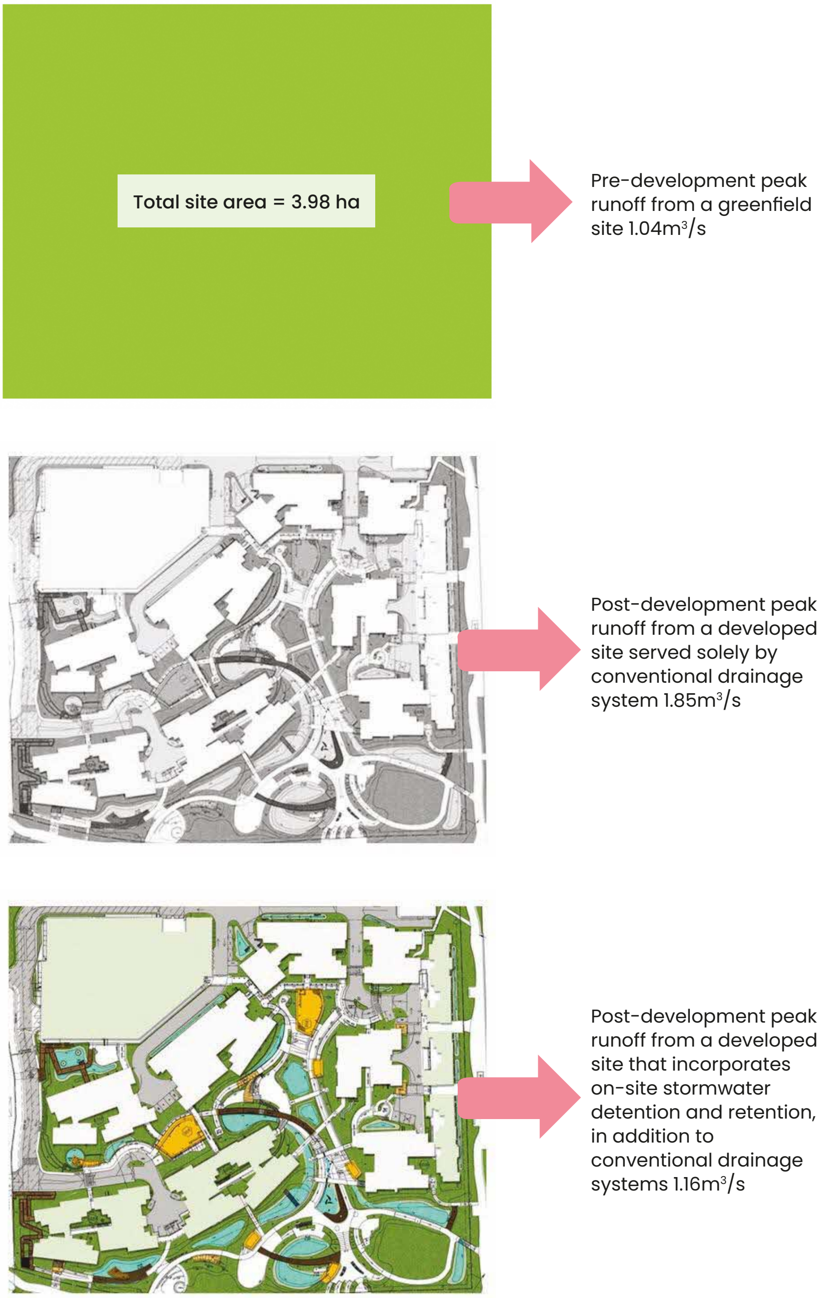


Figure 3.24 Comparison of the different peak runoff rates for different drainage systems adopted for the precinct.

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:

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 3.25 Bioretention basin serving as a multi-purpose lawn during dry weather. During a rain event, it temporary stores stormwater runoff. (Images courtesy of Henning Larsen)

4 Pathway Measures to Convey Stormwater Runoff



4.1 Where is the Pathway

Pathway refers to the means or routes through which stormwater is conveyed. The pathway measures aim to enhance the capacity of our conveyance systems and include drain widening and deepening and building catchment level detention systems, etc.

ROADSIDE DRAINS

Drains along the sides of roads discharging to outlet drains

OUTLET DRAINS

Tributaries that discharges to major canals

MAJOR CANALS AND WATERWAYS

Large canals/ waterways that lead to the reservoirs or sea

4.2 The Need for Implementing Pathway Measures

To manage flood risks, PUB implements pathway measures which serve one of the following purposes:

a) **Flood Prevention**
Providing adequate drainage infrastructure ahead of developments to cope with the needs of increased runoff.

b) **Flood Alleviation**
Improving the capacities of the drainage infrastructure to prevent the recurrence of flash floods.

c) **Structural Rehabilitation**
Restoring the structural integrity and operational functionality of damaged or old drains.

It may not always be feasible to build our drains to accommodate every extreme rainfall event as this would require massive land take and much higher costs. Given competing needs for other land uses such as housing, parks and roads, we have to be practical in our drainage expansion in Singapore. Building our drains for extreme conditions would mean that much of the capacity would be extremely costly, but not needed most of the time.

4.3 Planning and Designing Pathway Measures

4.3.1 DRAINAGE DESIGN STANDARDS

The design of a drainage system consists primarily of two components:

a) hydrological analysis, which involves the estimation of peak runoff generated from our catchments, and
b) hydraulic design, which includes the determination of drain sizes to convey peak runoff

Other factors such as the degree/type of development, catchment area and rainfall intensity are taken into consideration in the design of the drainage system.

In 2011, PUB raised the drainage design standards in the Code of Practice of Surface Water Drainage to cater for more intense rainfall events. These design standards will be regularly reviewed to take into consideration the latest climate change projections.

4.3.2 ACTIVE, BEAUTIFUL, CLEAN WATERS (ABC WATERS) PROGRAMME

As PUB continues to upgrade Singapore's extensive network of drains and canals to cope with more intense rainfall and enhance flood protection, we also look out for opportunities to create multi-use public spaces along waterways that enhance the overall liveability of the surroundings.

In 2006, PUB launched the ABC Waters Programme to transform our utilitarian drains, canals and reservoirs into beautiful streams, rivers and lakes that integrate naturally and holistically into the urban environment. These transformed spaces at the waterways and waterbodies goes beyond just managing stormwater, to create a greener and more liveable environment.

4.4 Drainage Improvement Projects

4.4.1 BUKIT TIMAH FIRST DIVERSION CANAL

The Bukit Timah First Diversion Canal was originally completed in the 1970s to alleviate flooding in the Bukit Timah Area. The diversion canal, which is about 3.2km long, diverts flow from the Bukit Timah Canal into Sungei Ulu Pandan.

The Bukit Timah area has been historically prone to flooding due to its topography and high urbanisation. Over the past decade, PUB had implemented concerted plans to mitigate flood risks in this area, progressively upgrading its drainage infrastructure. In 2019, PUB completes drainage improvement works for Bukit Timah First Diversion Canal. The upgrading works involved the deepening and widening of the canal and construction of additional tunnels, thereby increasing the drainage capacity by about 30 per cent (Refer to Figure 4.3). This will help alleviate the risk of flash floods along Bukit Timah Road (between Jalan Kampong Chantek and Maple Avenue) and Dunearn Road (between Swiss Club Road and Sixth Avenue).

The entire project was carried out over three phases starting from September 2012, and took nearly seven years to complete – at a combined cost of $300 million. From an open and shallow drain passing through hilly terrain, forested areas and private residential estates, the Bukit Timah First Diversion Canal has undergone a dramatic transformation into a major waterway that is now better equipped to deal with intense rainfall events.

Figure 4.3 The upgrading works involved the deepening and widening of the canal and construction of additional tunnels, thereby increasing the drainage capacity by about 30 per cent.

4.4.2 KALLANG RIVER

Kallang River at Bishan-Ang Mo Kio Park project is a joint collaboration between PUB and NParks to turn a concrete canal into a picturesque river teeming with life. Before the transformation, the park was bounded on one side by a concrete canal (i.e. Kallang River). The canal served the purpose of efficient drainage and flood control during heavy downpours.

Figure 4.4 Concrete canal prior to the upgrading works

This project commenced in Oct 2009 and completed in Mar 2012 at a cost of $76 million. Adopting the concept of integrating the river with the adjacent park, the previously concrete canal was reconstructed into a naturalised river with bioengineered riverbanks, using a variety of plants and natural materials. The plants and natural materials does more than just stabilising the riverbanks, it also slows down the flow within the waterway allowing sediments to settle upstream before it reaches Marina Reservoir. During dry weather, the flow of water is confined to a narrow stream in the middle of the river. In the event of a storm, the adjacent park area doubles up as a conveyance channel, carrying the rainwater downstream effectively.

This project demonstrates how agencies collaborated to meet various objectives – an increase in Kallang River conveyance capacity while adding more green spaces to the park and residential areas and developing multi-use public spaces where water resources are effectively weaved into the urban environment.

Figure 4.5 Kallang River at Bishan-Ang Mo Kio Park.

Figure 4.6 Riverbanks forming part of the community spaces for the public to enjoy.

4.4.3 STAMFORD DIVERSION CANAL AND STAMFORD DETENTION TANK

The Stamford Diversion Canal, together with the Stamford Detention Tank, is part of a holistic "source-pathway-receptor" approach to strengthen flood protection for the Stamford Canal Catchment, which covers the Orchard Road shopping belt.

STAMFORD DETENTION TANK (SDT)

Stamford Detention Tank (SDT), has a total size of 0.5ha, and extends 28m below the ground. Sited underneath the coach park of Botanic Garden's Tyersall Learning Forest and National Orchid Nursery. When there is a heavy downpour, excess storm water from the drains along Holland Road will flow into the SDT, which is big enough to hold 38,000 cubic metres of storm water temporarily – the equivalent of 15 Olympic-size swimming pools. After the storm subsides, the stored water will then be pumped back into the drains that flow to the Stamford Diversion Canal (SDC).

STAMFORD DIVERSION CANAL (SDC)

The new 2km-long diversion canal is located underneath the road, from Tanglin along Grange Road, across Hoot Kiam Road, through Irwell Bank Road, River Valley Road, off Kim Seng Road, and to the Singapore River. Connecting the upstream section of Stamford Canal to the Singapore River, the diversion canal varies from 6m to 14m wide and 3m to 4m deep. The SDC complements the SDT by diverting part of the storm water from the Stamford Catchment towards the Singapore River when it has spare capacity to cope with a surge in the storm water. With this alternative pathway to Marina Reservoir, the existing Stamford Canal is left to serve a smaller catchment, thus protecting the area against flooding during intense storms.

Both the SDT and SDC were completed in 2018 at a project cost of $227 million.

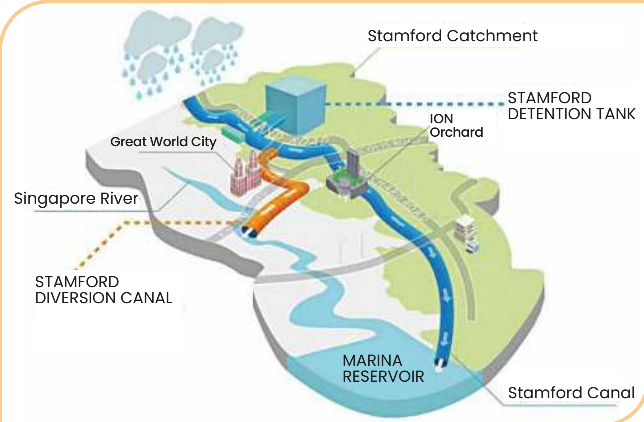


Figure 4.7 Schematic Plan of SDT and SDC.

Figure 4.8 This 2km-long diversion canal runs underneath Tanglin Road to Grange Road, across to Hoot Kiam Road, off Kim Seng Road and to the Singapore River. This canal is 6m to 14m wide in diameter and located 3m to 4m below ground.

Figure 4.9 The SDT can hold up to 38,000m^3 or 15 Olympic sized swimming pools of stormwater which can be emptied in four hours to prepare the tank for the next heavy rainfall.

5 Receptor Measures to Protect Developments from Floods

5.1 Where is the Receptor?

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

5.2 The Need for Implementing Receptor Measures

With more intense weather events arising from climate change, it is not feasible in Singapore to expand our drains to cater for every extreme rainfall event, as this would require massive land take and much higher costs. Therefore, building owners, contractors and individuals must do their part to protect their premises from flooding. Stormwater management and building flood resilience is a collective effort.

5.3 Planning Receptor Measures

Receptor measures include appropriate building design (e.g. platform levels for the ground levels of developments, crest levels for entrances to basements) and on-site flood protection measures (e.g. flood barriers). The Code of Practice on Surface Water Drainage requires developers to plan, design and implement these measures to minimise flood risk to people and property.

Figure 5.1 Minimum platform levels for developments and crest levels for entrances to basements are some examples of structural receptor solutions.

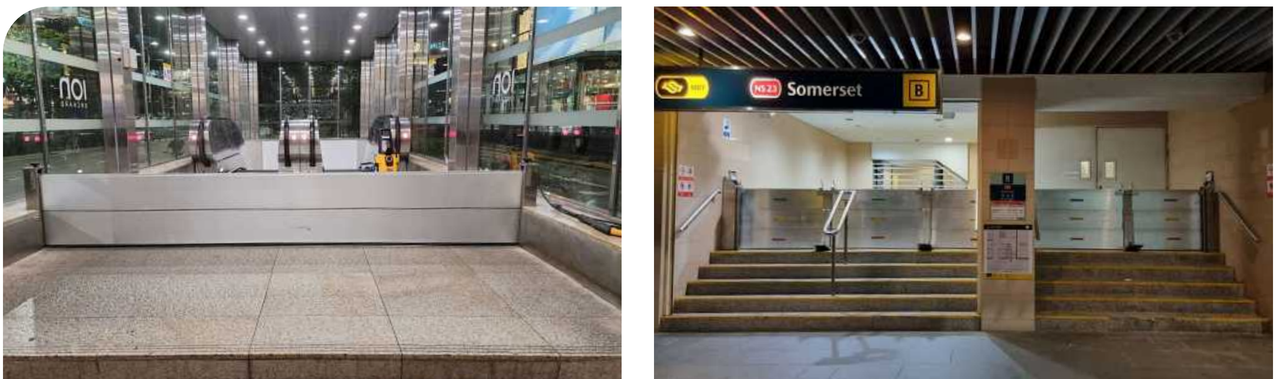


Figure 5.2 Flood barrier in developments as on-site flood protection measures.

PUB's website provides a map and table showing flood prone areas and hotspots in Singapore:
https://www.pub.gov.sg/drainage/floodmanagement

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

5.3.1 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.

PUB's website provides a list of flood prone areas and hotspots in Singapore.

5.3.2 UNDERSTANDING MINIMUM PLATFORM LEVELS AND MINIMUM CREST LEVELS

The COP describes requirements for 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 5.3).

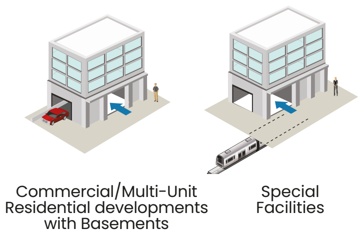
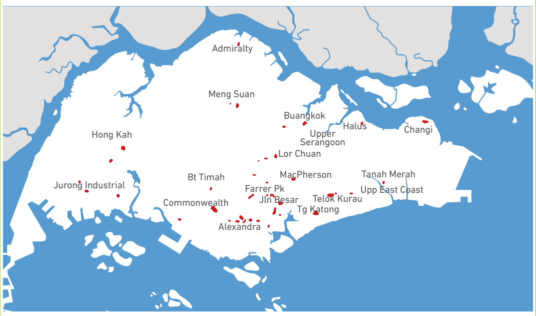
Figure 5.3 Steps and ramps are some of options to achieve the minimum platform levels for developments with entrances to underground facilities.

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. If the development is a critical infrastructure or key infrastructure; and
4. Adjacent road/ground levels

The highest level of the four factors or any other levels required by PUB will determine the minimum platform level of the development.

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 • **Industrial/Institutional/Commercial/ Multi-Unit Residential Developments:** 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
If development is a Critical Infrastructure or Key Infrastructure		• **Industrial/Institutional/Commercial/ Multi-Unit Residential Developments:** 300 mm above modelled flood level as advised by PUB • **Special facilities and developments with linkages to special underground facilities:** 300 mm above modelled flood level as advised by PUB
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 5.4 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.

5.4 Designing Receptor Measures

There are various options 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.

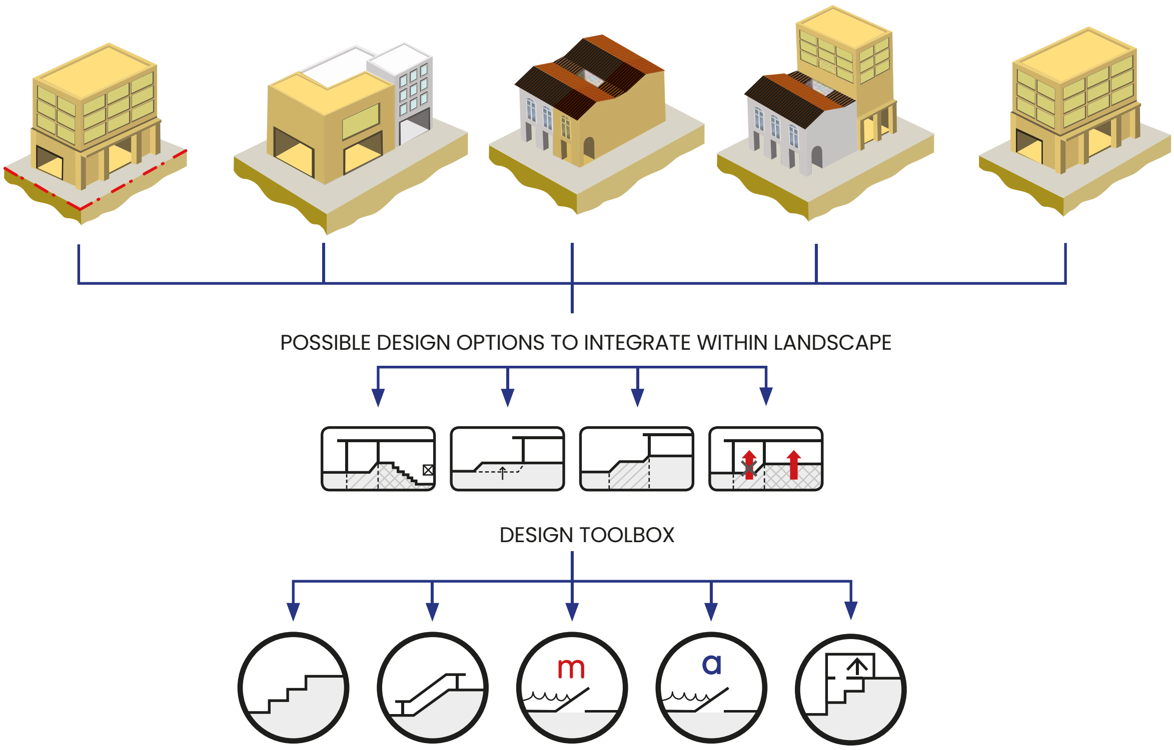
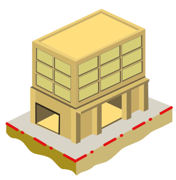
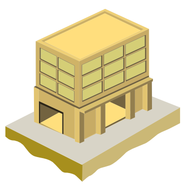
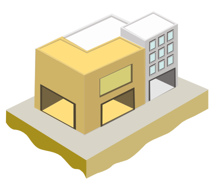
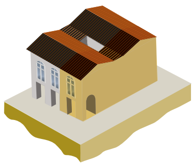


Figure 5.5 There are various design options for different building types to meet minimum platform and crest levels.

5.4.1 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.

5.4.2 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

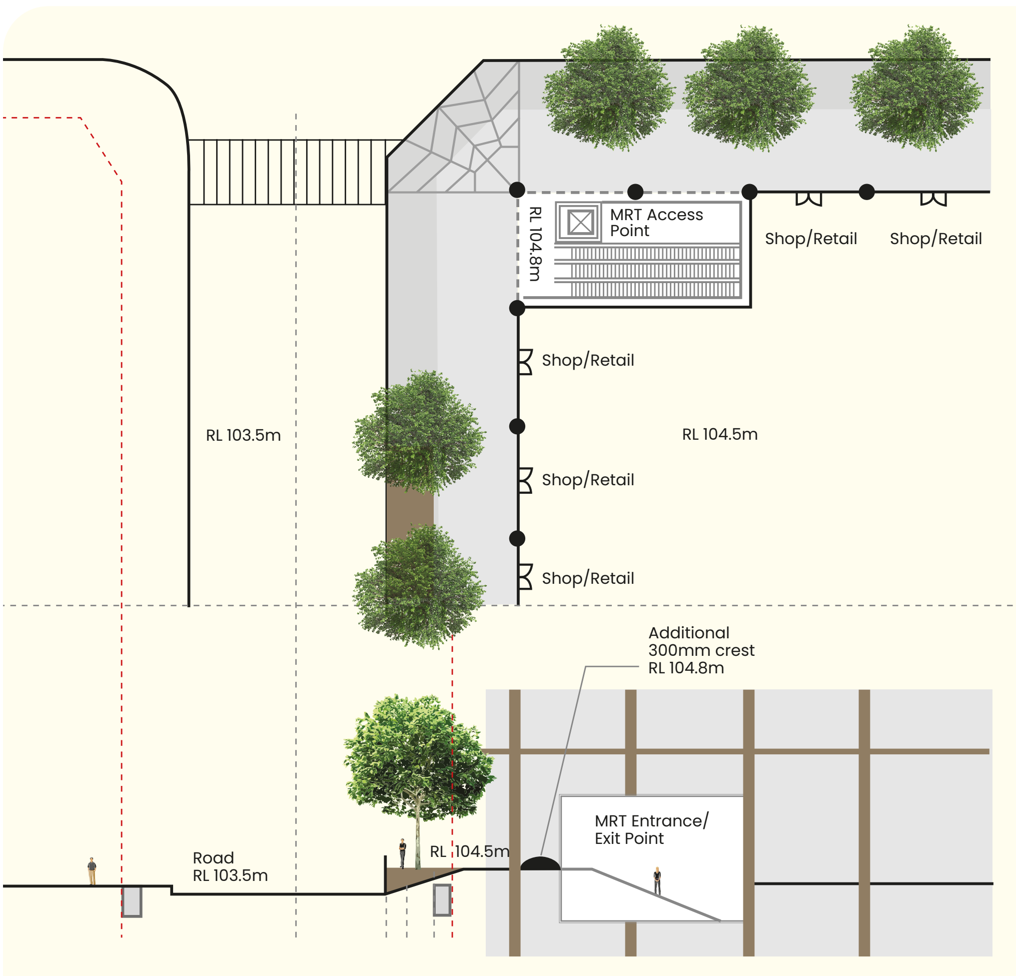


Figure 5.6 Example illustration of how a development can be partitioned to provide for an additional crest level of 300 mm for the entrance to a MRT station while the rest of the site is subject to an MPL of 104.5 mRL.

and crest level 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 5.6).

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 5.7).

Figure 5.7 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 5.8).

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 5.8 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 5.9).

Figure 5.9 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.

5.4.3 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 5.10 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 5.11 Examples of different types of mechanical lifts. Top – Platform lift for handicap access. Bottom – Car lift that is integrated into the building.

Benefits	Constraints	Applications
• 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.	• 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).	• 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 transport from storage location within an hour or shorter activation period as necessary; and

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

Figure 5.12 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 (Shutter 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 5.13 Manually installed slot-in barrier system.

Figure 5.14 Manually operated swing-type barrier system.

Figure 5.15 Sliding mechanical flood barrier system.

Benefits

- 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.

Constraints

- 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.

Applications

- 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 5.16).

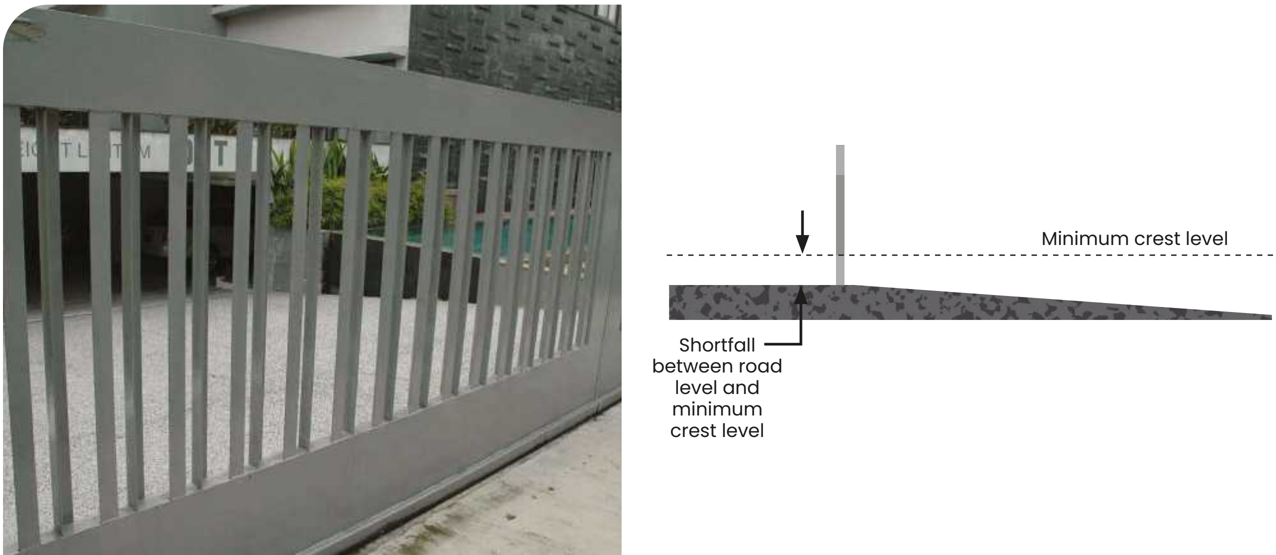


Figure 5.16 The entrance gate of this development leading directly to the basement car park was designed with a solid bottom section, with openings (for aesthetics) starting at the level above the required minimum crest level. A cross-section schematic of the gate is shown on the right.

Figure 5.17 Slot-in flood barriers.

AUTOMATIC FLOOD BARRIERS

Automatic flood barriers are permanently installed in place and can be activated very quickly compared with manual flood barriers (Figure 5.17). 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	Constraints	Applications
• 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.	• As the barrier is part of pedestrian or vehicular access, it may be prone to damage or wear and tear.	• Public areas. • Can be integrated into new developments for round-the-clock, unmanned activation.

5.5 Enhancing Flood Response Capabilities

Sudden and intense heavy storms, even during non-monsoon periods, can temporarily overwhelm our canals and drains and cause localised flash floods. To boost flood response capabilities, PUB has installed water level sensors around Singapore. These water level sensors provide data on water levels in the drains and canals, enhancing the monitoring of real-time site conditions during heavy storms and response time. CCTVs have also been installed in sensitive or flood prone areas to provide up-to-date images of conditions at these locations.

PUB provides advance warning to the public on potential floods via various platforms such as Telegram channel, MyENV mobile application so that safety precautions can be taken (See Figure 5.18 and Figure 5.19 below).

Building owners, contractors and occupants are encouraged to use PUB's communication channels to receive flood alerts and real-time information to take the necessary measures to protect the property and ensure the safety of occupants and members of public.

a) Weather outlook and tide info:

- Radio broadcast
- NEA Weather Information Hotline: 6542 7788
- NEA's website: www.weather.gov.sg
- myENV mobile app
- Predicted tide levels: https://www.nea.gov.sg/weather/tide-timings

b) Water levels in canals and drains:

- Subscribe to SMS alerts at PUB's website: www.pub.gov.sg/drainage/floodmanagement/subscribesms

c) CCTV images of road conditions:

- PUB's website: https://app.pub.gov.sg/waterlevel/pages/WaterLevelSensors.aspx

d) Updates on flash floods:

- PUB Telegram: t.me/sgflood
- www.facebook.com/PUBsg
- Report floods via PUB's 24-hour call centre at 1800-CALL-PUB (1800-2255- 782).

Figure 5.18 List of Information Channel.

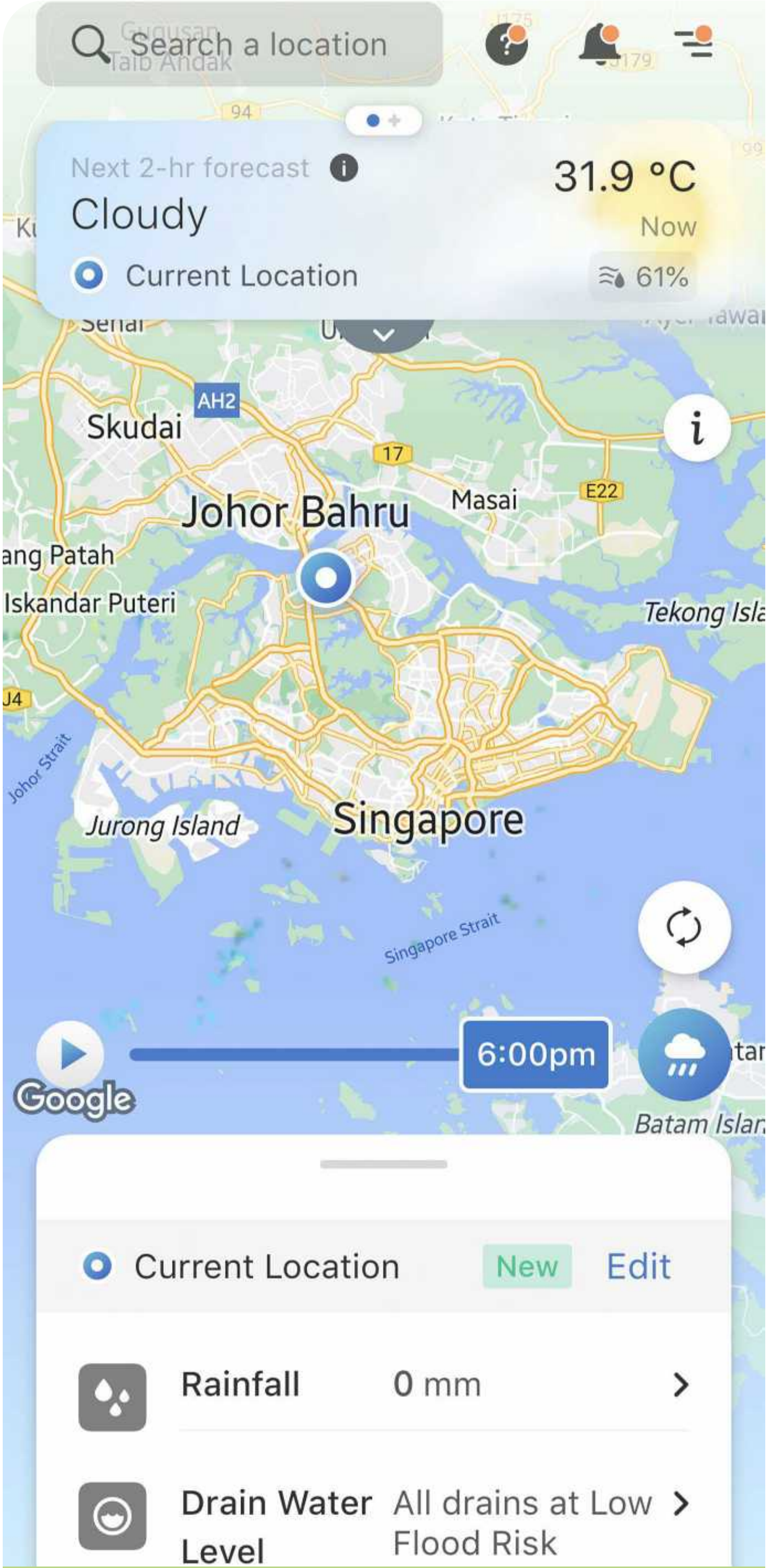


Figure 5.19 Weather and flood information available on myENV mobile app.

myENV app is a free mobile app that is available via Apple's App Store and Android's Google Play.

Android's Google Play | **Apple's App Store**

The Heavy Rain Warning information is available on MSS's website: **http://www.weather.gov.sg/warning-heavy-rain/**

5.6 Case Study : Tanglin Mall, Singapore

Figure 5.20 Tanglin Mall, located at the junction of Tanglin Road and Grange Road.

5.6.1 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 5.21 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 5.22 A flip-up barrier at the entrance to the basement carpark in closed (left) and open (right) positions.

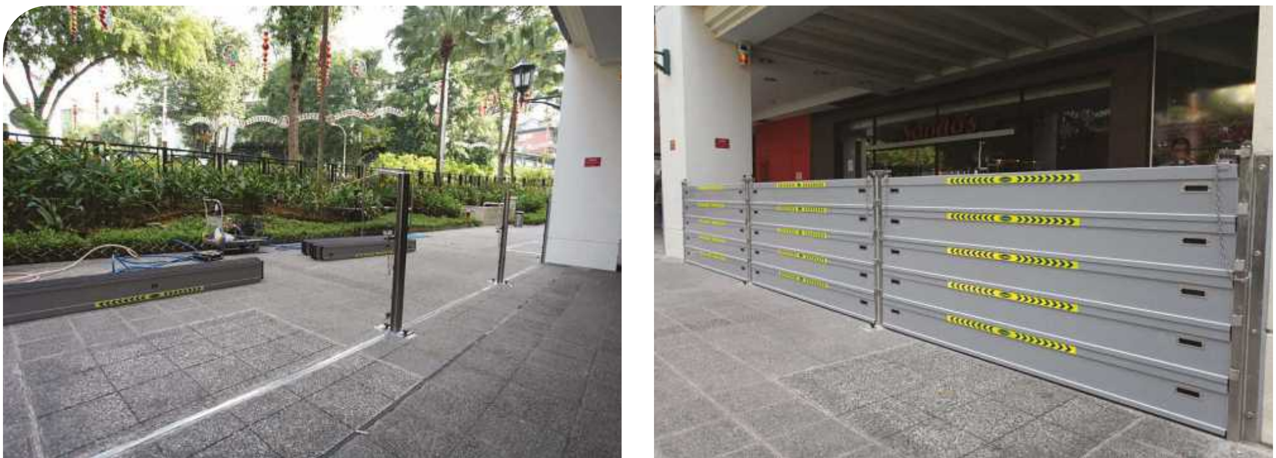


Figure 5.23 A multi-slot barrier at the front of Tanglin Mall before (left) and after (right) installation. These barriers have to be installed manually.

Figure 5.24 Swing-type flood barrier in open (top) and closed (bottom) positions at access to loading/unloading areas.

5.6.2 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 5.20). 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 5.21 and 5.22).

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 5.23 and 5.24).

In addition to implementing on-site flood protection measures, the building management subscribed to PUB's communication channels to receive flood alerts and information, 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 Safety, Operations and Maintenance Considerations

Figure 6.1 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 measures, it is important to keep in mind the safety, operations and maintenance aspects of the proposed measures. By considering these aspects right from the design stage, innovative and cost-effective source and receptor measures 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.

6.1 Safety Considerations

An 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).

Below are some examples on potential hazards associated with the various features on-site and the corresponding safety measures.

Hazards	Potential Consequence(s)	Measure(s)
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. • At some locations with steeper banks or higher flow volumes, softscape will be used to shield the user from the water edge.
Stagnant water that could possibly be a mosquito breeding site.	Risk of diseases, e.g. dengue fever	• Checks to be carried out twice a week for stagnant water and mosquito larvae. • For features with permanent waterbody, ensure constant water circulation and, where feasible, introduce anti-mosquito agent (e.g. BTI)
Areas designed to be accessed directly by users that have a waterbody/ waterbodies of varying depth and velocity.	Potential risk of drowning	• 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. • Designated entry points • Provide raised kerbs along areas of circulation in accordance with agencies'requirements • Provide railings along areas where there is an elevation difference in accordance with the agencies' requirements.

Figure 6.2 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.

Source measures, 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 6.3 A low seat wall, together with clear signage, can be used to limit access into the bioretention feature.

Examples of Operations and Maintenance Checklists for ABC Waters design features can be found in the Engineering Procedures on PUB's website: **https://www.pub.gov.sg/Professionals/Resources/Guides-and-Handbooks**

6.2 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.

6.2.1 OPERATIONS AND MAINTENANCE CHECKLISTS

Building owners are required maintain the internal drains, detention systems and flood protection measures to ensure they are effective during a heavy storm. Managing flood risks is a collective effort.

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.

6.2.2 OPERATIONS AND MAINTENANCE ISSUES FOR SOURCE MEASURES

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 debris 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 6.4 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 6.5 Sedimentation and excessive vegetation will grow inside the grass conveyance channel obstructing flow and reducing conveyance capacity during rain event. This could also potentially be a breeding ground for mosquitoes when stagnant water is trapped in bioretention feature. Regular maintenance is required to ensure its functionality.

DETENTION SYSTEMS

Detention systems collect and store stormwater runoff during a storm event, then release it at controlled rates to the downstream drainage system. In order to ensure that detention volume is available for the next storm event, discharge systems shall be designed to empty the tank within 4 hours after a storm event. Therefore, 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.

PUB's website also provides advisory information on how members of the public can exercise caution during flash floods: **https://www.pub.gov.sg/Public/KeyInitiatives/Flood-Management**

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.

6.2.3 OPERATIONS AND MAINTENANCE ISSUES FOR RECEPTOR MEASURES

Building owners and management shall take steps to ensure that receptor measures that are implemented continue 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 relevant chapters in the Code of Practice on Surface Water Drainage, which contains clauses on maintaining the integrity of the stormwater drainage system, including flood protection measures.

FLOOD OPERATIONS PLAN

When supplementing structural receptor measures like platform levels with mechanical receptor measures 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 6.7).

Figure 6.6 Regular tests and inspections of flood barrier systems are necessary to ensure that the system can be reliably activated during flood events.

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 6.7 Example of a Flood Operations Plan

6.3 FLOOD MONITORING

Owners and operations and maintenance personnel, especially those 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.

Building owners, contractors and individuals can subscribe to PUB's communication channels to receive flood alerts and information on flood incidents to determine which actions they need to take to protect themselves and their premises from flood risks.

Subscribe to SMS Alerts:
https://www.pub.gov.sg/Public/KeyInitiatives/Flood-Management

6.4 Operations and Maintenance of Source and Receptor Measures in Critical and Key Infrastructures

For Critical and Key infrastructures, owners may be required to submit supporting documents, such as photographs, videos and inspection records, annually to PUB to show that flood protection measures are tested and remain functional. PUB may also require the building owners to conduct annual exercise of flood barriers for PUB's inspection.

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.

REFERENCES AND RESOURCES

Singapore

BCA (latest edition) Code for Environmental Sustainability for Buildings

MEWR (2012) Report by the Expert Panel on Drainage Design and Flood Protection Measures

NEA (latest edition) Code of Practice on Environmental Health

NEA (2011) Guidelines on Mosquito Prevention in Domestic Rainwater Collection System for Non-Potable Uses

NEA (2008) Guidebook on Prevention of Mosquito Breeding

PUB (latest edition) Code of Practice on Surface Water Drainage

PUB (2024) ABC Waters Design Guidelines

PUB (2024) Engineering Procedures for ABC Waters Design Features

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PUB SINGAPORE'S NATIONAL WATER AGENCY

40 Scotts Road, #22-01 Environment Building, Singapore 228231.
Tel: (65) 6235 8888 | Fax: (65) 6731 3020
www.pub.gov.sg