PUB
Water for All : Conserve, Value, Enjoy

ACTIVE BEAUTIFUL CLEAN WATERS

DESIGN GUIDELINES

ABC
Active, Beautiful, Clean
Waters for All

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DESIGN GUIDELINES

Driven by the vision of sparkling, picturesque rivers and lakes with lush landscaped banks, Singapore has undertaken the challenge of transforming itself into a City of Gardens and Water.

CONTENTS

SECTION 1
INTRODUCTION

Under the Active, Beautiful, Clean Waters (ABC Waters) Programme, an initative by PUB, Singapore's national water agency, the country has embarked on a journey to a City of Gardens and Water.

The results are beginning to show as more and more developments have embraced the programme. The nation's vision of having sparkling rivers with landscaped banks, kayakers paddling leisurely in the streams with clean waterways flowing into the picturesque lakes is fast becoming a reality.

1.1 TRANSFORMING INTO A CITY OF GARDENS AND WATER

Over the years, Singapore has developed a pervasive drainage network of 32 major rivers, more than 8,000 km of waterways and 17 reservoirs. To realise the full potential of this water infrastructure, PUB, the national water agency, launched the Active, Beautiful, Clean Waters (ABC Waters) Programme in 2006. This strategic initiative harnesses the full potential of our water bodies to improve the quality not only of our waters but also of our lives. By integrating the drains, canals and reservoirs with the surrounding environment in a holistic way, the ABC Waters Programme aims to create beautiful and clean streams, rivers and lakes with postcard-pretty community spaces for all to enjoy.

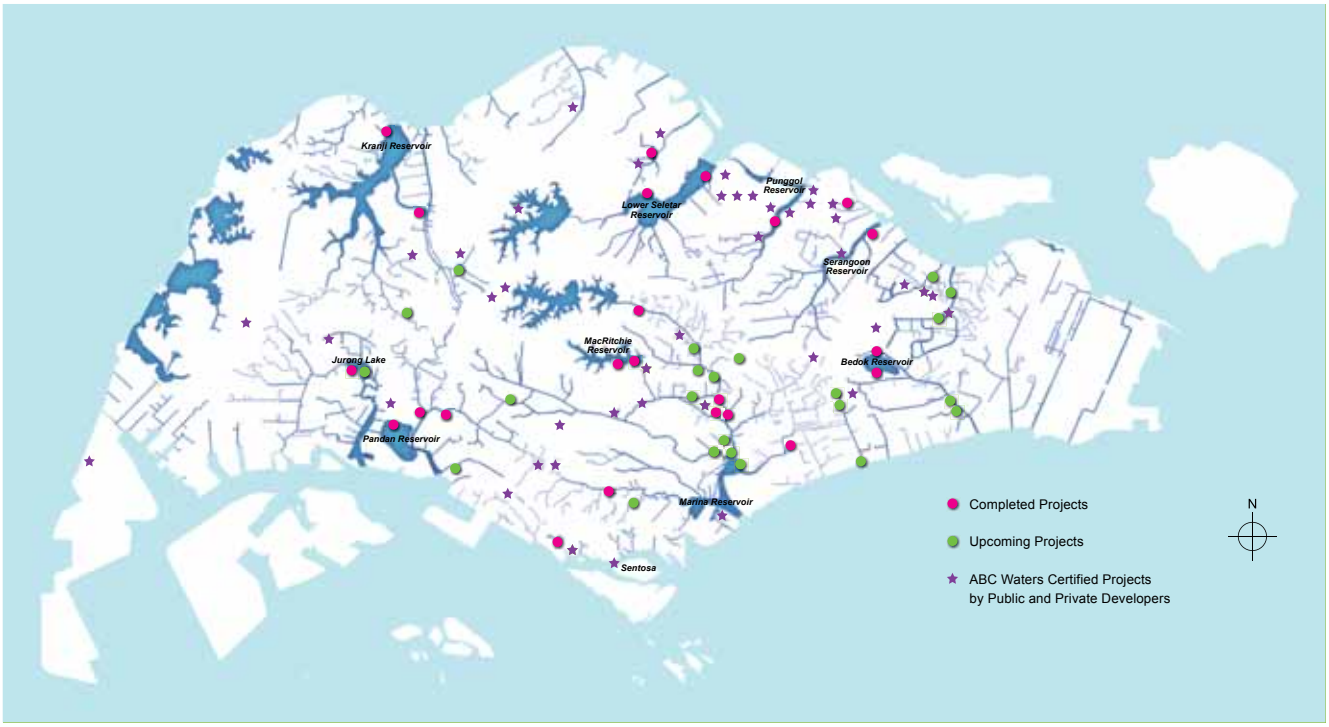


Fig. 1.1
Blue Map of Singapore.

1.2 ENSURING A ROBUST, SUSTAINABLE AND AFFORDABLE WATER SUPPLY

With investment in research and technology, Singapore has put in place a diversified and robust water supply through our Four National Taps, namely water from local catchments, imported water, NEWater and desalinated water. This diversification has allowed the nation to close the water loop, and helped her take a step towards water sustainability. It also forms the backdrop for ABC Waters, as Singapore moves beyond water sufficiency to capitalise on the potential of water to enhance the quality of life.

1.3 ABC WATERS

The aim of the ABC Waters Programme is to seamlessly integrate the Environment (Green), Water Bodies (Blue), as well as the Community (Orange) to create new community spaces and to encourage lifestyle activities to flourish in and around the waters. As the community gets closer to water, people will better appreciate and cherish our valuable water resource and hence develop a sense of stewardship towards water.

The three key strategies of the ABC Waters Programme are:

i) **Development of ABC Waters Master Plan and Project Implementation**
Launched in 2007, the master plan guides the overall implementation of projects to transform the city's utilitarian drains, canals and reservoirs into vibrant, picturesque and clean flowing streams, rivers and lakes that are well integrated with the environment. More than 100 potential projects across the island have been identified for implementation in phases by 2030. 23 ABC Waters projects have been implemented as of June 2014.

ii) **Promoting Adoption of the ABC Waters Concept**
The ABC Waters Concept encapsulates Singapore's ideology of harnessing the full potential of our waters and integrating them into our environment and lifestyles. PUB is beginning to see the benefits of this concept as public agencies and the private sector start to adopt ABC Waters design features in their developments. These features are natural systems that detain and clean stormwater runoff on site before allowing it to flow into the waterways and reservoirs. At the same time, they enhance biodiversity and the living environment.

The ABC Waters Design Guidelines was launched in 2009 as a call for partnership to encourage the private and public sectors to explore ways to implement ABC Waters design features and integrate waterways within their developments to enhance the environment.

iii) **3P (People, Public, Private) Partnership Approach**
The vision of attaining sustainable stormwater management would not be possible without the buy-in from the community. PUB constantly engages the community to adopt and take ownership of Singapore's water bodies. For example, schools are encouraged to develop educational learning trails for the various ABC Waters projects so that students can learn and appreciate our waters more. Private companies, grassroots organisations and community groups also help to facilitate the trails and carry out various activities at our ABC Waters sites to encourage more people to enjoy the sites and related facilities in a responsible manner.

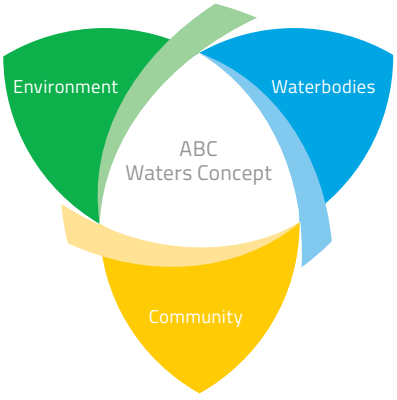


Fig. 1.2
ABC Waters Concept

1.4

BENEFITS OF EMBRACING THE ABC WATERS CONCEPT

ABC Waters design features use natural purification processes to protect the water quality in our reservoirs and waterways, enhance the aesthetics and biodiversity of the landscape and slow down the flow of stormwater runoff. ABC Waters sites also bring the community closer to water, creating new recreational spaces for all to enjoy.

In 2010, PUB launched a new scheme, the ABC Waters Certification, to provide recognition to public agencies and private developers who embrace the ABC Waters Concept and incorporate ABC Waters design features holistically in their developments.

The implementation of ABC Waters design features is also recognised by several government agencies including the Building & Construction Authority (BCA). The BCA Green Mark Scheme is a benchmarking scheme that incorporates internationally recognised best practices in environmental design and performance. The scheme includes ABC Waters design features as a mean of best stormwater management practice.

In 2011, PUB and the Institution of Engineers Singapore (IES) rolled out the ABC Waters Professional Programme aimed at building up the expertise of industry professionals in the area of ABC Waters design features. Participants of the programme who complete and pass the examinations for all four core modules and two elective modules, and satisfy the necessary criteria, will be eligible to be registered as an ABC Waters Professional. The programme is supported by Singapore Institute of Architects (SIA) and Singapore Institute of Landscape Architects (SILA).

Fig. 1.3
2011 ABC Waters Certification Award Ceremony

SECTION 2

ABC WATERS: SUSTAINABLE STORMWATER MANAGEMENT

Two-thirds of Singapore's land are water catchment areas. Hence it is critical that we leverage every opportunity to capture and clean stormwater runoff before it is channelled into the reservoirs.

In this section, we take a closer look at a sustainable stormwater management strategy – the ABC Waters Management Strategy.

Singapore receives about 2,400 mm of rainfall annually. It is important to have an effective stormwater management system to ensure a cleaner water supply in Singapore's reservoirs. With stormwater runoff collected in two-thirds of the island, an effective stormwater management system helps to capture and treat the water before channelling it into our reservoirs through the drains and canals.

2.1 TRADITIONAL STORMWATER MANAGEMENT

Traditionally, the country negates the risk of flooding by channelling water into the reservoirs and the sea via a network of concrete canals and rivers. These rivers and canals are designed to quickly and efficiently convey stormwater runoff to the sea or the nearest water body. In the past, most natural waterways such as Kallang River and Sungei Sembawang were enlarged and lined with concrete to increase their conveyance capacity and reduce bank erosion.

Fig. 2.1
Typical outlet drain (lined with concrete), an example of traditional stormwater management element.

2.2 HOLISTIC STORMWATER MANAGEMENT

Recognising that expanding canals and drains will not be sufficient, especially for areas that are more developed and have site constraints, PUB has gone beyond implementing pathway solutions (e.g. drain capacity improvements, diversion canals, centralised detention tanks and ponds, etc.) to work with developers to install source solutions (e.g. decentralised detention tanks and ponds, rain gardens, etc.) and receptor solutions in order to better manage stormwater runoff and protect developments from floods. By implementing a range of appropriate measures that covers the entire spectrum of the drainage system, flood risks can be more significantly reduced and effectively managed.

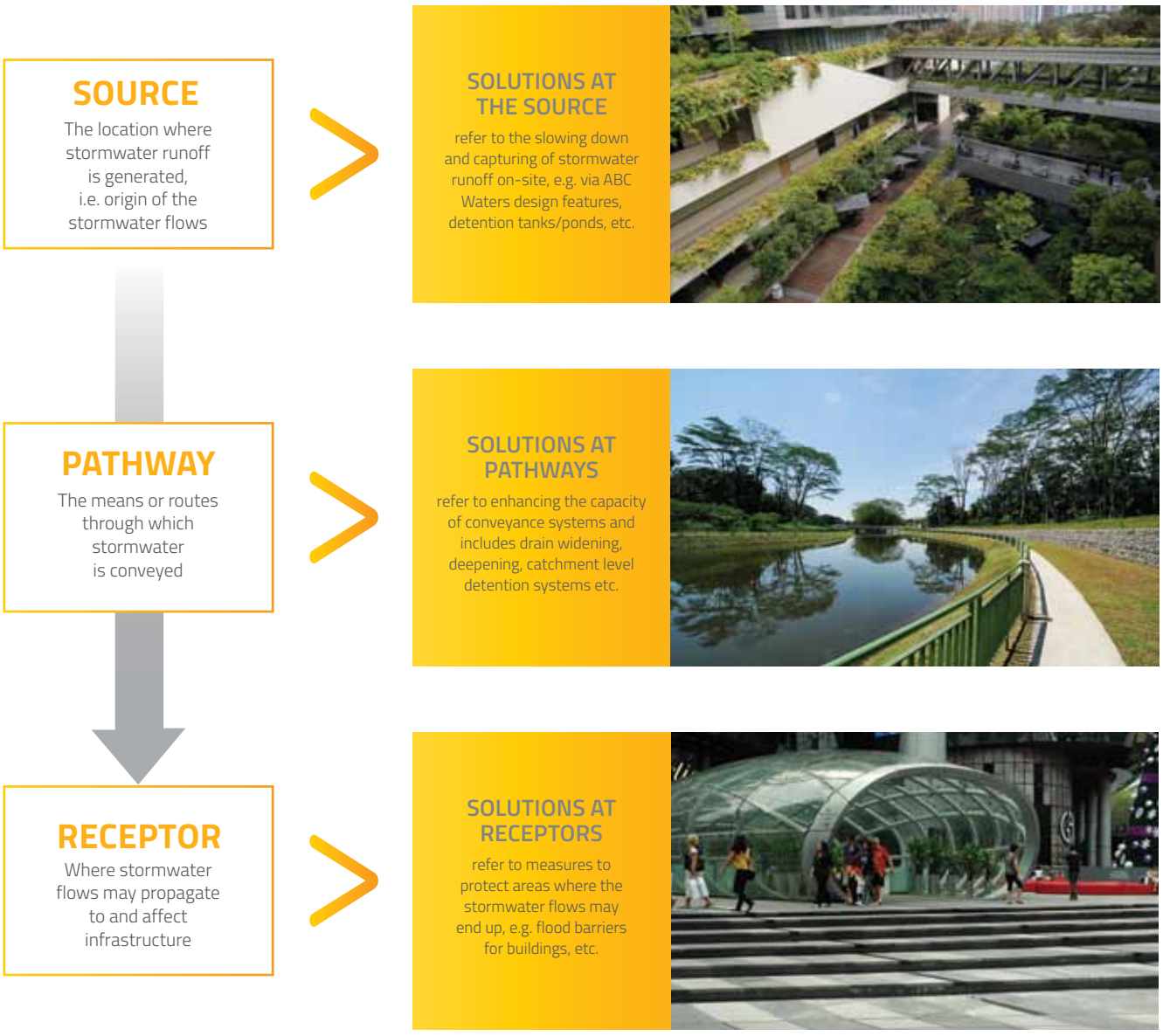


Fig. 2.2
Source-Pathway-Receptor Approach.

2.3
ABC WATERS MANAGEMENT STRATEGY

Source solutions can incorporate 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 the drainage systems' design, ABC Waters design features will 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. This in turn reduces the risk of flooding at the development site and the larger catchment area.

Individual developments are therefore encouraged to implement ABC Waters design features to mitigate the impact of urbanisation caused by the development on water bodies downstream. These environment-friendly features like rain gardens, bioretention swales and wetlands not only improve water quality, but also enhance the biodiversity and aesthetics of the surroundings (Refer to Chapter 4 for more details).

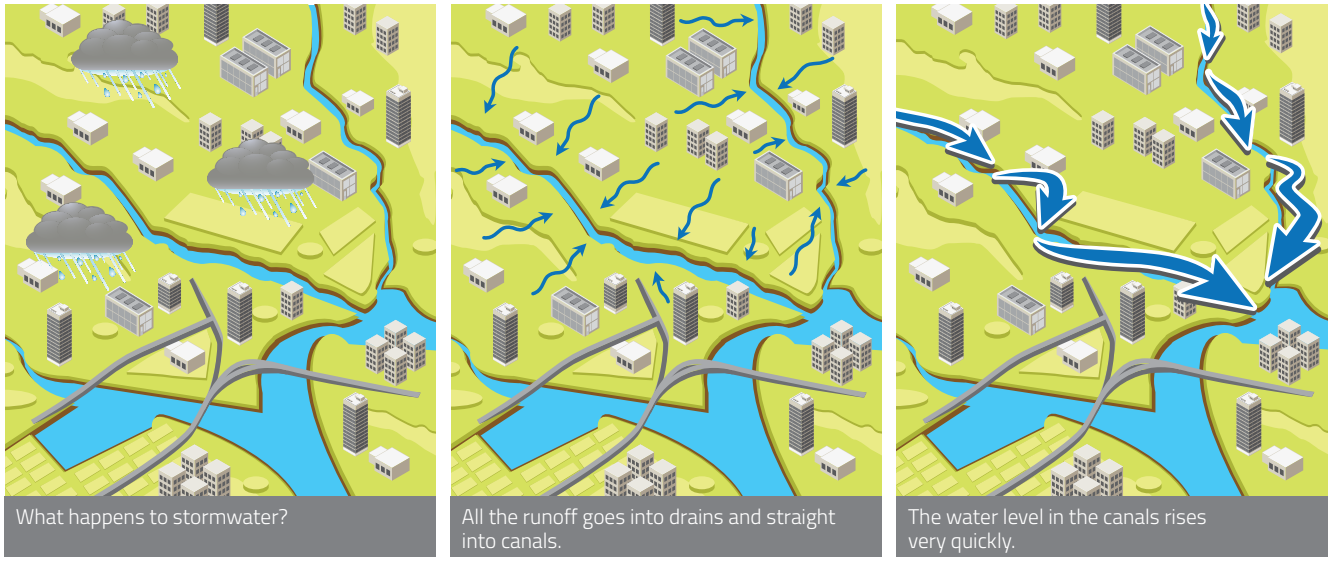


Fig. 2.31
Traditional stormwater management.

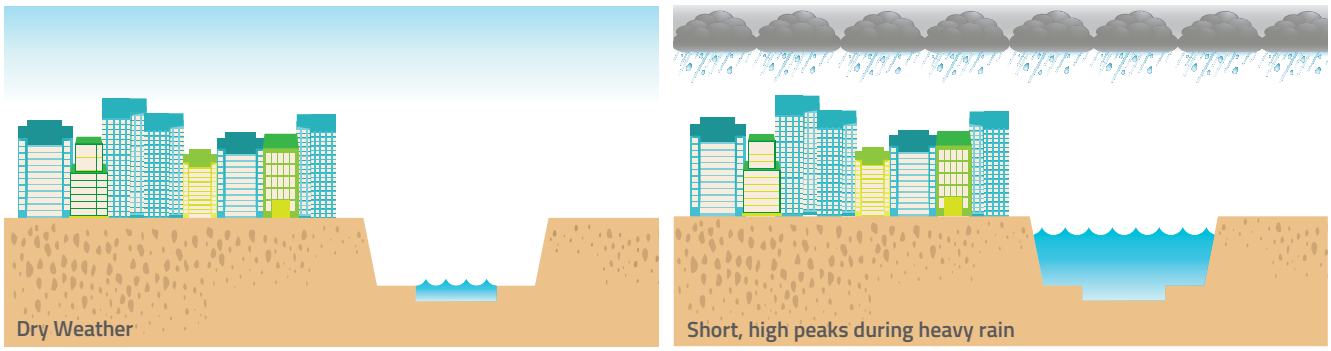


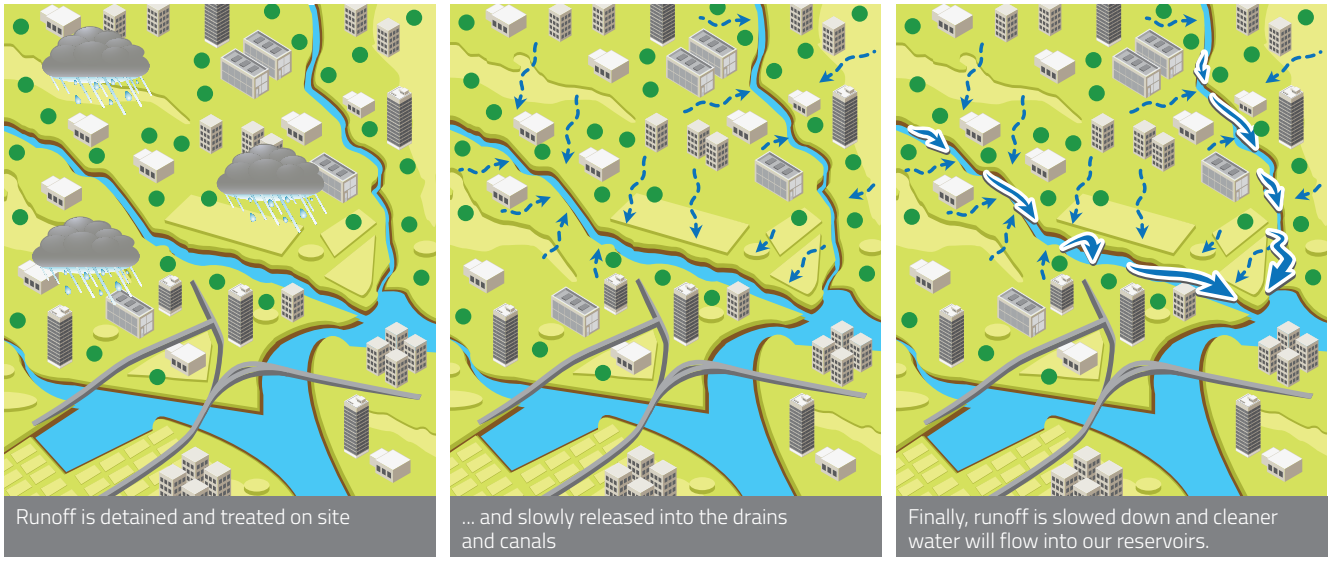
Fig. 2.32
Water levels in the canals under traditional stormwater management.

2.4 ON-SITE DETENTION AND RETENTION

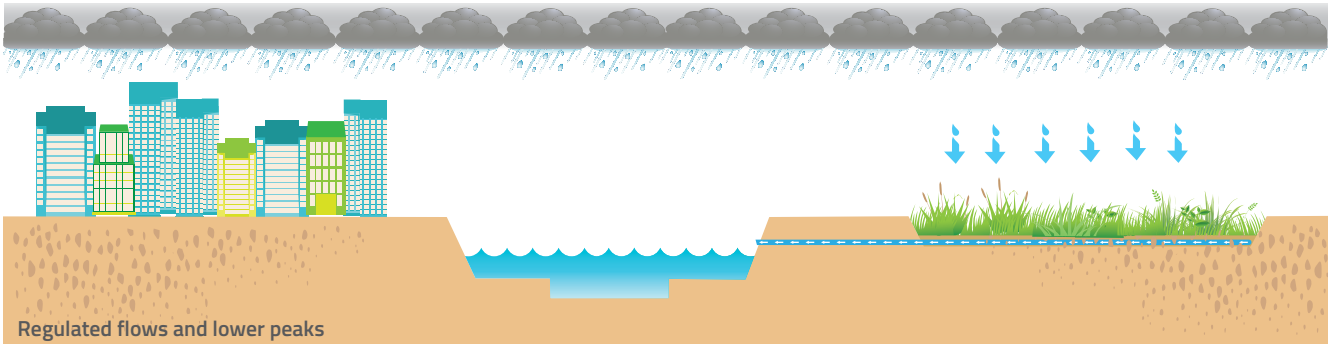
In Singapore's highly urbanised environment, many developments are largely made up of impervious surfaces such as roofs, parking lots, streets and sidewalks that do not allow stormwater to infiltrate into the ground. This generates increased runoff that enters the stormwater drainage system. As a result, during intense storms, peak runoff from the urbanised catchment may exceed the design capacity of public drains, resulting in flash floods. Source solutions such as decentralised detention tanks and ponds provide temporary storage of stormwater on-site. This water is released at a controlled rate to the downstream drainage system.

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 such as irrigation, general washing, etc. Developers are encouraged to incorporate localised rainwater harvesting and on-site detention and retention in their developments.

Managing the water quality of the harvested rainwater is an important consideration for a sustainable rainwater-harvesting scheme. ABC Waters design features offer the advantage of water quality improvement via natural means by channelling the stormwater through the components to remove pollutants before the water is collected and used for non-potable purposes.



ABC Waters management strategy



Water levels in the canals if the ABC Waters management strategy is applied catchment-wide.

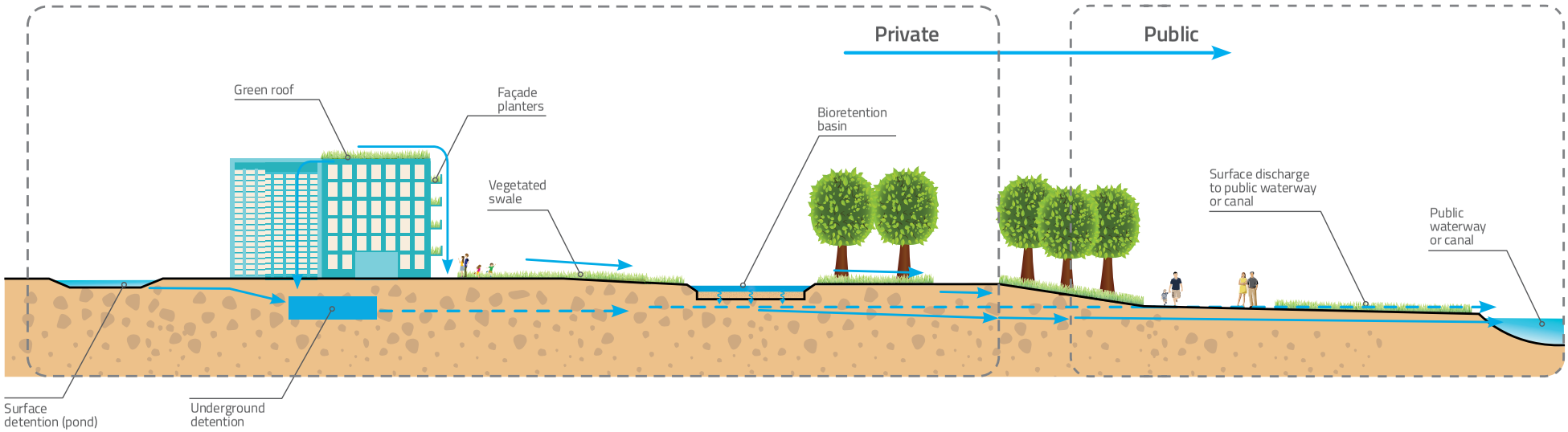


Fig. 2.33
An example of how ABC Waters design features can be integrated within a building development to slow down runoff.

SECTION 3

GUIDELINES FOR ABC WATERS MANAGEMENT STRATEGY

This section highlights the key considerations that the designer should be familiar with when implementing the ABC Waters management strategy.

This chapter highlights the key considerations that the designer should be familiar with when implementing the ABC Waters management strategy. These include the following:

- Surface water drainage
- Source solutions to manage stormwater on-site
- Flood control
- Stormwater quality
- Site safety and public health risks

The designer should also refer to:

- The **Engineering Procedures for ABC Waters Design Features**, which forms an integral part of the ABC Waters Design Guidelines. This publication gives specific guidance on selection, sizing, construction and maintenance of the ABC Waters design features.

- The **Code of Practice on Surface Water Drainage**, which specifies the minimum requirements for the surface water drainage systems of new developments. (This document is available for download at http://www.pub.gov.sg/general/code/Pages/default.aspx)

- The **Drainage Handbook on Managing Urban Runoff**, which explains PUB's stormwater management strategies to manage flood risks. (The document is available for download at http://www.pub.gov.sg/abcwaters/ABCWatersProfessional/Documents/managingUrbanRunoff.pdf)

- The **Code of Practice on Environment Health**, which addresses the various aspects of mosquito control. (This document is available for download at http://app2.nea.gov.sg/public-health/food-hygiene/code-of-practice-on-environmental-health)

3.1 PLANNING CONSIDERATIONS

i) Internal Drainage System

All runoff within a development site must be discharged into a roadside or outlet drain/waterway. A system of internal drains is required to intercept, convey and discharge all runoff from the development site into the roadside or outlet drain.

Any overflow, by-pass and treated water from ABC Waters design features, including constructed wetlands and retention ponds, must subsequently be discharged to a roadside drain or an outlet drain/waterway.

From January 2014, all developers/owners are required to manage their peak runoff by implementing on-site detention measures (e.g. detention tanks and/or ABC Waters design features) to hold back or slow down runoff before discharging it to the public drainage system. These on-site detention measures will complement PUB's on-going drainage improvement works to provide a

higher level of protection against flood risks in our catchments (http://www.pub.gov.sg/managingflashfloods/FMS/Pages/buildingdesign.aspx).

ii) **Structure within or adjacent to a Drain/Drainage Reserve**

Subjected to the approval of PUB, ABC Waters design features could be located within/adjacent to the drainage reserve or adjacent to a drain. The following conditions apply:

- The affected drain must meet the required hydraulic capacity or be upgraded in size.
- All foundation structures must be independent. The foundation structures must be stable when excavations up to 1.0 m below the invert or proposed invert of the affected drain are carried out. The structures must be kept at least 300 mm away from the drainage structures.

iii) **Natural Hydrological Features**

Existing site conditions may present opportunities naturally conducive for the implementation of ABC Waters design features, for example:

- Areas of permeable soil suited for infiltration
- Existing vegetation that can function as bio-filters
- Land forms (e.g. natural depressions)

The designer could capitalise on the site condition for environmentally friendly and sustainable design.

3.2 DESIGN CONSIDERATIONS

i) **Quantitative Objectives:**

Flood Control

The following criteria must be met to address public safety and protection of property:

- Use of the Rational Formula to compute the peak runoff from the catchment. The peak runoff from design storms shall be used to size the overflow system for ABC Waters design features if the features are designed to cater for small frequent storms.
- Use of Manning's Formula to compute the size of incoming and outgoing drains connected to the ABC Waters design features.
- For effective use of land, the ABC Waters design features can be designed for treatment of frequent storms (such as 1-in-3-month storms). Proper by-pass and overflow system from ABC Waters design features should be provided and connected to the storm drain so that the surrounding area will not be flooded. The downstream storm drain should have adequate hydraulic capacity to cater for the flows from the ABC Waters design features up to storms with 10-year return period.
- The minimum engineering requirements for surface water drainage are specified in the **Code of Practice on Surface Water Drainage**.

ii) **Qualitative Objectives:**

Setting Performance Targets

The stormwater quality objectives or the performance targets of ABC Waters design features are directed at the protection of urban water bodies in Singapore such as the Marina Reservoir, Punggol Reservoir and Serangoon Reservoir etc. It is desirable that new developments incorporate ABC Waters management strategies that minimise the impact of the development on our waterways and reservoirs.

Table 3.1 Stormwater quality objectives for Singapore

Pollutant	Stormwater Treatment Objectives
Total suspended solids	80% removal or less than 10 ppm
Total nitrogen	45% removal or less than 1.2 ppm
Total phosphorus	45% removal or less than 0.08 ppm

** Stormwater quality objectives may be revised as more monitoring results are gathered over time*

Performance curves developed to guide the professionals in the design of ABC Waters design features are available in the Engineering Procedures for ABC Waters design features.

The stormwater quality objectives have been developed to represent achievable targets. In Singapore, based on preliminary assessment and monitoring of pilot projects, the objectives as shown in Table 3.1 are realistic. Achieving these objectives is a practical approach to institutionalising best practices in stormwater quality management.

iii) Erosion and Sedimentation Control

It is important to prevent sediment from construction sites from flowing into the ABC Waters design features and the downstream drains during rain events as these particles will clog up the filter media of bioretention systems or the downstream drains and make the waterways unsightly. The following measures should be taken into consideration:

- Installing a barrier to prevent sediment from leaving the site (e.g. silt fence)
- Introducing a phased development approach to minimise bare areas and potential erosion
- Providing silty water treatment facilities to capture and remove sediment from the runoff
- Employing soil stabilisation techniques, such as bioengineering, close turfing, etc.

A system of earth control measures (ECM) shall be provided at construction sites before the commencement of work. The specific requirements on ECM can be found in the **Code of Practice on Surface Water Drainage**.

iv) Mosquito Control

The ABC Waters design features have to be designed to prevent mosquito breeding by eliminating conditions that are favourable for mosquito breeding. These include the use of filter media with adequate permeability or hydraulic conductivity to prevent prolonged water stagnation, keeping a constant flow through constructed wetlands and avoiding the use of plants with receptacles or thick axils that can trap water. The designer should also refer to the **Code of Practice on Environmental Health**, which addresses the various aspects of mosquito control.

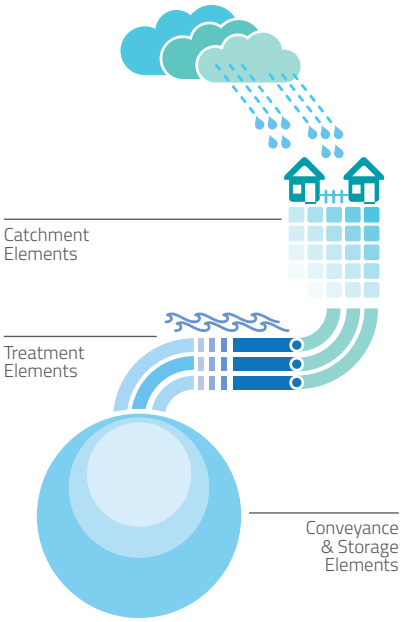
SECTION 4

PLANNING, DESIGN AND PERFORMANCE OF ABC WATERS DESIGN FEATURES

In this section, we will explain the various elements in a typical stormwater passage as well as the principles and applications of ABC Waters design features and elements. We will also explore how these features could be assimilated into a plaza, architectural structure, or even introduced at vehicular roads and pedestrian walkways.

Stormwater is relatively clean. When it comes in contact with the surfaces of a catchment, it picks up sediments, nutrients and other impurities. In a typical stormwater passage, the runoff is conveyed by drains and canals into reservoirs for storage without treatment.

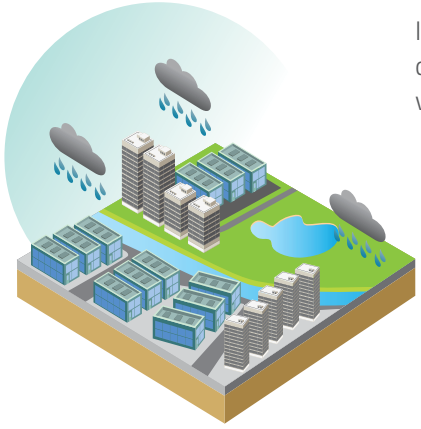
With the use of ABC Waters design features, this runoff will be temporarily detained and cleaned before it flows into waterways and reservoirs. In essence, ABC Waters design features help to minimise the hydrological impact of urbanised catchments, and safeguard water quality in our reservoirs and waterways. They also beautify the surroundings while improving biodiversity. With water catchment areas covering two-thirds of Singapore's land, it would be ideal, while planning any development, to incorporate ABC Waters design features.



In this section, we will examine the elements involved in a typical stormwater passage and discuss the following elements in detail:

a) **Catchment Elements**
b) **Treatment Elements**
c) **Conveyance and Storage Elements**

4.1 CATCHMENT ELEMENTS



The surfaces found in our urban environment (catchment elements) vary and can be categorised as: circulation infrastructure (vehicle roads, bicycle paths and pedestrian walkways), structures (buildings, shelters and urban plazas), softscape (fields and parks), waterways (rivers, canals and outlet drains) and water bodies (lakes, ponds and reservoirs).

In this section, we will discuss the planning strategies involved and the various design elements and ABC Waters design features that could be integrated into the various catchment elements.

4.1.1 PLANNING STRATEGY

Before starting the design of a development, it is essential to understand the constraints and potential of the site and factors that would affect stormwater flow:

- Topography (natural slopes/depressions)
- Geology (soil type and quality – porosity, infiltration and conveyance properties)
- Internal drainage, sub-catchments and the connection points to public drains.

The design of a development is also bound by the basic urban planning parameters such as site coverage, plot ratio, height restrictions and land use.

In addition to being elements of a sustainable stormwater management system, it is important that ABC Waters design features complement the land use requirements and functions of the space. For example, rain gardens, which would pond and treat runoff intermittently, can be used to enhance the landscape or various water features.

Due to urban planning parameters, various spatial configurations, each with a different landscape strategy, can be employed, as illustrated in the diagrams below. Design elements and ABC Water design features can be customised for each of the different landscape strategies employed. This will be elaborated upon in the subsequent sections.

Developments with the same site area may have two different site strategies:

SAME SITE AREA SMALL STRUCTURES

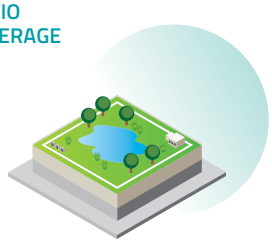
1. Smaller structures interspersed throughout the site, affording no large open space, but a network of interstitial spaces

SAME SITE AREA LARGE STRUCTURE

2. A high-density building set within a field, allowing space for the landscape to be utilised as a park

The diagrams below show a comparison of two sites with the same plot ratio:

SAME PLOT RATIO MORE SITE COVERAGE



1. A site that has a lower height restriction but larger site coverage could leverage a large rooftop garden for its outdoor recreational space

SAME PLOT RATIO LESS SITE COVERAGE

2. A site that is restricted by smaller site coverage could rely on sky-rise greenery such as green walls and planters to increase vegetation and to implement tiered ABC Waters design features

4.1.2
ANALYSIS OF A TYPICAL PLAZA

Public plazas are a common feature in Singapore's urban landscape, particularly in commercial and retail spaces where large crowds gather, such as Orchard Road and Shenton Way. The following is a common approach to the design of a typical plaza:

i) **Separation of landscape and hydrology**
In Singapore, landscape and hydrology are often kept as separate systems in the design of urban public plazas. Water features are common but they are seldom natural elements. They are typically tiled concrete pools with little or no landscaping. Where plants are included in these water features, they remain only as aesthetic elements, often planted in separate pots and planters.

ii) **Separation of recreational water feature and stormwater management system**
Fountains are increasingly provided for recreation in public plazas. However, they play mostly aesthetic roles. They seldom take on stormwater management functions, and are usually replenished with fresh tap water, thus adding to potable water consumption.

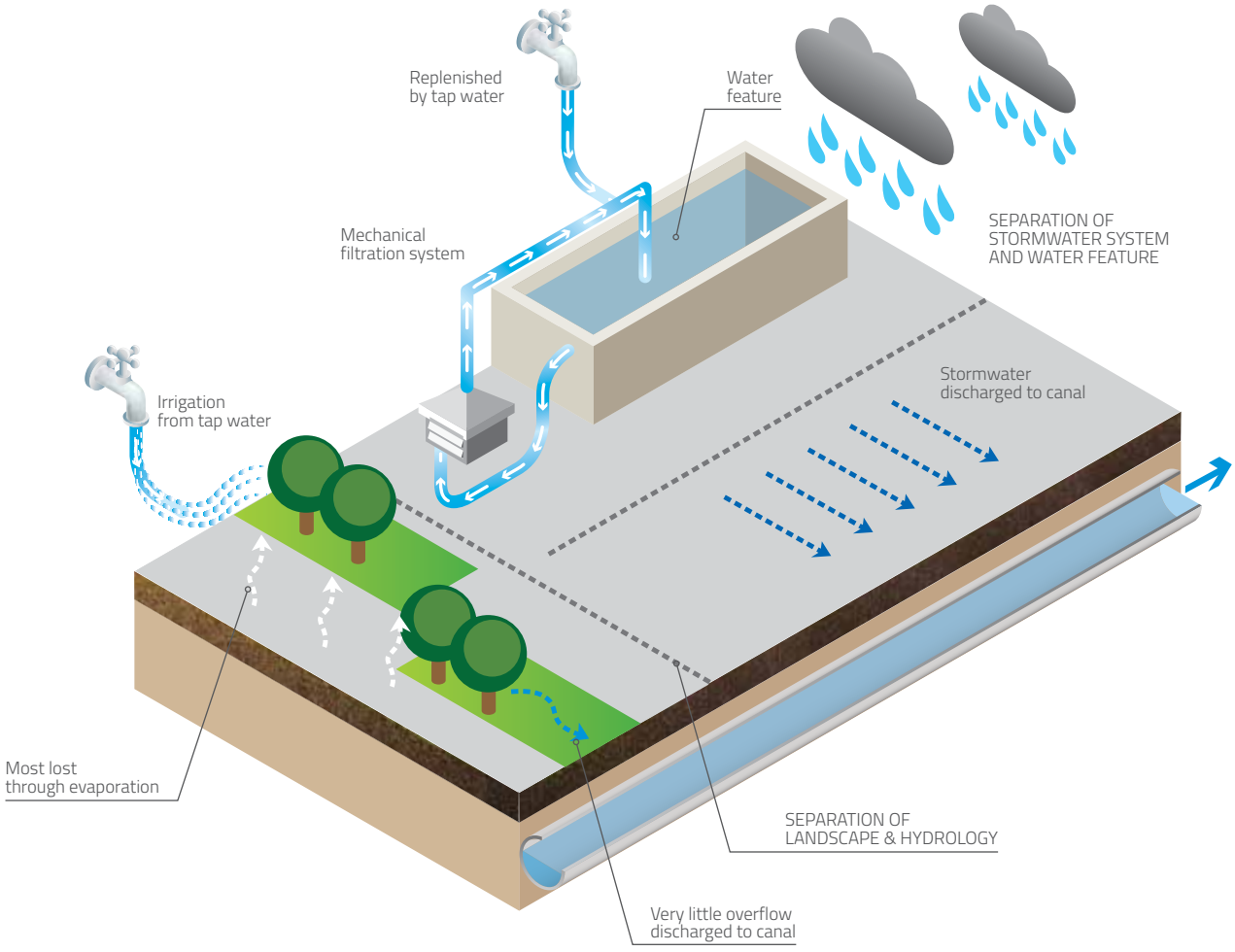


Fig. 4.2
Existing situation of a typical plaza.

4.1.3
AN INTEGRATED PLAZA WITH ABC WATERS DESIGN FEATURES

The ABC Waters concept of integrating the environment, water bodies and the community, albeit on a smaller scale, would be simple to implement and help to develop a more efficient plaza design. Specifically, they contribute to the following design factors:

i) **Cleaning**
The plants take on a cleaning or treatment function for runoff that improves water quality by uptaking nutrients and other pollutants.

ii) **Low Maintenance**
ABC Waters design features are self-sustaining natural systems that require minimal maintenance.

iii) **Aesthetics**
While meeting stormwater treatment and management functions, ABC Waters design features, with the integration of water features and plants, provide a dynamic yet relaxing environment for social enjoyment.

ABC Waters Concept — integration of environment, waterbodies and community

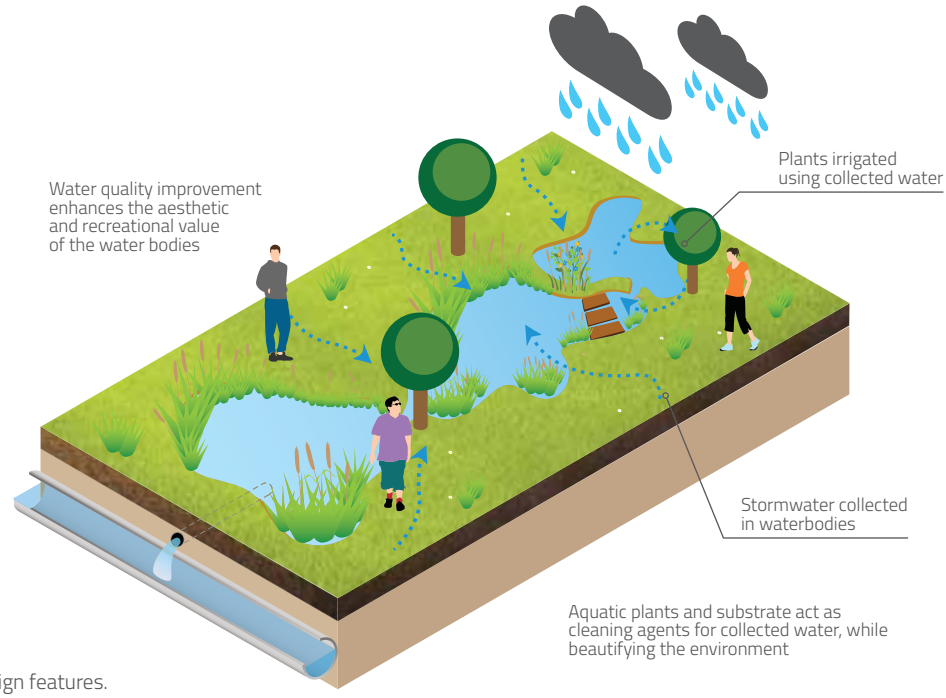


Fig. 4.3
Proposed situation with ABC Waters design features.

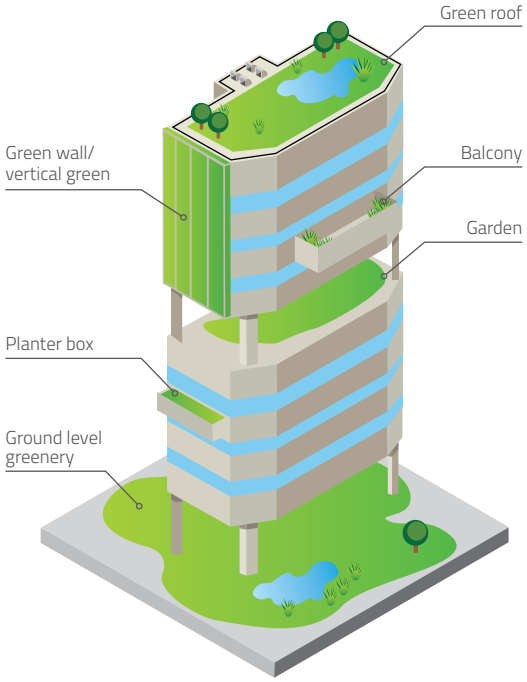
Fig. 4.4 & **Fig. 4.5**
Cleansing Biotopes installed at Potsdamer Plarz, Berlin, Germany (left), and the Centre of Excellence, Sindelfingen, Germany (right).

4.1.4
ARCHITECTURAL STRUCTURES

In Singapore, the most common applications of ABC Waters design features for buildings can be categorised under the following building elements:

- Rooftop
- Sky garden or terrace
- Balcony
- Planter box
- Ground level greenery
- Green wall or vertical green

To implement the ABC Waters design concept, different ABC Waters treatment elements can be applied to each of the building elements mentioned above or in combinations.



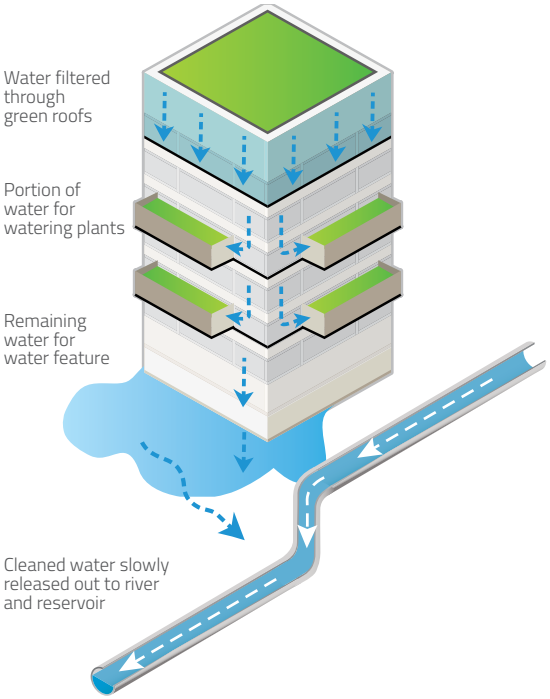


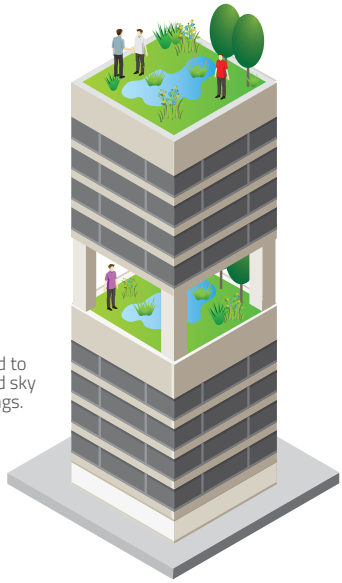
Fig. 4.6
Vertical greenery being employed at 158 Cecil Street.

Intensive Green Roofs

Intensive green roofs are large green spaces at rooftops that are designated as recreation areas. The development of public recreational spaces and gardens on the rooftops of commercial buildings has had a long history in Singapore and continues to be highly popular. Examples include Parkway Parade, Suntec City and Vivocity.

There is, however, greater potential for integration of greenery, water features and the building itself that promote synergy. Plants can serve many functions apart from creating aesthetically pleasing environments.

Stormwater can first be collected and cleaned (using rain gardens or cleansing biotopes) on the roof, then channelled to the various water features. Alternatively, the cleaned stormwater can be used to water the plants on the planters and balconies, or for the washing of pavements and walkways.



Cleansing biotopes and rain gardens can be used to clean water on roofs and sky terraces of larger buildings.

Fig. 4.7
Popular and well designed rooftop recreational spaces at various shopping centres in Singapore could benefit from the implementation of an intensive green roof (Orchard Central).

Fig. 4.8
An intensive green roof at a multi-storey car park in Punggol.

Extensive Green Roofs

An extensive green roof is a low-maintenance vegetated roof system that uses a lightweight plant growing medium with shallow drainage/storage layer to store stormwater that could be supplied to plants when there is no rain. It is not designed as a recreational space.

As a result, less stormwater runs off the roof as compared to conventional rooftops without any extensive green roof. In addition to conserving potable water for irrigation and improving air quality, extensive green roofs also cool down buildings and reduce the "heat island" effect by providing a permeable and moist layer to shade the building from sunlight.

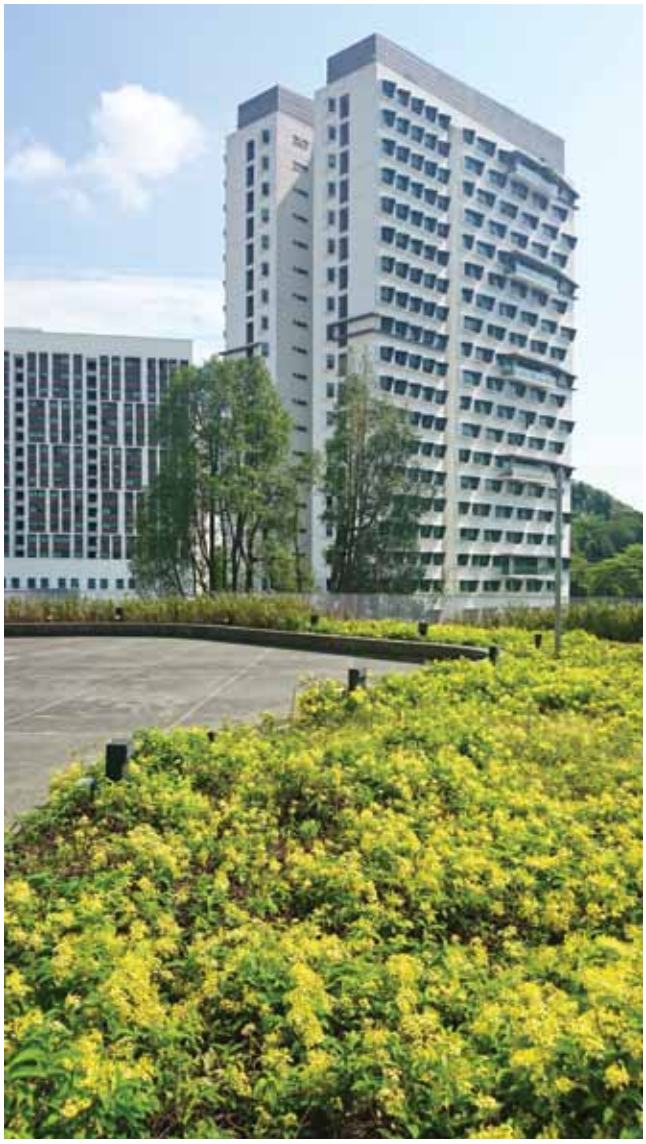


Fig. 4.9
NUS Tembusu.

The Housing & Development Board (HDB) has piloted extensive green roofs in existing HDB public housing blocks since 2006 to reduce heat build-up on exposed concrete roof surfaces in public housing estates. Besides enhancing the greenery in estates, it also helps to slow down stormwater discharge. It adopted the HDB-patented extensive green roof system, also known as Prefabricated Green Roof (PEG) Tray system, which is a lightweight and modular system that requires minimal maintenance.

(Image by Housing & Development Board)

Fig. 4.10
Extensive green roof at Blk 119 Edgefield Plains.

Balconies, Planter Boxes and Vertical Green

The use of treatment elements does not have to be limited by the lack of space. Cleansing biotopes and bioretention planter boxes can be implemented in a tiered or multi-level and sequential system to achieve the same purification standards.

Currently in Singapore, individual families and collective residential bodies (facility-managed condominium or apartments) alike have shown keen interest in incorporating high-rise greenery into the living environment.

These existing trends could be combined with sustainable stormwater management to harness effective stormwater harvesting capabilities with improved water quality.

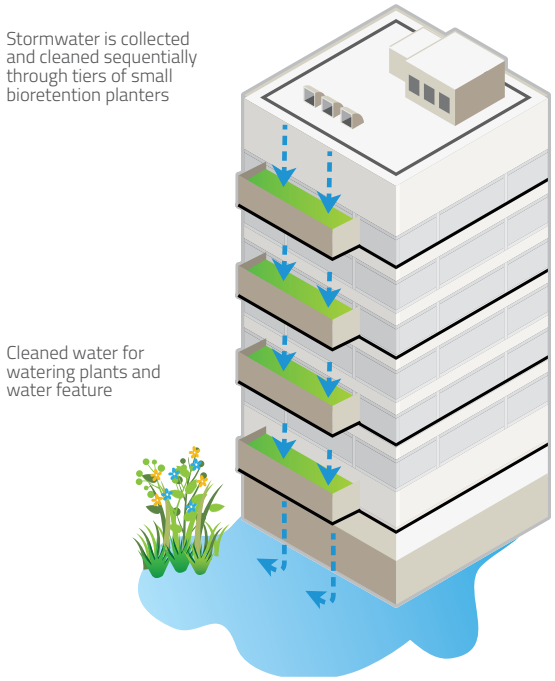
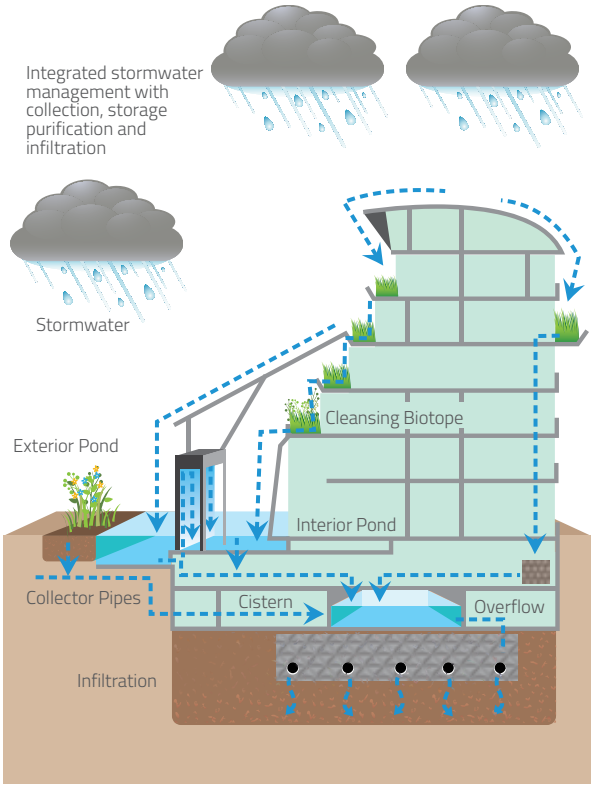


Fig. 4.11
Balconies and planters are greatly utilized in public as well as private developments in Singapore (ParkRoyal @ Pickering).

The following is an example taken from Nuremberg Prisma, Germany, where multi-level planters of cleansing biotopes clean runoff from the roof while creating a pleasant atmosphere in the building all year round. The cleaned water is stored in the cistern that functions as a stormwater detention storage.

The water from the cleansing biotopes feeds a 5m high water wall. A slit in the wall allows air to be sucked into the building, cleaned and cooled as it is pulled down the water wall by the falling water, and then released into the interior. This creates a constant light wind that moderates the heat during the summer.



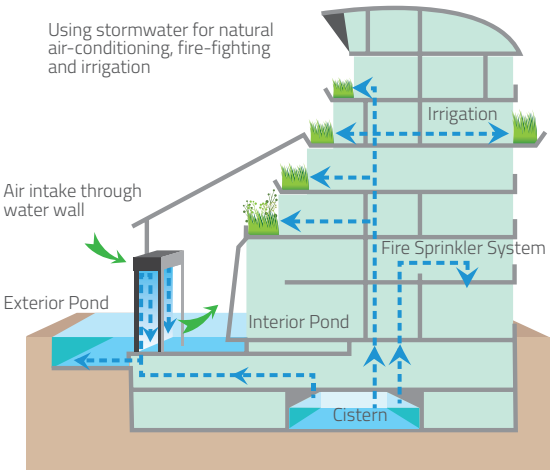


Fig. 4.12 & **Fig 4.13**
Interior and sections of Nuremberg Prisma, Germany showing the application of cleansing biotope and its integration with the rainwater harvesting and treatment system.

4.1.5
VEHICULAR ROADS AND PEDESTRIAN WALKWAYS

The typical road in Singapore comprises carriageways that are sloped towards either the kerb or central dividers, where drop inlet chambers channel the stormwater runoff into drains and culverts that bring it to the main stormwater canals.

Bioretention swales and basins can be incorporated relatively easily and employed effectively in this situation, not only for detention purposes (to slow down the flow of runoff into the drains and canals), but also as a way of cleaning stormwater runoff before it is discharged to receiving waterways.

For small catchment, vegetated swales can be used as roadside drains to convey the runoff. The swales slow down runoff and allow some sediments to settle.

Fig. 4.14 shows the cross section of a typical bioretention system. Details of the soil layers are given in the **Engineering Procedures for ABC Waters Design Features.**

Fig. 4.15 shows how bioretention systems are incorporated into planting verges while co-existing with shady trees along a roadside verge.

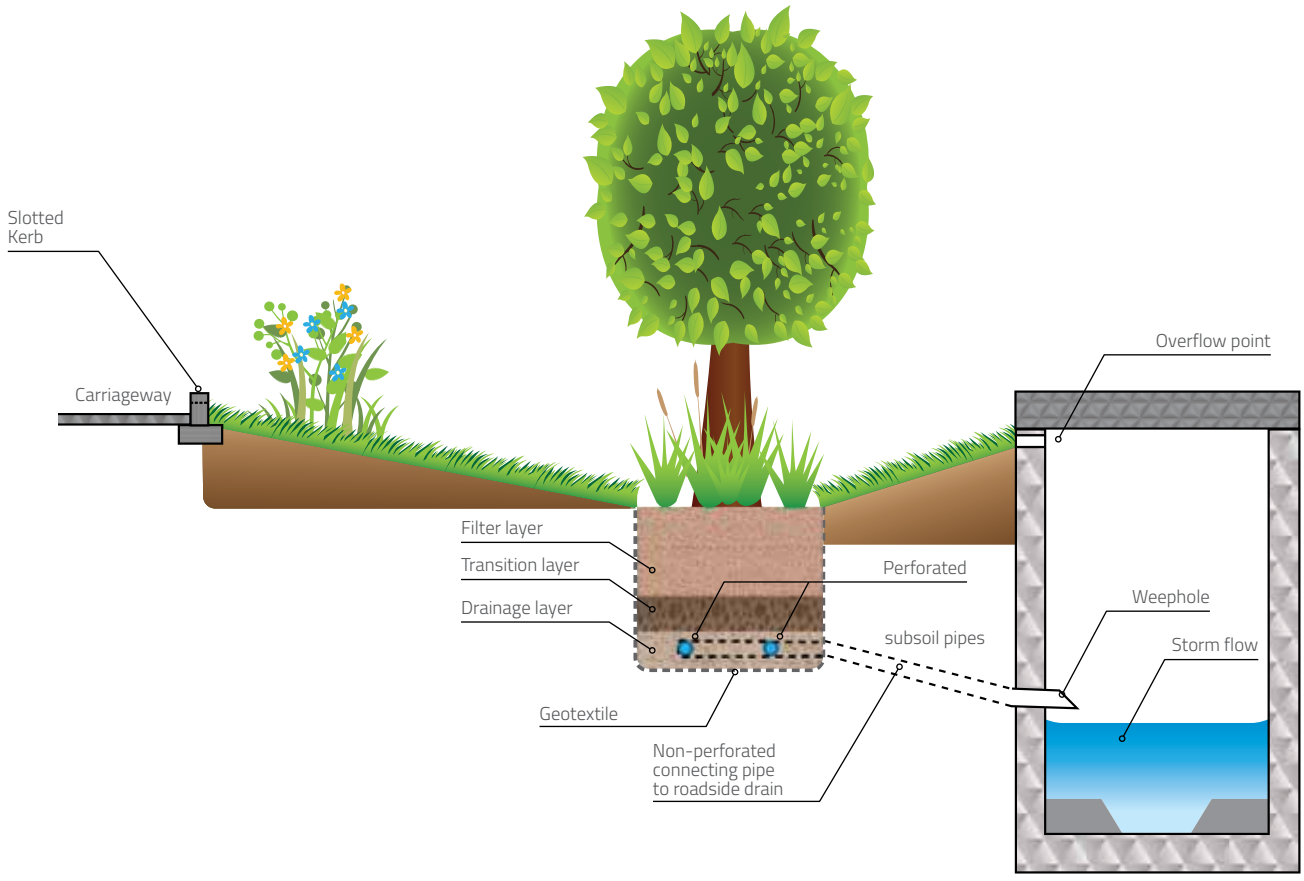
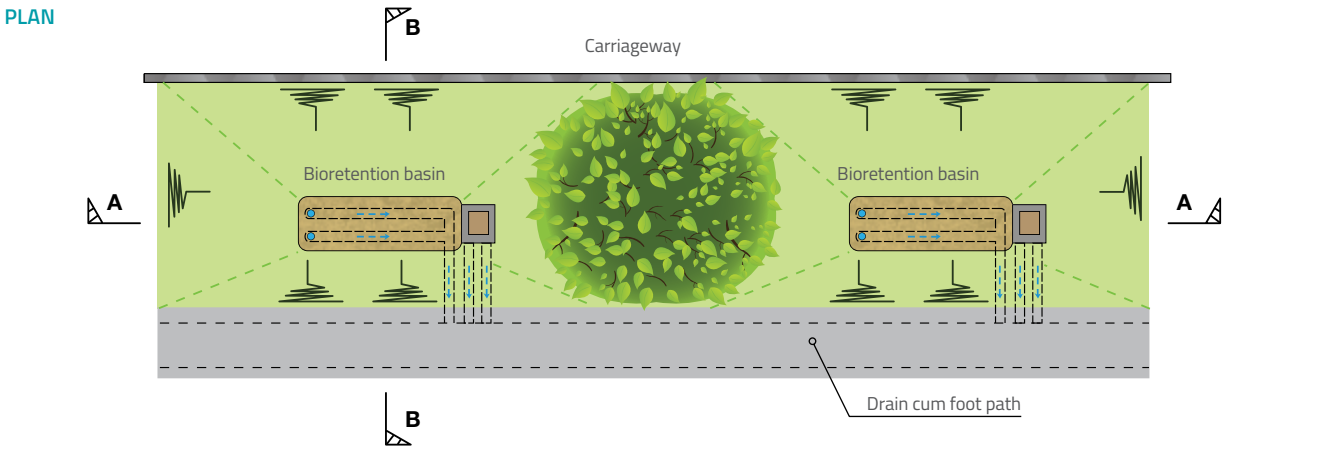
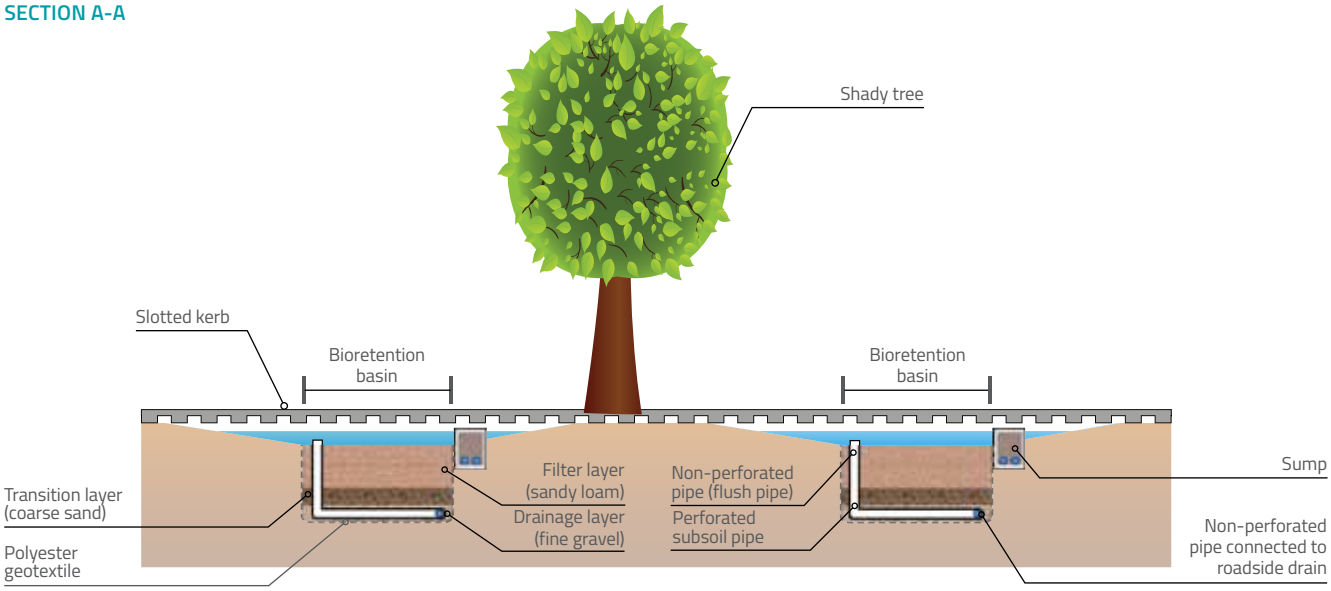


Fig. 4.14
Application of a bioretention system within a roadside verge.





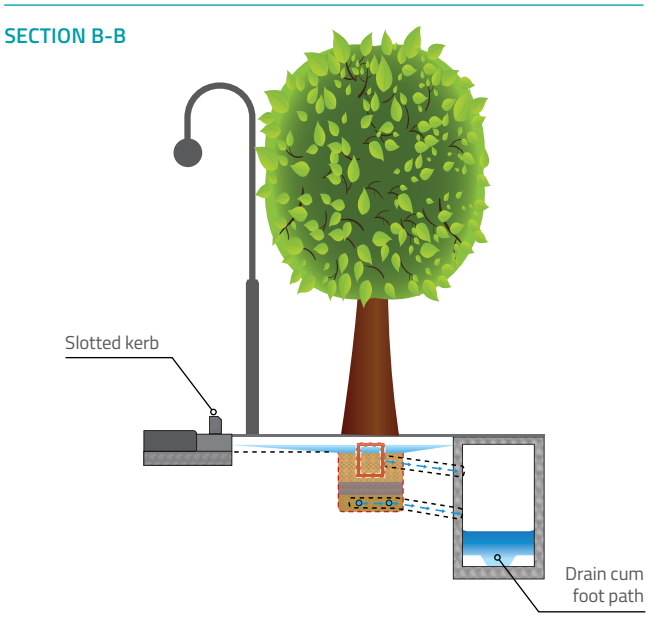
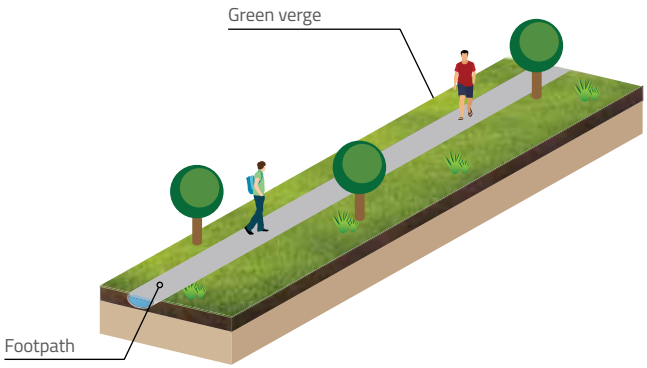


Fig. 4.15
Plan & sections of bioretention basin application in a roadside verge.

Fig. 4.16
Bioretention swales along Margaret Drive.

Existing roads in Singapore typically comprise footpaths, carriageways, green verges and roadside drains running in parallel alongside each other. Where there is sufficient space (e.g. a road beside a park), footpaths can be made to meander and integrate with drains or design features as a way of enhancing the experience of the pedestrian.

TYPICAL EXISTING SITUATION



POSSIBLE VARIATION

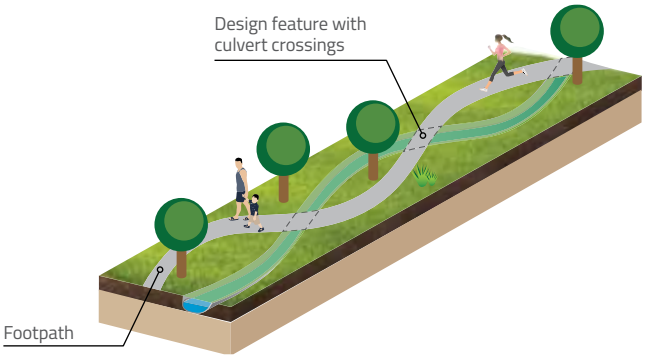


Fig. 4.17

Fig 4.18 Typical car-parking facilities (above), **Fig. 4.19** roads with pedestrian pathways (top right) and **Fig. 4.20** expressways with green verges and roadside drains in Singapore (right).

Fig. 4.21 shows the stone footpath in CleanTech Park that meanders through the lush planting and overcross a vegetated swale.

Fig. 4.22 shows how an open concrete roadside drain along Ontario Avenue at Windsor Park Estate, Singapore has been re-configured to a lush swale with filter media to convey and clean stormwater runoff. Overflow pits are located along the swales for overflow purpose during heavy downpour, conveying excess runoff into a concrete drain beneath the swale. Low weirs are provided at suitable locations to slow down the flow of runoff.

Fig. 4.21
The meandering stone path in CleanTech Park

Fig. 4.22
A lush swale at Windsor Park Estate

4.2
TREATMENT ELEMENTS

Treatment elements (or ABC Waters design features) can be applied to urban components to slow down, detain or retain the first flush of stormwater runoff while simultaneously cleaning it.

They are cost-effective, sustainable and environment-friendly features for urban stormwater management. The cost is a small percentage of the total capital cost of the development, while the resulting environmental benefits are many.

As ABC Waters design features are natural systems of plants and soil, minimal maintenance is required. Please refer to **Engineering Procedures for ABC Waters Design Features** for specific maintenance requirements. The document also gives specific guidance on selection and sizing of the treatment elements with worked examples and checklists.

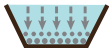
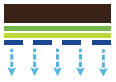
Stormwater Management Functions	Purification	Detention
Purpose	Clean stormwater runoff so that cleaner and clearer water enters our reservoirs. This also beautifies the waterbodies so people can enjoy them. Stormwater runoff can be purified through one or a combination of the following: ▪ Sedimentation  ▪ Filtration  ▪ Biological uptake 	To slow down the flow of stormwater runoff into the downstream stormwater management system. The runoff can be slowed down through a variety of methods, such as draining it through vegetation, increasing the roughness of an area or decreasing the gradient of the runoff surface and storing it temporarily (for a few hours) in an on-site facility.
ABC Waters design features	▪ All ABC Waters design features	▪ Vegetated swales  ▪ Bioretention swales  ▪ Bioretention basins  ▪ Cleansing biotopes 

Table 4.1
Roles of ABC Waters design features in stormwater management.

Every treatment element explained in this chapter has different cleaning capabilities. They clean runoff either in one or a combination of the processes described in Table 4.1. For example, a sedimentation basin has negligible ability to remove fine particles or soluble nutrient compounds, but is very effective in allowing large to medium size pollutants to settle and be separated.

Each treatment element can be understood in two basic properties:

1. What treatment process(es) it primarily employs (sedimentation, filtration or biological uptake)
2. What its primary stormwater management function is (conveyance, detention or retention)

Retention	Conveyance	Infiltration
 The purpose is to ease the stress on the downstream stormwater management system. Water is retained for a longer period of time (in a cistern, basin or pond) either for use at a later stage or until it is ready to be released to the public drainage system or waterbodies.	 Conveyance refers to the measure by which surface runoff is transported and directed from the point of initial rainfall to its final discharge. This is necessary for flood control.	 Infiltration is the process by which water seeps into the ground to recharge groundwater and aquifers, and has the added benefit of purification. However, in Singapore, natural infiltration is not common due to the high content of clay in the soil. Instead, layers of suitable filter media are used to facilitate infiltration. Stormwater runoff is cleaned as it percolates down. The cleaned water is collected by sub-soil pipes or allowed to soak away into in-situ soil. Plants with suitable root systems are used to keep the filter media porous.
▪ Sedimentation basin  ▪ Constructed wetlands 	▪ Vegetated swales  ▪ Bioretention swales 	▪ Bioretention basins  ▪ Bioretention swales  ▪ Infiltration systems

4.2.1
VEGETATED SWALES

Introduction

Vegetated swales are natural drainage channels with mild slope. They are used to remove soil particles and convey stormwater via overland flow. They protect downstream treatment elements or waterways from damage by erosive flows from frequent storm events because flow velocities are slower for vegetated swales than concrete-lined drains. They can be used in combination with bioretention systems (eg. located upstream of a bioretention swale).

Application and Principles

Vegetated swales are widely applicable at residential estates, parks and other sites. The landscape design of vegetated swales addresses stormwater quality while incorporating landscape functions. As such, it is important that vegetated swales are carefully designed to integrate with the characteristics of the surrounding landscape. In Singapore, where rainfall intensity is high, vegetated swales are applicable for small catchment areas (e.g. small perimeters or compound drains and roadside drains near the summit point or use with an overflow system).

The interaction between stormwater flow and vegetation within the vegetated swales facilitates pollutant settlement and detention. Vegetated swales alone usually cannot provide sufficient treatment to meet the stormwater treatment or water quality objectives as it has limited capability to remove soluble nutrients. However, vegetated swales are particularly good at removing coarse sediments and can provide the necessary pre-treatment for downstream treatment systems such as wetlands and bioretention systems.

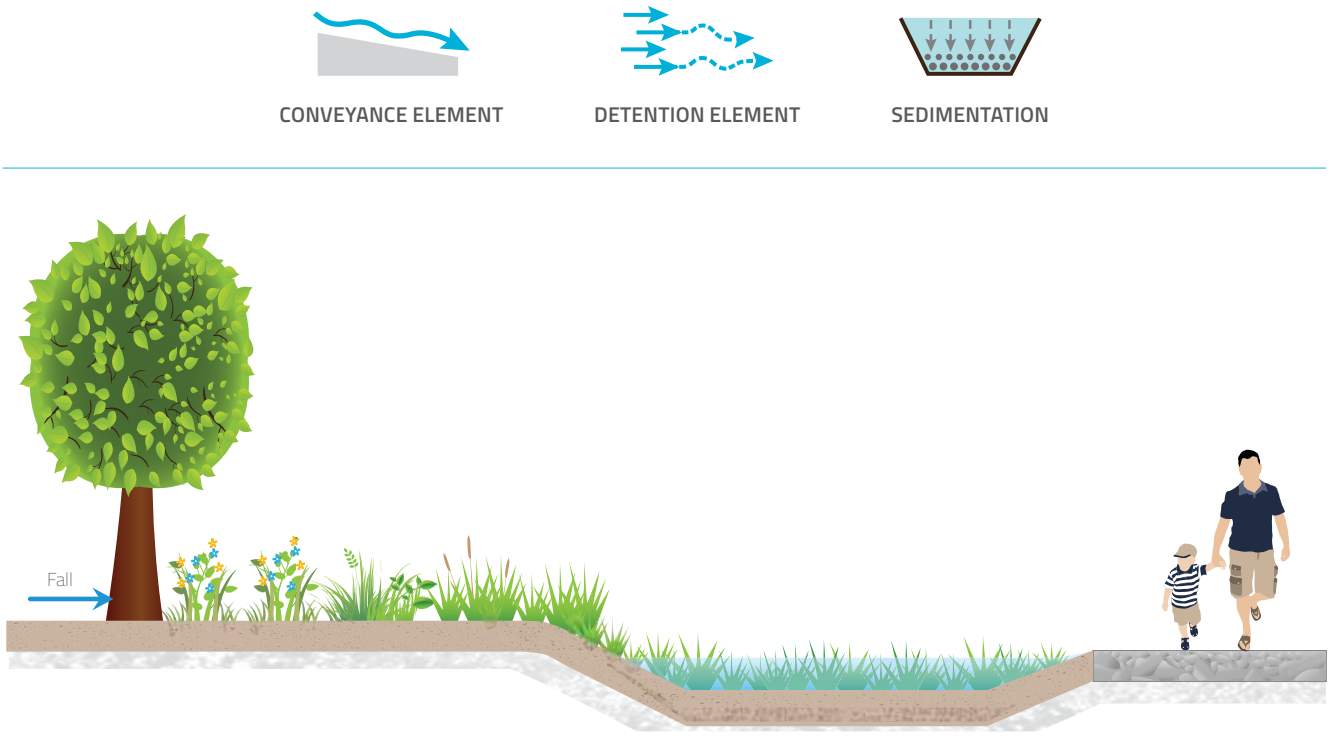


Fig. 4.23
Typical section of a vegetated swale.

Benefits

- Reduces flow velocities and protect downstream waterways from erosive flow during storms
- Provides effective pre-treatment for downstream ABC Waters design features like bioretention swales, rain gardens or constructed wetlands by trapping coarse particles
- Beautifies the surrounding landscape and may also help to satisfy green space requirements
- Functions as a cost-effective natural drainage system for small catchments

Operation & Maintenance

Vegetated swales have a flow conveyance role that needs to be maintained to ensure adequate flood protection. In this regard, a key maintenance requirement is to ensure that the cross-section profile of the vegetated swale is maintained and that it is not subjected to erosion or excessive deposition of debris or overgrown vegetation that may impede the passage of stormwater.

Maintenance of vegetated swales primarily consists of:

- Routine inspection of inlet and overflow points to clear any blockage
- Routine removal of litter, debris and sediments
- Routine inspection and repair of the vegetated swale profile
- Maintaining healthy vegetation growth – regular care, such as weeding, mowing, pruning and pest-control, is necessary
- Removal and management of invasive weeds
- Irrigation may be needed during drought

Fig. 4.24
Vegetated swales at The Interlace.

4.2.2
BIORETENTION SWALES

Introduction
Bioretention swales are vegetated swales with bioretention systems located within the base. They provide efficient treatment of stormwater runoff and are designed with gentle gradient and temporary ponding (extended detention) to facilitate infiltration. Runoff is cleaned as it percolates downwards. The filtered water is then collected by perforated subsoil pipes and re-used on site or conveyed to downstream waterways.

Application and Principles
Bioretention swales can be widely applied to treat runoff from roads, car parks, residential areas and parklands, etc. They can form attractive streetscapes and landscape features in many urban developments.

Surface runoff is first filtered through the surface vegetation, removing coarse to medium sediments. It then percolates through a filter media where fine particles are removed and soluble nutrients are taken up by the roots of the plants and soil microbes. Vegetation plays a key role in maintaining the porosity of the soil media of the bioretention system and also in the taking up of nutrients from the percolating surface runoff. The plants selected must be able to withstand both wet and dry conditions. They should have fibrous root systems to help keep the filter media porous. It is preferable for plants with good nutrient removal capabilities to be selected.

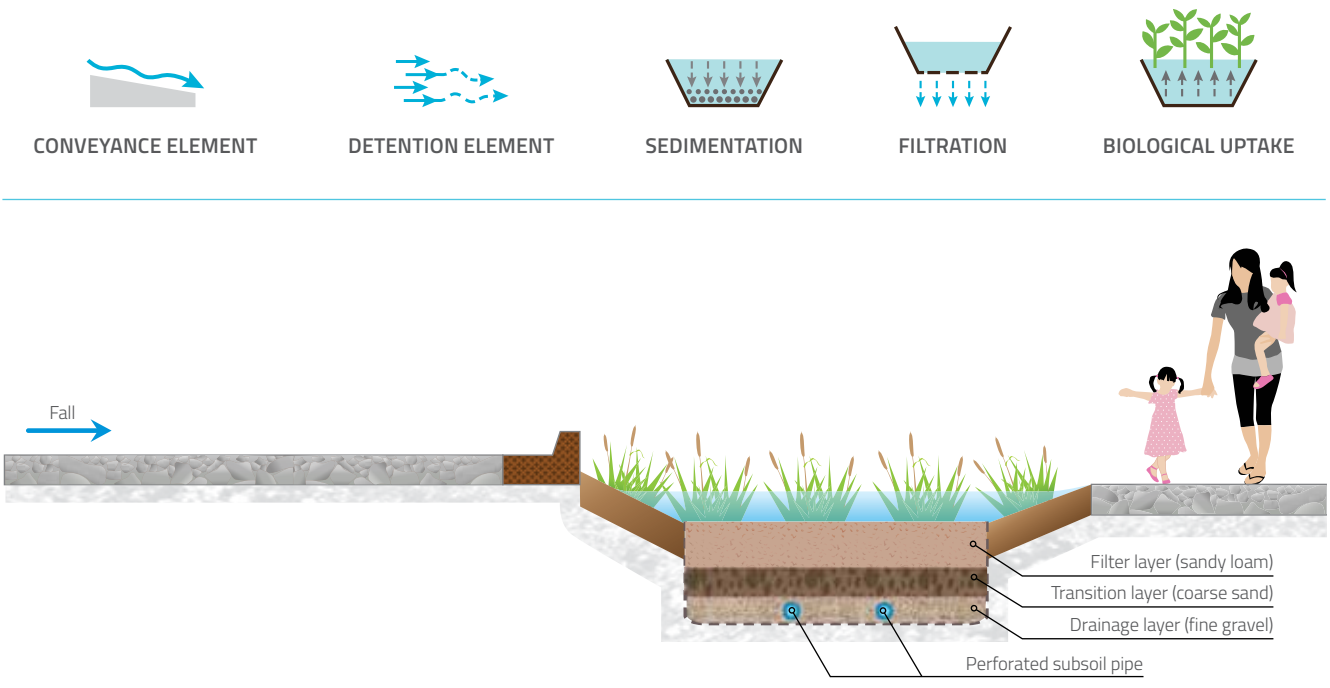


Fig. 4.25
Typical section of a bioretention swale.

Benefits

- Reduces flow velocities and settles coarse sediments
- Encourages habitat creation and promotes biodiversity
- Beautifies surrounding landscape
- Filters and cleans water naturally without the use of any chemicals

Operation and Maintenance

Bioretention swales have a flow conveyance role that needs to be maintained to ensure adequate flood protection. In this regard, a key maintenance requirement is to ensure that the shape of the bioretention swale is maintained and that it is not subjected to erosion or excessive deposition of debris that may impede the passage of stormwater. The inlet points and overflow points or pits have to be kept clear.

Typical maintenance of bioretention swale elements will involve:

- Routine inspection and repair of the bioretention swale profile
- Routine inspection of inlet and overflow points to clear any blockage
- Routine removal of litter, debris and sediment
- Raking of the bioretention swale surface and flushing of the subsoil perforated pipes if there is evidence of clogging
- Maintenance of healthy vegetation growth, as it plays a key role in maintaining the porosity of the soil media and the taking up of nutrients from percolating surface runoff. Regular care such as irrigation, weeding, mowing, pruning and pest-control is necessary

Fig. 4.26
Bioretention swales at Lower Seletar Reservior.

Fig. 4.27
Bioretention swales at Firefly Park.

4.2.3
BIORETENTION BASINS (RAIN GARDENS)

Introduction

Bioretention basins are vegetated land depressions designed to detain and treat stormwater runoff. Their treatment process is the same as bioretention swales; the runoff is filtered through densely planted surface vegetation and then percolated through a prescribed filter media (soil layer). Unlike bioretention swales, they do not convey stormwater runoff.

Application and Principles

Similar to bioretention swales, impurities are removed through sedimentation, filtration and some biological take-up (by plants, bacteria, etc). Rain gardens can be installed at various scales and shapes: in planter boxes or integrated with streetscapes. They can also act as 'standalone' soil filtration systems within residential areas, parklands, schools, carparks and other developments.

As the bioretention basin is configured for the removal of finer particles and soluble pollutants, it is advisable that a sedimentation basin (refer to section 4.2.4) be constructed upstream of the bioretention basin as a pre-treatment measure to remove coarse to medium-sized sediments. This helps to ensure that the treatment efficiency of a bioretention basin is sustained over time, and minimises the maintenance requirements of the bioretention basin. If space is limited, a sedimentation forebay can be included as an integral part of the rain garden.

The vegetation in a bioretention system is a vital functional element of the system both in terms of maintaining the hydraulic conductivity of the filter media and the taking up of nutrients. The plants selected for bioretention basins should have fibrous root systems to help keep the soil porous, and be able to withstand wet and dry conditions. It is also good to select plants with good nutrient-removal capabilities.

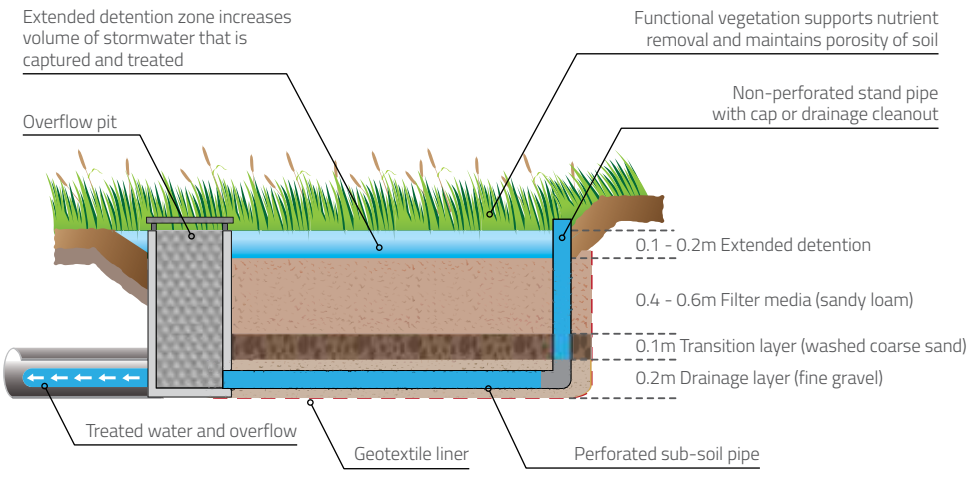


Fig. 4.28
Typical section of a bioretention basin.

Benefits

- Reduces flow velocities
- Encourages habitat creation and promotes biodiversity
- Beautifies surrounding landscape
- Filters and cleans water naturally without the use of any chemicals

Operation & Maintenance

Vegetation plays a key role in maintaining the porosity of the surface of the filter media and the taking up of nutrients from percolating surface runoff. It also facilitates the transport of oxygen to the soil microbial communities for the biological transformation of pollutants. Thus, a strong healthy growth of vegetation is critical to its performance.

Maintenance is primarily concerned with:

- Maintenance of depression profile to keep a clear flow path to and through the bioretention basin
- Routine inspection of inlet, outlet and overflow points to clear any blockage
- Routine removal of litter, debris and sediment
- Raking of the bioretention basin surface and flushing of the subsoil perforated pipes if there is evidence of clogging
- Maintaining healthy vegetation growth, as it plays a key role in maintaining the porosity of the soil media and the taking up of nutrients from the percolating surface runoff. Regular care such as irrigation, weeding, mowing, pruning and pest-control is necessary

Soak away rain garden

Typically, sub-soil pipes are installed in the drainage layer to discharge the filtered water to a nearby drain. However, if there is no suitable drain nearby, a soak away type of rain garden can be used if the surrounding soil is adequately permeable. A soak away rain garden is easy to construct and is suitable for small developments like schools or even private homes. Test-bedding of soak away rain garden has been carried out in 3 local schools (see case study in Section 10).

Fig. 4.29 & **Fig. 4.30**
Bioretention basins at Lower Seletar Reservoir (left) and Balam Estate (right).

4.2.4
SEDIMENTATION BASINS

Introduction

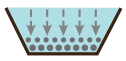
Sedimentation basins are ponds that provide temporary retention and a reduction of stormwater flow velocity to promote the settling of particles by gravity. They are designed to capture 70–90% of coarse to medium-sized sediment (typically above 125µm) that can then be removed periodically. Sedimentation basins are deployed as pre-treatment units that could be applied to constructed wetlands and bioretention basins. Large water storage pond can be an aesthetic water feature if integrated with lush landscape. At the same time, sediments are settled in the pond and cleaner water in the upper part can be channelled for use.

Application and Principles

Sedimentation basins can be permanent water features in an urban design or temporary measures to control sediment discharge during construction. Its primary function is to capture coarse to medium-sized sediment as a pre-treatment measure before the water enters a downstream treatment system (e.g. macrophyte zone of a constructed wetland or a bioretention basin) configured for the removal of finer particles and soluble pollutants.

The second function of sedimentation basins is to control or regulate flows entering the downstream treatment system. The outlet structures of sedimentation basins are designed such that flows up to the design flow will enter the downstream treatment system, whereas excess flows are bypassed around the downstream treatment system (e.g. via a spillway). In providing this function, the sedimentation basin protects the downstream treatment system against scouring and other damages during extreme high flows.

RETENTION ELEMENT



SEDIMENTATION

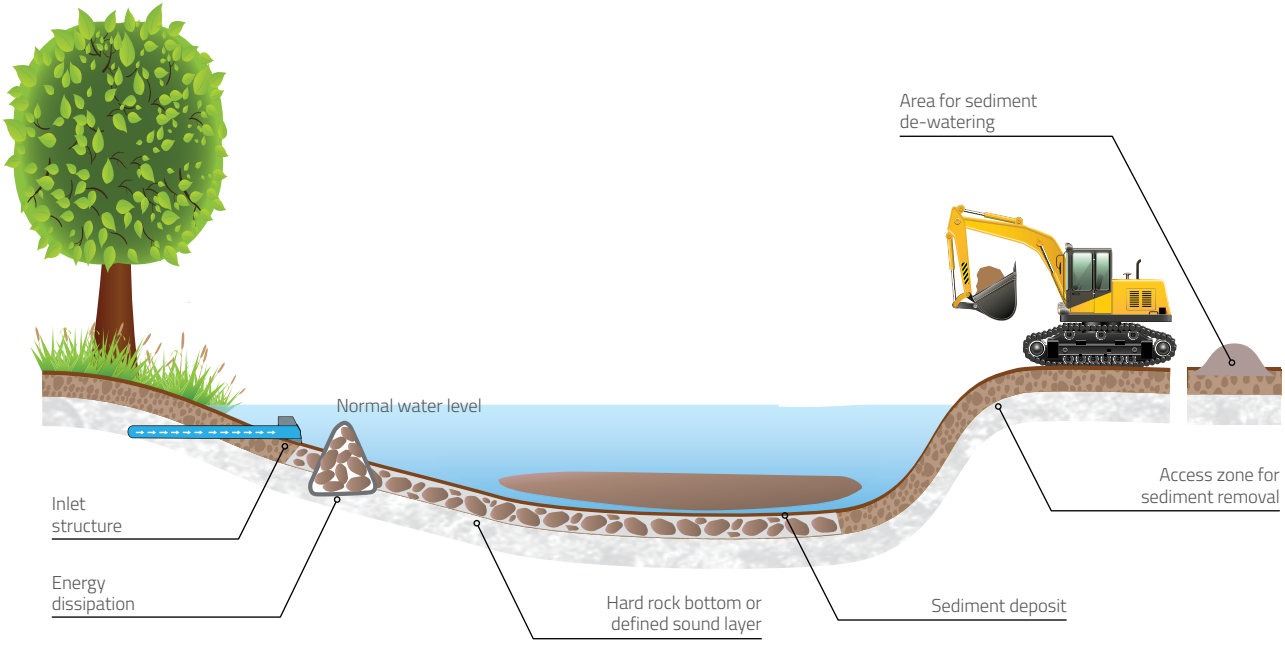


Fig. 4.31
Typical section of a sedimentation basin.

Benefits

- Pre-treats the runoff to facilitate further treatment by downstream ABC Waters design features
- Slows down the runoff to protect downstream features
- Provides easy sediment removal
- Adds environmental benefit with wetland plants around the edge
- Can be designed as an aesthetic water feature
- Stored water can be used for non-potable uses

Maintenance

- Ensuring proper operation of inlet scour protection or energy dissipation structures
- Monitoring of sediment accumulation and timely removal of sediment
- Removal of debris to ensure that outlet is not blocked
- Weed management to ensure the healthy growth of species as required in the design of each specific site

Fig. 4.32
Sedimentation basin at Yishun Pond is an aesthetic water feature next to Khoo Teck Puat hospital.

Fig. 4.33
Sedimentation forebay at Grove Drive

4.2.5
CONSTRUCTED WETLANDS

Introduction

The use of constructed wetlands for stormwater management is widely adopted in many urban environments. Constructed wetland systems are shallow and extensively vegetated water bodies that generally consist of the following zones:

- An inlet zone (designed as a sedimentation basin to remove coarse to medium-sized sediment – see Section 4.2.4)
- A macrophyte zone (a shallow heavily vegetated area to remove fine particles and soluble pollutants)
- A high flow bypass channel (to protect the macrophyte zone)

Constructed wetlands are designed primarily to remove suspended particles and dissolved contaminants. The wetland needs to be configured such that system hydraulic efficiency is optimised, healthy vegetation is sustained and a balance eco-system is maintained.

Application and Principles

Wetlands can be constructed on different scales, from building scale, park scale to large regional systems. The design of constructed wetlands is scalable according to the size of the contributing catchment and this has made its application extremely versatile. In highly urbanised areas, they can have a hard edge form and be part of a streetscape or forecourts of buildings. In regional settings, they can be over 10 hectares in size and can provide significant habitat for wildlife.

Wetland processes involve slowly passing runoff through heavily vegetated areas. Sediment settles and plants filter fine sediments and soluble pollutants from the runoff. Microorganisms that grow on the plants and soil can absorb nutrients and other associated contaminants from the runoff.

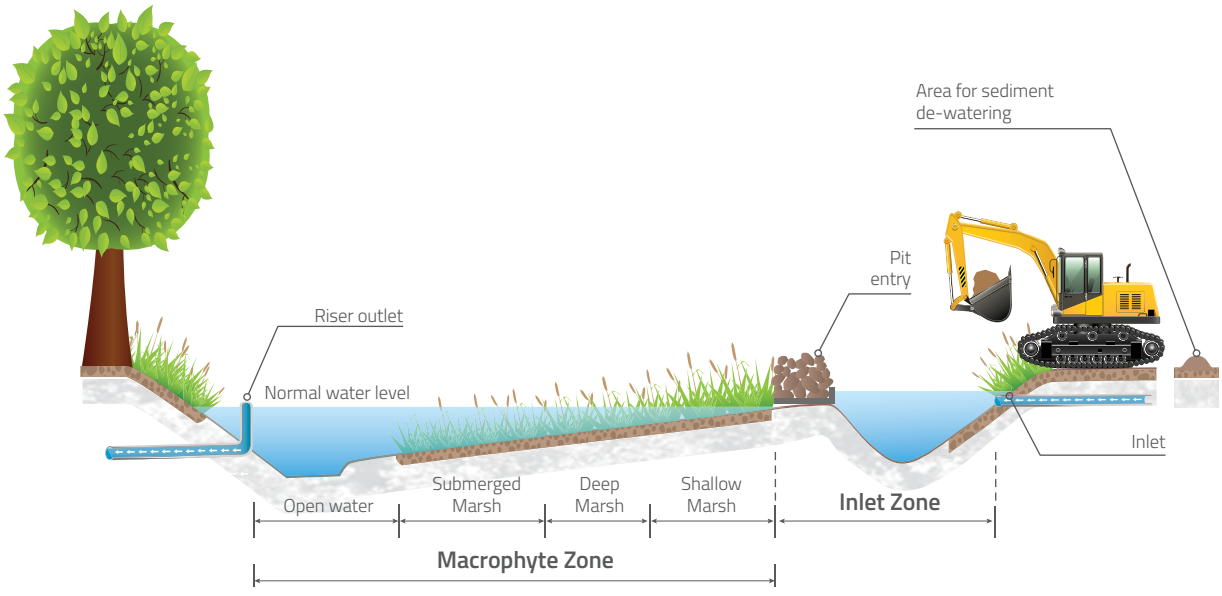


Fig. 4.34
Typical section of a wetland system.

Fig. 4.35 (a), (b), (c)
From top, Grove Drive surface flow wetland, Lorong Halus sub-surface flow wetland and Sengkang Floating Wetland.

In Singapore, wetlands can perform very efficiently due to warmer climate, faster plant growth and other biological activities.

In general, wetlands can be categorised into surface flow, sub-surface flow and floating wetlands. Among them, the surface flow wetland is most suitable in treating surface runoff for sustainable stormwater management. Wetlands also create habitats and can contribute to flood control.

i) Surface Flow Wetland

This wetland comprises a shallow marsh of mainly emergent water plants through which water slowly flows. The water level is kept at a fairly constant depth. The plants help to remove impurities in the water, resulting in cleaner water at the outlet.

ii) Sub-surface Flow Wetland

In this wetland, no water can be seen as it is flowing below the surface, through the filter media, which retains suspended solids. The roots of the plants absorb impurities in the water, thereby cleaning it. The filter media sustains a vast bacteria population that can consume and break down pollutants. This wetland type is typically used to clean water with more organic content.

iii) Floating Wetland

A floating wetland is an engineered system that employs plants growing on a floating mat on the surface of the water. Rooted emergents (plants that grow in water with leaves and flowers above the water surface) are selected for planting on floating wetlands.

The plant's roots also serve as a natural environment (or substrate) for the growth of a community of microorganisms that breaks down organic pollutants in the water.

Benefits

- Filters and cleans water naturally without the use of any chemicals
- Encourages habitat creation and promotes biodiversity
- Beautifies surrounding landscape

Maintenance

- Maintain continual flow to and through the wetland system
- Maintain vibrant vegetation. Suitable plants must be chosen for survivability and ability to remove pollutants like nutrients
- Routine removal of accumulated sediment
- Routine weeding and removal of dead plants
- Routine removal of litter, debris and sediments
- Inlet zone needs to be maintained in the same way as the sedimentation basins

4.2.6
CLEANSING BIOTOPES

Introduction
Cleansing biotopes are a form of artificially constructed vertical flow wetland, typically with recirculation. They consist of nutrient-poor substrates that are planted with wetland plants that are known for their water cleaning capacity.

Principles and Applications
The degradation of pollutants in a cleansing biotope occurs with the help of microorganisms within the substrate that is fed by oxygen from the root zones of the wetland plants. The layers of substrate filter out particulates and have mineral composites that bind and remove phosphates. The dense planting also filters out sediment while partially feeding off and removing nitrates in the water. The cleaned water is often recirculated for further treatment by the cleansing biotopes.

They can be implemented in a variety of situations:
- Revitalisation of lakes and the cleaning of urban water bodies
- Outdoor areas such as parks, open fields, ponds and lakes
- Rooftop gardens, gardens in building interiors, open plazas next to buildings or even under elevated structures
- Subdivided into smaller areas (such as small sky gardens and planters) that work together in sequence for incremental cleaning

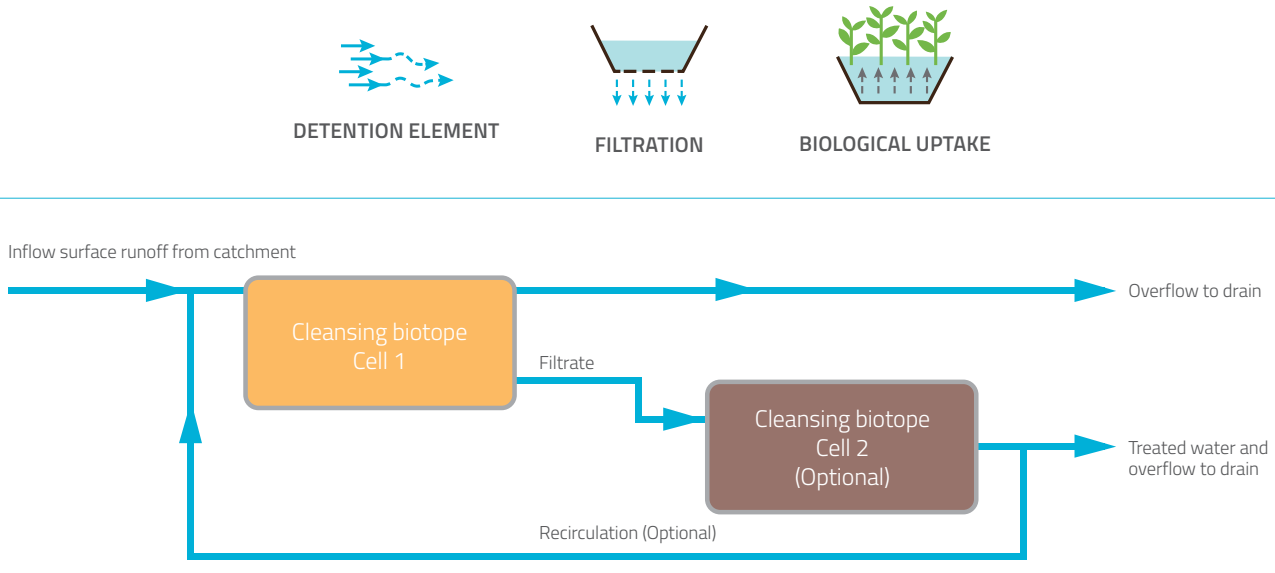


Fig. 4.36
Typical schematic of a cleansing biotope system.

Benefits

- Filters and cleans water naturally without the use of any chemicals
- Encourages habitat creation and promotes biodiversity
- Beautifies surrounding landscape

Maintenance

- Maintain healthy vegetation growth, as it plays a key role in maintaining the porosity of the soil media, taking up of nutrients and promoting the growth of microorganisms that degrade pollutants from the percolating surface runoff. Regular care such as irrigation, weeding, mowing, pruning and pest-control is necessary.
- Cleansing biotopes can be divided into several areas that are alternately activated. This allows each section to be deactivated for a few days for regeneration.
- Under extreme conditions, the filter media may become clogged at the surface by organic matter. When this happens, the water feed is switched off or diverted to allow the substrates and organic matter to dry for several days and the biotopes surface to be mineralised. The top layer of the filter media should also be raked to loosen it. The cleansing biotope system can then be turned on again.

DETAILS OF A TYPICAL CLEANSING BIOTOPE PROFILE

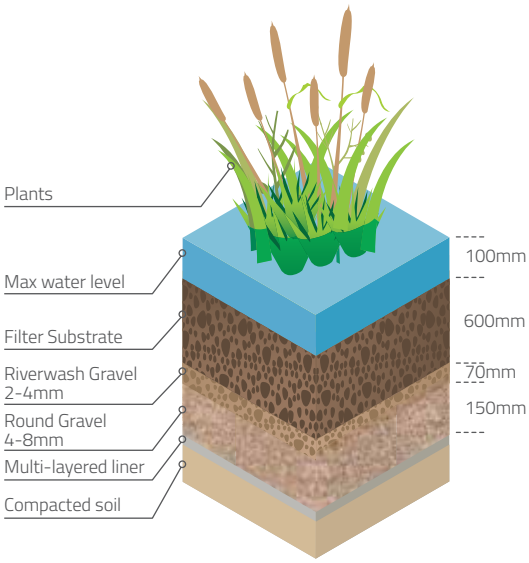


Fig. 4.37
Cleansing biotope at Bishan-Ang Mo Kio Park.

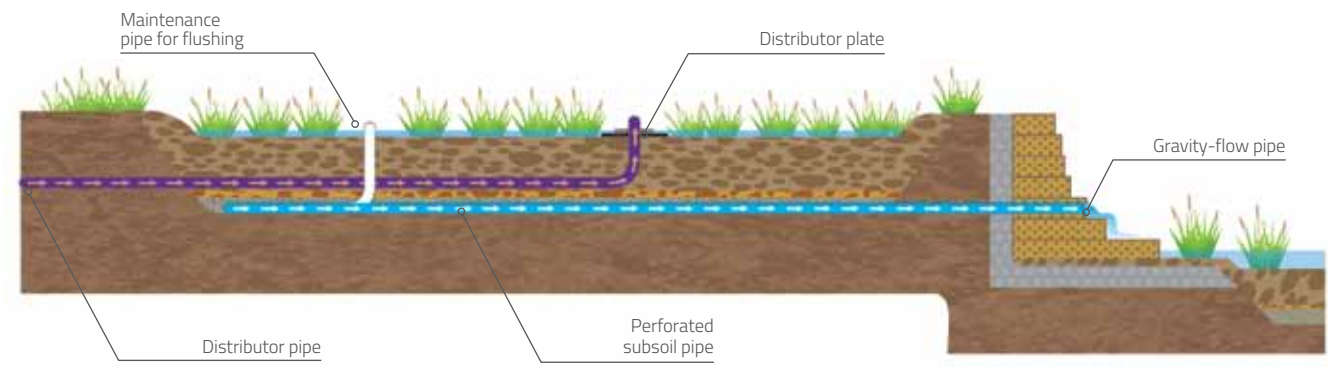


Fig. 4.38
Typical section through a cleansing biotope.

4.3
CONVEYANCE AND STORAGE

WATER BODIES WATERWAYS

Waterways and Water Bodies

Singapore's extensive stormwater network comprises some 17 reservoirs, 32 major rivers and more than 8,000 km of canals and drains.

Without attempting to exhaust the many possible permutations of the ABC Waters elements, this section aspires to demonstrate some of the many possible interventions that can be applied to waterways and water bodies.

It is, however, important to note that there are many factors that influence the plausibility and suitability of implementing specific ABC Waters elements, including the following:

i) Land Use

- **Affects the kind of pollutants**

  Stormwater pollutants from urban developments originate from a variety of sources in the catchment. Suspended solids are mainly from soil erosion; nutrients, organic matters and microorganisms are from sullage discharge, animal droppings and fertilisers; oils are generally from vehicles and petrol stations; litters are from populated areas and dry leaves are from landscaped areas. Suspended solids, nutrients, oils and litters have a negative aesthetic impact, which is often a cause for concern for the community.

- **Affects facilities and activities**

  Recreational facilities are commonly integrated along the edges of rivers close to business or residential areas, and reservoirs that are close to residential areas. On the other hand, rivers and reservoirs within and close to the nature reserves, such as Sungei Buloh and Kranji Reservoir, are kept tranquil and natural to benefit the flora and fauna community found there.

Fig. 4.39
Lower Seletar Reservoir, one of the 17 reservoirs in Singapore.

- **Affects quantity of runoff**
  The generally high percentage of clay in most of Singapore's soil translates to a minimal level of infiltration or ground-water recharge. Nevertheless, the high density of buildings and paved areas would still have an inverse effect on stormwater infiltration levels, and increase the runoff rates.

ii) Soil and Geological Condition

The composition of soil has an effect on a variety of properties. As mentioned, soil that is predominantly clay in nature would impede infiltration but it would facilitate conveyance. It would also be more plastic and can sustain a steeper slope along banks and in landforms. However, it may not be as suitable for bioengineering as plants may not thrive due to the lower porosity and hence decreased capacity for containing oxygen.

Surface roughness of the coarse soil that contains larger rocks and aggregates would also decrease the velocity of the water flow as compared with a concrete-lined canal.

iii) Ecological Integration

Each canal is part of a larger drainage system and catchment area. Careful analysis to determine the effect of any intervention on upstream and downstream conditions prior to any changes is imperative.

The biodiversity of a natural system is highly sensitive and susceptible to the slightest change. Careful studies to identify existing species of plants and animals would ensure the preservation of the delicate ecological balance.

Fig. 4.40
An ABC waterway is aesthetic and helps to convey stormwater during rain events.

4.3.1
ENHANCING WATERWAYS

i) **Greening of Waterways**

A technique that can be used to enhance waterways without the demolition of the concrete canal is the greening of waterways with the use of creepers. This has been implemented by PUB at some of the canals in Singapore and an example is shown below.

Another method to green our waterways is via the use of gabions, which can be integrated into canal walls that are partially removed. Creepers grow over the gabions to enhance the aesthetics of the canal. This is illustrated in the cross sections shown below (a good example where this is applied is at Sungei Whampoa – St George's Lane).

Fig. 4.41
The landscaped trapezoidal canal walls along Sungei Kallang - River Vista.

Fig. 4.42
The applications of gabions greened with creepers has helped to soften the look of the canal at Sungei Whampoa - St George's Lane.

ii) Soil Bioengineering

Soil bioengineering is a construction technique that harnesses the inherent qualities and capabilities of natural materials (plants, stones, branches, roots, etc.) for the purpose of providing structural integrity while being ecological and aesthetically pleasing. Soil bioengineering is typically employed in natural environments such as stabilising a river embankment.

In the context of enhancing waterways, soil bioengineering can be used to naturalise them. Soil bioengineering not only stabilises the slopes of the river bank, but also protects the slopes from erosion during storm events.

Some soil bioengineering techniques are "softer" in that they rely almost entirely on plant matter for their construction materials. These include techniques such as brush mattresses, fascines and geotextile with planting. Alternatively, there are "harder" soil bioengineering techniques, such as rip-rap and gabion walls, which are predominantly constructed using rocks and come closer to traditional engineering.

Principles and Applications

The suitability of specific techniques depend on site conditions such as:

- Gradient of slope
- Soil type
- Water velocity along waterways

These would determine whether techniques that are more resilient are required. Professional soil bioengineering consultants should be engaged to provide an accurate assessment of the site conditions and to propose appropriate techniques. The hydraulic capacity of the waterways also need to be checked for compliance.

Fig. 4.44
Bioengineering testbed for the Kallang River at Bishan-Ang Mo Kio Park project, showing 3 techniques: stone wall with cuttings, log cribwall, and gabions with brush layers.

Benefits

- Protects the soil surface from erosion caused by climatic elements (rain, wind)
- Reduces the velocity of water flow
- Facilitates settlement and deposition of sand and silt, thus protecting the water quality of downstream water bodies
- Enhances soil fertility through retention of nutrients
- Beautifies surrounding landscape
- Increases soil integrity through establishing root networks
- Encourages habitat creation and promotes biodiversity

Maintenance

As long as appropriate conditions for plant growth are maintained, bioengineering techniques are dynamically sustained, self-regulated and enhanced without the need for excessive maintenance. The deepening of the roots over time improves soil stabilisation and protects against erosion.

Unlike hard structures, bioengineered waterways comprise live, dynamic and loose elements. Bedrock movements (e.g. stones and pebbles moved and carried along by high water velocity) and sedimentation (debris and silts generated from eroded rocks, plant damage and degeneration) are natural processes along the river. Periodically but infrequently, minor maintenance (replacement of displaced rocks, trimming of plants to prevent breakage, etc.) is necessary.

Some of the maintenance requirements are as follows:

- Litter and debris removal from the natural river channels and slopes
- Removal of sediment accumulated at designated sedimentation basins
- Maintenance of healthy vegetation growth. Regular care such as weeding, mowing, pruning and pest control is necessary.

The first of its kind in Singapore, the Kallang River at Bishan-Ang Mo Kio Park project, completed in 2011, is an example of a naturalised waterway (refer to the case study in this guideline for more details.)

Nevertheless, the naturalisation of waterways and water bodies does not have to be limited to public projects or large developments. ABC Waters design features can be applied to a short segment of a canal that intersects or passes through a private development. Likewise, sections of an artificial pool or just small segments on one side of a canal bank can be naturalised to enhance the aesthetic, ecological and social value of adjacent developments.

SECTION 5

SAFETY CONSIDERATIONS, PUBLIC HEALTH AND MAINTENANCE

When implementing ABC Waters design features, all projects should be designed with a system of safety designs and checks in place. Maintenance is also equally important to ensure the lifespan and sustain the benefits of the features. Various safety and maintenance considerations are outlined in this section.

5.1 DESIGN STAGE

Safety to users is a key criterion and an integral part of the the project design. As such, it is important that adequate measures are put in place to ensure public safety.

The developer and/or his Qualified Person (QP) must consult the following agencies on safety aspects of their proposals:

- PUB, the national water agency
- Singapore Civil Defense Force (SCDF)
- Building & Construction Authority (BCA)
- Fire Safety Bureau (FSB)
- Fire Safety & Shelter Dept (FSSD)
- Land Transport Authority (LTA) (if public streets are affected or if proposed features are within roadside verge)
- Housing & Development Board (HDB) and Town Councils (if features proposed are within HDB land)
- Any other agencies as advised by PUB and SCDF

The following organisations should also be consulted for developments that include water sports facilities:

- People's Association (PA)
- Sport Singapore, formerly known as Singapore Sports Council (SSC)

The following key aspects should be addressed in the design of the project and ABC Waters design features:

i) **Sufficient Overflow Discharge Capacity**
With the exception of vegetated/gravel swales that are sized adequately to convey stormwater runoff, in accordance to the latest edition of the **Code of Practice of Surface Water Drainage**, overflow with sufficient discharge capacity must be in place when designing any ABC Waters design feature.

The designer must ensure that installation of the ABC Waters design features does not cause ponding/flooding to the adjacent areas.

- ABC Waters design features are not designed to detain and treat runoff from intense storms
- Adequate overflow points with sufficient discharge capacity must be provided to channel stormwater effectively to the storm drain during intense storms
- The storm drain must be adequately designed to channel the overflow to the downstream drainage system

ii) Illumination

It is important that sufficient lighting is provided for illumination of the area, particularly in relation to the following safety and security concerns:

- General visibility — consistent lighting along paths to prevent people from tripping and knocking into obstacles
- Crime prevention — areas of complete darkness should be avoided. Ambient and/or sensor lighting are possible energy-saving solutions
- Areas which pose potential hazards, such as steps, changes in levels, water crossings and bridges, should be illuminated

Energy-efficient lighting should be specified for ecological sustainability and durability, as well as to minimise maintenance frequency.

It is recommended that landscape consultants and/or lighting specialists are engaged to address the specific lighting needs of each project.

Fig 5.1
Informational signage with prohibitive icons at Lower Seletar Reservoir.

Fig 5.2
A safety node with warning lights at Kallang River at Bishan-Ang Mo Kio Park.

iii) Signage

Signs are important tools to give direction and information. Any inherent risks within the project site should be highlighted:

- Directional signage to locate specific areas of risk to expedite emergency responses
- Safety warning boards illustrating potential risks to both adults and children

iv) Accessibility

Applicable guidelines in the Building & Construction Authority's (BCA's) Code on Accessibility in the Built Environment should be followed. Specifically, the following must be provided:

- Handrails to be located along vertical drops, side drains as well as on all bridges to prevent accidents. A height of 110 cm conforms to Singapore's safety design standards for guardrails. Other aesthetically pleasing safety barriers such as planter boxes, rocks, ornamental walls and bushes can be used too
- At public areas, provisions should be made for the disabled. BCA's requirement for barrier free access shall be complied.
- In areas where activities are conducted, the slope should have a gradient of not more than 1:4
- Sufficient traction for handholds and footholds should be provided

In addition to the above, the following is applicable for the design of bioretention systems to minimise tripping hazards:

- Where possible, batter slopes with gradients not exceeding 1:4 should be used. Batter slopes are preferred as compared to a sudden level difference at the edge of the bioretention basin with the surrounding area. In the event that batter slopes are not possible, adequate safety barriers must be provided at the edge of the bioretention system
- The extended detention depths of bioretention systems must not exceed 300 mm

v) Emergency and Rescue Plan

Fire and other hazards may be considered as an integral part of the whole development.

- Fire and emergency access – In the case of fire or emergency, there must be an access road that is wide and gentle enough for vehicles to access the structures in key areas
- Fire access and Hydrants – Fire truck access and hydrants are to be provided in accordance with FSSD requirements and the developer's fire risk assessment
- Other appropriate safety equipment (e.g. life buoys) must be provided at visible and easily accessible locations

vi) Specific Requirements for Waterways

The following should be considered when waterways are naturalised and made accessible to the public:

a) Signs, lights and markers should be used to warn and inform the public of any rise in water levels.
- Safety nodes with warning lights should be located at critical locations of the waterway to act as visible safety aids and communication/rescue landmarks during sudden increases in water levels and/or velocities
- Depth markers should be placed to increase visitors' and rescue officials' awareness of gradually rising water levels

b) Velocity and depth checks for safety should be carried out during design, and the following factors to be considered if the design is to allow public to walk in the water:
- Velocity, depth, substrate, local uses and norms in the region
- Firm channel bed to provide good footing

c) Classifications of waterways – Waterways or segment of waterways can be classified according to the following factors:
- Flow velocity of waterway
- Slopes of bank for easy access into and out of the water

This classification can be used to assess appropriate activities for the waterway.

Other considerations to be taken into account include the following:
- Certain water activities have to be organised by an appointed organiser (e.g. boating/kayaking)
- Participants of organized water activities (such as kayaking) need to have the required level of proficiency certification.

vii) Plant Selection

Plants that have receptacles or thick axils that may trap water should be avoided to prevent mosquito breeding.

viii) Rigorous Review Process before Tender Calling

During the detailed design stage, the projects should be jointly reviewed by the developer, consultants and safety auditor for further refinements on design and operational safety.

5.2 CONSTRUCTION STAGE

i) Workplace Safety and Health

It is imperative that all construction projects adhere to the requirements stated in the Ministry of Manpower's Workplace Safety & Health Act to ensure the safety of all employees, consultants and the general public during the site preparation, construction and site handover phases.

5.3 POST-COMPLETION

i) Mosquito Control

Efforts to prevent, detect, identify and destroy any mosquito breeding, as well as to eliminate potential habitats (places that could collect water or contain water stagnation) require the implementation of environmental management measures. These include:

a. Routine surveillance (at least once a week) to eliminate potential habitats. This includes:
   - Drainage of places that could collect water or contain water stagnation
   - Removal of discarded items
   - Clearance of choked subsoil pipes or discharge outlets
   - Removal of plants with thick axils

b. Regular monitoring and maintenance of subsoil drain pipes to ensure that they do not sag and create areas of water stagnation.

c. Regular monitoring of the time taken for stormwater runoff to infiltrate through the filter layer of bioretention systems. Prolonged detention times exceeding 12 hours are likely to indicate clogging within the filter layer or subsoil pipes. As such, the following actions will need to be taken:
   - Flushing of subsoil pipes through the capped maintenance standpipes
   - Raking of the soil surface of the filter layer

d. Introduction of fishes in surface flow wetland systems to aid in the control of mosquito larva.

e. Engagement of a Pest Control Operator (PCO) to implement mosquito control programmes on-site.

ii) Safety Audit

The developer, consultants and external safety auditor should conduct audit checks at the site to ensure that adequate safety measures have been put in place within the project site, and that water activities are carried out properly and safely (if applicable), and in accordance with safety procedures. Such audit checks should occur periodically.

iii) Public Education

There are various methods of educating the public about the proper and safe use of facilities, in addition to the roles and functions of the ABC Waters design features implemented. These include:

- Signage
- Workshops/educational programmes
- Media (e.g. brochures/videos/websites)

iv) **Raising Awareness of Individual Responsibility**
While safety measures have been implemented, the public is encouraged to exercise individual responsibility and good sense when having fun near ABC Waters design features or at water bodies. Where areas have been designated for water-play, parents should educate their children on general safety measures. In general, the public should not enter any waterway as there may be swift currents due to a sudden surge of rapid water flow caused by a storm.

5.4 MAINTENANCE CONSIDERATIONS

Like any system, maintenance is a necessary and important consideration, and sufficient thought should be given to long-term maintenance during the design stage. The facilities and features must be monitored, inspected and maintained regularly to sustain the various benefits. Routine inspections and maintenance programmes help to prolong the lifespan of these facilities and features. By detecting the problems early, the maintenance cost can be reduced and any major repair or high replacement costs can also be avoided. Poor or irregular maintenance will result in system failure, additional expenses and adverse environmental impacts such as mosquito breeding, accumulation of pollutants in downstream water bodies, and flooding.

The following are key considerations to be taken into account when maintaining ABC Waters design features:

i) **Natural Systems**
ABC Waters design features are green infrastructures that mimic natural systems. They are cost effective, sustainable, and environment friendly. These features harvest the natural cleaning capability of plants and soil to remove pollutants like nutrients and suspended solids without the need for sophisticated mechanical equipment and chemicals.

ii) **Landscape Maintenance**
ABC Waters design features (e.g. Bioretention systems, vegetated swales, and wetland, etc.) rely on the establishment of good vegetation to clean stormwater runoff. Vegetation also plays a key role in maintaining the porosity of the filter media of bioretention systems, while a uniform turf layer is important for vegetated swales to prevent scouring and soil erosion. Hence, ensuring adequate vegetation growth is a key maintenance objective as a healthy growth of vegetation is critical to the proper performance of the systems. The most intensive period of maintenance is during the plant establishment period when weed removal and replanting may be required. The use of fertilisers is to be restricted as far as possible. ABC Waters design features are meant to clean stormwater runoff from which the vegetation can extract their nutrient requirements.

iii) Bioretention Filter Layer Soil Porosity

The filtration of stormwater runoff through the filter layer is a key treatment process for bioretention systems. In addition to ensuring healthy vegetation growth to maintain the porosity of the filter layer, regular monitoring of the time taken for stormwater runoff to infiltrate through the filter layer should be undertaken. Prolonged detention times exceeding 12 hours are likely to indicate clogging within the filter layer or subsoil pipes. As such, the following actions will need to be taken:

- Flushing of subsoil pipes through the capped maintenance standpipes
- Raking of the soil surface of the filter layer

iv) Cleaning and Hydraulic Maintenance

Routine cleaning maintenance to ABC Waters design features is recommended, especially after a storm event, in order to clear any blockage to inlets, outlets and overflow points, and to remove litter and debris from the systems. Routine inspection, especially for the surface of bioretention system, to identify any areas of obvious increased sedimentation for removal is necessary.

Swales play an important role in the conveyance of stormwater runoff. It is important to inspect the swale profile to ensure that the swale has adequate conveyance capacity and that there is no hindrance to conveyance of stormwater runoff.

v) Specific Checklists

The maintenance requirements of the major types of ABC Waters design features can be found in Chapter 4. The specific maintenance checklists are provided in the **Engineering Procedures for ABC Waters Design Features.**

SECTION 6

ACTING TOGETHER FOR A SUSTAINABLE ENVIRONMENT

For the community to enjoy clean water, everyone must play a part. PUB encourages the various stakeholders – landowners, private developers to incorporate ABC Waters design features into their developments, and the community to embrace these infrastructures for recreational & educational purposes.

6.1 VALUING OUR WATERS

Under the ABC Waters Programme, aesthetic enhancements to Singapore's waterways and reservoirs will be made, creating new community spaces to bring people closer to the water.

We hope that the community will enjoy these new spaces and forge a closer bond with water, ultimately becoming a Friend of Water. As a Friend of Water, they will learn to value our water resources, play their part to keep the waterways clean and contribute by looking after the future of Singapore's water resources.

6.2 EDUCATING THE PUBLIC

To convince the public to help keep our waters clean while enjoying various water-based recreation at our reservoirs and waterways, public education is vital. The 3P (people, public, private) sectors are encouraged to conduct educational activities in and around the waterbodies. For example, they can tap on these resources as outdoor classrooms to increase understanding of the river ecology, and learn how littering on land can pollute our waterbodies. To share knowledge with the public, educational posters and signage can also be displayed at project sites. This helps to engage the public as well as show them that every effort counts and that their participation can make a difference.

Fig 6.1
Residents learning about ABC Waters design features at Sungei Ulu Pandan.

6.3 ENGAGING THE COMMUNITY

PUB recognises the importance of actively engaging the community in the ABC Waters Programme. One of the key aims of the programme is to ensure community ownership of the water assets upon completion. The projects are customised to meet the public's needs through community consultation during the early conceptualisation stages.

The ABC Waters @ Geylang River is one of PUB's latest projects. To encourage the grassroots and other stakeholders to organise and participate in activities at Geylang River, PUB gathered their views and ideas in the early planning process.

Today, the community at Geylang River organises many activities and projects, and enjoys the facilities and features constructed for their use, which have transformed the area into a beautiful and vibrant waterfront.

ABC Waters @ Sungei Ulu Pandan aims to create an outdoor classroom setting where residents and students can learn more about water and the environment. Driven by the large presence of schools and the Van Kleef Centre in the vicinity, the project includes various types of ABC Waters design features across five focal points.

The School of Science and Technology (SST), which has started conducting water quality tests at Sungei Ulu Pandan and Sungei Pandan as part of their curriculum, is the first school to use the site as an outdoor classroom. Besides SST, schools like Nan Hua High School and Queensway Secondary School have also expressed interest in expanding their experiential learning at the two waterways.

In addition, Asia Pacific Breweries (APB) Singapore and the National University of Singapore (NUS) will partner to establish an APB Singapore Water Education Fund @ Van Kleef Centre. This collaboration aims to conduct further research of water quality, education and conservation. APB Singapore has pledged its contribution to this fund, which will support public education and community outreach programmes such as an ABC Waters Learning Trail, research projects and an internship programme for tertiary students.

Fig 6.2
Residents at a rain garden workshop at Geylang River.

As with all ABC Waters projects, PUB consults and updates the grassroots and community during the project design and construction phases. During the construction phase, students from Nan Hua High, SST, Clementi Town Secondary School and Crest Secondary School had the opportunity to learn more about the development through a hands-on planting activity.

Arising from residents' feedback, a new staircase design with a wheeling ramp was piloted at Sungei Ulu Pandan. This feature enables cyclists to easily transport their bicycles up and down the stairs.

A similar approach is encouraged for all projects that implement ABC Waters design features.

6.4
A CALL FOR PARTNERSHIP

The ABC Waters Programme aims to provide clean water for all. It will enhance the city landscape and land value surrounding the projects as developments located near water tend to command a premium price. Hence, PUB encourages private developers and landowners to incorporate waterways into their developments and implement ABC Waters design features which will contribute to a beautiful, clean and green living environment. We also encourage the various stakeholders – public agencies, private developers, landowners, grassroots and the public, to participate in this programme to realise Singapore's vision of remaking Singapore into a vibrant City of Gardens and Water.

Fig 6.3
Residents enjoying water activities at Jurong Lake.

SECTION 7

ABC WATERS CERTIFICATION

The ABC Waters Certification is a scheme that was launched by PUB on 1 July 2010. This certification provides recognition to public agencies and private developers who have embraced and incorporated the ABC Waters concepts and features in their developments. The scheme also aims to ensure that the design features meet the minimum design standard.

7.1 APPLICATION AND ASSESSMENT

With applications open throughout the year, developers of completed projects or projects that have the finalised detailed design are encouraged to apply for ABC Waters certification, which is valid for three years. Evaluation and assessment of the projects is conducted based on the information and declaration submitted in the application form.

Applicants are to ensure that the information provided is accurate and up-to-date. To verify that the certified projects are executed in accordance to the design, random checks will be conducted during the Temporary Occupancy Permit (TOP) stage.

Under this scheme, public agencies and private developers of the ABC Waters-certified projects are allowed to make use of the ABC Waters logo to promote their developments as ABC Waters-certified.

The ABC Waters Certification application form can be downloaded from http://www.pub.gov.sg/abcwaters/abccertified/Pages/default.aspx. The projects that have received ABC Waters certification are publicized on the same website.

7.2 ABOUT THE CERTIFICATION

The ABC Waters Certification Scheme is evaluated based on four categories – Active, Beautiful, Clean and Innovation.

For a project to be certified, it needs to receive a minimum of 45 points, with at least 5 points in each of the first 3 categories.

Category	Points
Active	30
Beautiful	30
Clean	30
Innovation	20
Total : 110 Points	

Active Section

This section aims to encourage vibrancy and activity in each site by providing new community spaces for people to enjoy recreational activities and bringing people closer to water.

Section Criteria

Active	Points
1) Provision of facilities for new community spaces & public enjoyment, with possible educational values	**20**
a) Provision of facilities that bring people closer to water and promote waterside or fringe activities in development (E.g. viewing decks / lookout decks / boardwalks / seating spaces by the waterway or ABC Waters design features — excluding swimming pools / fountains)	5
b) Accessibility and safety consideration for the facilities provided (e.g. barrier free design)	5
c) Maintainability of the ABC Waters design features (e.g. design features which involve minimal maintenance)	5
d) Scope for public education (E.g. signage to explain facts about water / nature / ABC Waters design features)	5
2) Usage by stakeholders & community engagement	**10**
a) Proposal for formation of interest groups or for organising activities (with plans to ensure sustainability of activities) at project site	5
b) Convenience of usage by members of the public	5

Beautiful Section

This section focuses on achieving integration between water and greenery to achieve scenic waterscapes that promote biodiversity and encourage the use of native plants.

Section Criteria

Beautiful		Points
1)	**Integration of water features within site architecture**	**20**
a)	Aesthetic improvements of surface water drainage (e.g. use of vegetated swales / bioretention swales instead of concrete drains, use of retention ponds, wetland plantings etc)	10
b)	Aesthetic improvements to the sky terrace / roofs (e.g. usage of intensive or extensive green roofs to slow down runoff)	5
c)	Aesthetic improvements to the façade (e.g. through use of vertical greenery, planter boxes for treatment of rainwater)	5
2)	**Integration with greenery**	**10**
	Planting scheme with a variety of plants (preferably native plants) that encourage habitat creation (eg. for butterflies, dragonflies and birds) and enhance biodiversity	10

Fig 7.1
Integration of water features within site architecture.

Clean Section

This section focusses on sustainable and holistic stormwater management through the adoption of ABC Waters design concept that detain stormwater runoff on-site and improve water quality.

Section Criteria

Clean		Points
1)	**Incorporation of ABC Waters design features to treat surface runoff from site**	**20**
a)	Treatment or retention of runoff from more than 35% of the total catchment area (site area) through infiltration, retention ponds and other ABC Waters design features	20
b)	Treatment or retention of runoff from 11% to 35% of the total catchment area (site area) through infiltration, retention ponds and other ABC Waters design features	15
c)	Treatment or retention of runoff from up to 10% of the total catchment area (site area) through infiltration, retention ponds and other ABC Waters design features	5
	Note: Treatment of more than 35% of total paved area of the site through infiltration, retention ponds and other ABC Waters design features will qualify for an additional 15 points, subject to a maximum of 20 points	
2)	**Holistic water management of the site**	**10**
a)	Rainwater harvesting and integration with ABC Waters design features	7
b)	Rainwater harvesting and re-use of rainwater (e.g. for irrigation)	3

Fig 7.2
Incorporation of ABC Waters design features to treat surface runoff.

Innovation Section

This section recognises creativity and innovation in incorporating ABC Waters design elements or other environment-friendly features to minimise the impact of urbanisation on the quality and quantity of stormwater runoff. It also acknowledges exemplary designs that go beyond the standard criteria listed in the ABC Waters certification scheme.

Section Criteria

Innovation	Points
1) Incorporation of innovative ABC Waters design in projects	**Up to 20**
Examples: a) Infiltration measures such as porous pavement or engineering soil b) Creative drain cover designs that carry ABC Waters messages c) Innovative irrigation systems that conserve portable water or use stormwater d) Gross pollutant traps that reduce the amount of litter entering the waterways e) Other natural drainage systems f) Grey water recycling	

SECTION 8

ABC WATERS PROFESSIONAL

With the increasing number of ABC Waters projects, there is a constant need for suitably qualified individuals to undertake the designs of these unique water features. As highly trained individuals, ABC Waters Professionals inspect and endorse installed design features, ensuring that they harness the full potential of Singapore's waters to create new recreational spaces for the public.

8.1 ABC WATERS PROFESSIONAL PROGRAMME

Recognising the importance of developing the industry's competence in order to bring the ABC Waters concept to fruition, PUB collaborated with the Institution of Engineers Singapore (IES) to launch the ABC Waters Professional Programme with the support of the Singapore Institute of Architects (SIA), Singapore Institute of Landscape Architects (SILA), HDB, LTA and NParks in 2011. Comprising four core modules and four elective modules, the programme aims to equip industry professionals with the necessary expertise in various aspects of ABC Waters design features from design to construction and maintenance. The 4 core modules are:

1. Understanding ABC Waters Design Guidelines and Certification
2. Stormwater Quality Management – Planning and Design ABC Waters Design features
3. Design, Construction and maintenance of Swales and Buffer Stripes
4. Design, Construction and maintenance of Bioretention Basins and Bioretention Swales

Fig 8.1
Launch of ABC Waters Professionals Registry in May 2013. Guest Of Honour, Chief Executive (PUB) addressing industry professionals.

8.2 ABC WATERS PROFESSIONAL REGISTRY

Following the introduction of the ABC Waters Professional Programme, the ABC Waters Professional Registry was launched in May 2013.

The Registry aims to enable the industry to recognise the quality design work of ABC Waters Professionals who have successfully completed the accredited four core and two elective modules under the ABC Waters Professional Programme. In addition, ABC Waters Professionals will be assisted in achieving better quality standards of ABC Waters design through continuous education and training, increasing competitiveness in the Singapore market and the region.

Professionals who have successfully completed all 4 core modules and 2 elective modules of the ABC Waters Professional Programme are eligible to be registered as an ABC Waters Professional with IES, SIA or SILA, if they also meet the respective registration criteria of the professional bodies. To date, over 200 professionals have attended at least one Programme module. Out of these, more than 40 participants have completed the required number of modules and registered as ABC Waters Professionals.

8.3 REVISIONS TO THE COP

In the revisions to the Code of Practice on Surface Water Drainage (COP), which came into effect on 1 Jan 2014, developers and owners must engage an ABC Waters Professional to design, oversee the construction of, and develop a maintenance plan for the ABC Waters design features. Developers and owners must submit to PUB, as part of their Development Control (DC) submission, the concept design and design calculations, endorsed by an ABC Waters Professional.

An ABC Waters Professional may also inspect and endorse a Certificate of Inspection on the installed ABC Waters design features annually to certify that the features have been inspected, are maintained satisfactorily and are functioning well.

8.4

DRAINAGE HANDBOOK ON MANAGING URBAN RUNOFF

The **Drainage Handbook on Managing Urban Runoff** was jointly developed by PUB and the IES after the revisions to the **Code of Practice on Surface Water Drainage**. This book, launched in May 2013, will help developers, architects and engineers to better understand the holistic Source-Pathway-Receptor approach to stormwater management and the technical considerations of "Source" and "Receptor" measures.

The handbook includes concepts and case studies of on-site stormwater management and flood protection practices as well as ABC Waters design features and structural detention and retention features that can be adopted to ease surface runoff and reduce the peak flow of stormwater into the public drainage system.

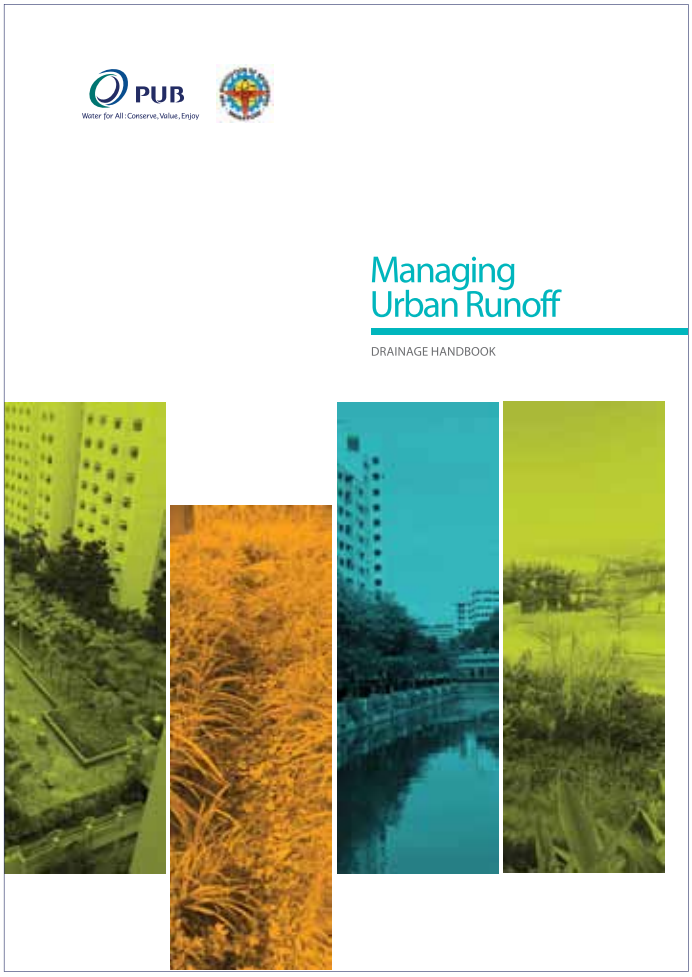


Fig 8.2
Managing Urban Runoff Drainage Handbook.

SECTION 9
APPENDICES

9.1 GLOSSARY OF TERMS

Average Recurrence Interval (ARI)
An estimated time period between storm events of a given magnitude. Typical ARIs include 1 in 50 years, 1 in 10 years, 1 in 5 years, and 1 in 2 years.

Biodiversity
Biodiversity is the variation of life forms within a given ecosystem, biome, or for the entire Earth. Biodiversity is often used as a measurement of the health of biological systems.

Brownwater / Blackwater
Sewage contains pathogens that have to be decomposed before discharging into the environment.

Catchment
An area of land from which stormwater flows to a common point, usually ending in a river or canal, and eventually a reservoir or the sea

Ecology
Ecology is the scientific study of the distribution and abundance of life and the interactions between organisms and their natural environment.

An ecosystem is a natural unit consisting of all plants, animals and microorganisms (biotic factors) in an area functioning together with all of the non-living physical (abiotic) factors of the environment.

Eutrophication
Eutrophication is an increase in chemical nutrients – compounds containing nitrogen or phosphorus – in an ecosystem, and may occur on land or in water. However, the term is often used to mean the resultant increase in the ecosystem's primary productivity (excessive plant growth and decay), and further effects including lack of oxygen and severe reductions in water quality, fish, and other animal populations.

Floodplain
The flat,or nearly flat area adjacent to a waterway that is designed to be inundated during a heavy storm.

Greywater
The used water generated from domestic activities, such as bathing, laundry and dish-washing. These comprise 50-80% of residential wastewater and require relatively less-intensive treatment processes. There has been increasing interest in the safe recycling and reuse of greywater.

Nutrients
These are substances that promote growth of plant and algae such as nitrogen and phosphorus. Excessive nutrients in waterways contribute to algal blooms and degrade our waterways.

Plot Ratio
The ratio of the gross floor area of the building(s) in a development to its site area.

$$\text{PLOT RATIO} = \frac{\text{GROSS FLOOR AREA}}{\text{SITE AREA}}$$

Pollutants
Substances that may naturally occur but are present at harmful levels (e.g. sediment or nutrients in a water body) or which may be unnatural in the environment and capable of producing environmental harm (e.g. chlorinated pesticides).

Receiving Water
This is a water body that may receive runoff from the catchment area, and generally has some environmental value or beneficial use. Natural wetlands are included in the definition of receiving waters, as opposed to constructed wetlands that have been built primarily for the purpose of stormwater treatment.

Treatment Train
A series of stormwater treatment devices that collectively address all stormwater pollutants.

Sediment
Particulate matter such as sand or mud that is generally derived from the lands and can be suspended and transported by fluid flow.

Scouring
Severe water erosion.

Site Area
The area of a development plot measured between the survey boundary lines. The boundary line defines the legal ownership of the property or development site.

Stormwater Runoff
Surface water runoff following a rain event, which includes piped flows from catchment surfaces such as roads, pavements, rooftops, car parks, vegetated area and open space.

Urban Development
Non-rural development forms such as rural-residential, suburban and dense urban, which includes residential, commercial, and non-rural industrial areas. Urban development forms could comprise greenfield, redevelopment, infill and retrofit of urban built infrastructure.

Water Quality
Physical, chemical and biological characteristics of the water column, including nutrients and sediment

9.2 REFERENCES AND SUPPORTING MATERIALS

It is important that all designs and implementations comply with the various building and planning authorities' regulations. The following is a suggested list:

Building & Construction Authority (BCA)

- http://www.corenet.gov.sg/einfo/
- http://www.bca.gov.sg/GreenMark/green_mark_projects.html
  (Green Mark Awards)
- http://www.bca.gov.sg/BarrierFree/barrierfree_buildings.html
  (BCA Code of Accessibility)

Housing & Development Board (HDB)

- http://www.hdb.gov.sg

Land Transport Authority (LTA)

- http://www.lta.gov.sg
- http://www.lta.gov.sg/content/ltaweb/en/industry-matters/development-and-building-and-construction-and-utility-works.html
  (Development, Building, Construction & Utility Works)

Ministry of Manpower (MOM)

- http://www.mom.gov.sg
- http://www.mom.gov.sg/workplace-safety-health/wsh-regulatory-framework
  (WSHA - Workplace Safety & Health Act)

National Parks Board (NParks)

- http://www.nparks.gov.sg
- http://www.nparks.gov.sg/cms/index.php?option=com_content&view=article&id=36&Itemid=150
  (Development Plan submission requirements)

Urban Redevelopment Authority (URA)

- http://www.ura.gov.sg
- http://www.ura.gov.sg/uol/publications/technical/dc-handbooks.aspx
  (Development Control Handbooks)
- http://www.ura.gov.sg/uol/circulars/2009/apr/lushprogramme.aspx
  (Circular Package: LUSH Programme - Landscaping for Urban Spaces and High Rises Programme)
  http://www.ura.gov.sg/uol/circulars.aspx
  (Circulars)

The following provides detailed information regarding the implementation of ABC Waters design features:

Engineering Procedures for ABC Waters Design Features

- **Engineering Procedures for ABC Waters Design Features** gives specific guidance on selection and sizing of the features, computational procedures with worked examples, performance charts to develop the detailed designs and checklists for construction and maintenance". A copy of the document is in the CD attached.

Code of Practice on Surface Water Drainage

- http://www.pub.gov.sg/general/code/Pages/default.aspx

The following are additional resources:

A Selection of Plants for Bioretention Systems in the Tropics

- https://www.cuge.com.sg/research/download.php?product=47

Code of Practice on Environmental Health

- http://app2.nea.gov.sg/public-health/food-hygiene/code-of-practice-on-environmental-health

Concept Design Guidelines for Water Sensitive Urban Design (Southeast Queensland, Australia)

- http://www.waterbydesign.com.au/conceptguide

Green Roofs and Heat Island Effect (United States Environmental and Protection Agency)

- http://www.epa.gov/heatisland/mitigation/greenroofs.htm

A Selection of Plants for Waterways and Waterbodies in the Tropics

by Jean W.H. Yong, Tan Puay Yok, Nor Hafiz Hassan, Tan Swee Ngin

SECTION 10

CASE STUDIES

We now look at 15 case studies in Singapore that have benefited from embracing the ABC Waters Concept. These projects not only contribute to cleaner waters but also beautify the environment and provide recreational spaces for the community to enjoy.

10.1 CENTRAL GREEN CORE @ CLEANTECH PARK

The CleanTech Park was developed by JTC Corporation, adopting sustainable development strategies to safeguard the neighbouring rainforest environment teeming with the tropical flora and fauna. CleanTech Park's Central Green Core retains the natural topography as much as possible and use ABC Waters design features to enhance the existing hydrological flow of the site and improve water quality.

Key Design Features

- **Vegetated swales**
  The vegetated swales are placed along each of the three green fingers to convey water from the roadside drains to the cleansing biotope for treatment. Designed to be aesthetically and environmentally unique, various types of pathways such as detention walls, boardwalks, gravel paths and stepping stones are either built across or alongside the swales. These walkways present park users with a wide range of interactivity with the park and the water, from simple visual enjoyment of the environment to getting up close to observe the plants and wildlife. In addition, the detention walls located along the swales slow down water flow during a storm event.

Fig. 10.1.1
Vegetated swales.

- **Wetland swamp forest**
  The runoff is conveyed by the swales to the freshwater swamp which is the second freshwater wetland in Singapore. The swamp facilitates sedimentation and water purification via the biological uptake of pollutants by the aquatic plants. This rare eco-habitat serves as a conservation and educational site, allowing ecological researchers to observe and document the flora and fauna in its natural environment. The water is then circulated through a cleansing biotope to further clean the water before being reused on site or discharged out to the public drains.

- **Cleansing biotope**
  Planted with specially selected aesthetically pleasing flowers, the cleansing biotope cleans stormwater runoff by filtering pollutants and absorbing nutrients. The treated water from the cleansing biotope will be recycled for the flushing of park toilets. Park users will be able to enjoy the beautiful landscape and water features in this system by walking along the boardwalk that skirts the cleansing biotope. With vantage points and educational signage, visitors are able to learn more about the functions and capabilities of the system's ABC Waters design features.

Fig. 10.1.2
Freshwater swamp.

Fig. 10.1.3
Cleansing biotope.

10.2
FIREFLY PARK

The Firefly Park in Clementi is a 1.5 hectare environment-friendly space that is designed to harmonise its immediate surroundings and provide the community with a place to go for serenity and relaxation. The rustic-themed park is divided into three main activity zones based on a "play-event-garden" activity arrangement comprising an *Aromatic Terrace Garden*, an *Open Lawn* and a *Singing Forest*.

The *Aromatic Terrace Garden* is located in Zone 1, which lines the park entrance off Clementi Avenue 6. The tactile Open Lawn, in Zone 2, is an open-air multipurpose area that can hold community events and activities. Zone 3 features the *Singing Forest*, which is a wooded area that houses several rustic garden components such as the Onion Shelter, Children Play Garden and fitness stations.

The park's design embraces environmental sustainability through the installation of ABC Waters design features. To educate the public and promote community involvement in stormwater management, signages are displayed to inform residents and park users on the functionalities and ecological benefits of the park's green features.

Fig. 10.2.1
A neighbourhood park that embraces environmental sustainability.

Fig. 10.2.2
A walkway that brings people closer to ABC Waters design features.

Key Design Features

- **Bioretention swales and rain garden**
  To minimise the use of concrete drains, bioretention swales and rain gardens are used to convey and treat stormwater runoff. These bioretention systems filter, detain and treat stormwater runoff as well as convey stormwater. The environment-friendly features are complemented by a conventional drainage system to discharge excess stormwater quickly in the event of a heavy downpour.

- **Meandering jogging track**
  The layout of the 2.5 meter wide jogging track is designed to meander in between existing trees and around the open lawn to encourage the preservation of existing mature trees to preserve existing wildlife. Part of the bioretention swales run along and across the jogging track thus giving park users a closer view of this ABC Waters design feature.

- **Environmentally friendly construction**
  Minimum earthwork and no export/import of earth was involved in the construction of the park.

Fig. 10.2.3
Bioretention swales and rain gardens convey and treat runoff.

Fig. 10.2.4
Educational signages in Firefly Park.

10.3
GARDENS BY THE BAY

Developed by the National Parks Board (NParks), Gardens by the Bay is a key component of the Singapore government's City in a Garden vision, which evolved from Singapore's reputation as a Garden City. Spanning over 101 hectares of reclaimed land in southern part of Singapore, the park consists of three waterfront gardens – Bay South Garden, Bay East Garden and Bay Central Garden.

To promote environmental sustainability in the Gardens, sustainable water cycles were meticulously planned and designed throughout Bay South Garden.

Key Design Features

- **Ecological lake system**
  Incorporating key eco-friendly processes and functions, the Gardens' lake system is a living system on its own. With a natural eco-filtration system, these lakes enhance water quality and biodiversity by providing aquatic habitats for fishes and dragonflies.

  The lake system, which comprises Dragonfly Lake and Kingfisher Lake, is designed to be an extension of the Marina Reservoir. These environmentally sustainable lake systems clean the collected runoff from the Gardens before discharging it into the reservoir. The built-in garden irrigation system also uses the naturally treated water from the lake system.

Fig. 10.3.1
Gardens by the Bay - Dragonfly Lake.

- **Reed bed and wetland filtering system**
  To enhance the cleaning and ecological function of the lake system, a water sensitive landscape design was implemented. Filter beds comprising of aquatic reeds are located where water enters and discharges from the lake. Flow velocity is reduced and sediments are filtered out through islands of filter beds and floating wetlands. These islands absorb nutrients such as nitrogen and phosphorus in the water. This reduction of nutrient levels is critical in ensuring better water quality by minimising algae bloom.

- **Bring people closer to water**
  A board walk of 44 km long next to the Dragonfly Lake brings people closer to the reed beds and filter beds. Story boards and other interpretive media tell story of how plants clean water in nature.

- **Maintaining an aquatic ecosystem**
  With a wide range of aquatic plants, good water circulation and aeration, the lake system is an ideal habitat for fishes and dragonflies. This vibrant aquatic environment helps to keep in check potential problems such as mosquito breeding.

Fig. 10.3.2
Gardens by the Bay - Board walk.

10.4
GOODWOOD RESIDENCE

This premier housing development is enclosed within 20 hectares of the Tree Conservation Area in the prime Orchard-Scotts district of downtown Singapore. The lush greenery is multi-levelled with both extensive ground level and facade planting. A vast tree planting central lawn provides all apartment units excellent views of the greenery. Reed beds are integrated with the ground level landscape areas to serve as a biofiltering system by filtering the runoff as well as the daily irrigation water from a 12-storey high vertical green wall.

Fig. 10.4.1
Green wall.

Fig. 10.4.2
Vertical green.

Key Design Features

- **Reed beds**
  Integrated into ground level landscape areas, the reed beds serve as a biofiltering system by cleaning the stormwater runoff. This water is first filtered through densely planted surface vegetation and then percolated through a prescribed filter media before being collected in a centralised tank to be recycled as irrigation water for plants on the ground floor.

- **Infiltration trenches with integrated subsoil drainage**
  Placed at various locations on the ground level, these trenches were constructed in areas with high water table to collect groundwater which is channelled to a centralised water tank for irrigation. The subsoil pipes beneath planting beds are also connected to the infiltration trenches to ensure that excess water is recycled.

- **Rainwater harvesting system**
  The stormwater runoff collected is either biologically treated or filtered before being channelled via gravity to a centralised bank at basement level. This water, which is collected from designated areas such as tennis courts, reed beds and infiltration trenches, is used for automatic irrigation for ground-floor landscape areas.

Fig. 10.4.3
Infiltration trenches.

Fig. 10.4.4
Reed beds.

10.5
KALLANG RIVER @ BISHAN-ANG MO KIO PARK

A joint collaboration between PUB and the National Parks Board (NParks), the ABC Waters project at Kallang River @ Bishan-Ang Mo Kio Park was designed with a holistic sustainable approach in mind. Adopting a concept to integrate the park with the river, one of the main features of the redevelopment is the restoration of the concrete canal into a naturalised river with bioengineered riverbanks, using a variety of plants and natural materials.

The gently sloped riverbanks forms part of the park features, and park users are able to walk along the water's edge. In the event of a storm, the water level in the river will rise and the area adjacent to the river will be used to contain the stormwater. Additional facilities include a Riverside Gallery, which is suitable for events, community gatherings and festive celebrations and three new playgrounds, each with a distinctive theme. The Bishan-Ang Mo Kio Park is home to diverse flora and fauna, with the natural river and existing water bodies in the park playing an important role in promoting biodiversity. Completed in March 2012, the project has created more green and blue spaces for the public to enjoy in one of the most popular parks in Singapore.

Fig. 10.5.1
Natural river with bioengineering riverbanks.

Fig. 10.5.2
Cleansing Biotopes.

Key Design Features

- **Soil bioengineering techniques**
  This is the first time that soil bioengineering techniques were applied in urbanised Singapore, and a test bed was earlier constructed to evaluate the suitability of the various techniques and plants in the nation's tropical climate. Soil bioengineering techniques, which combine traditional civil engineering and natural materials such as vegetation and rocks with aesthetics and ecological considerations, were widely employed here to transform the straight concrete canal into a natural river with landscaped banks.

- **Cleansing biotope**
  Located further upstream in the park, the cleansing biotope replaced an existing pond and comprises 15 cells in four terraces. Water is pumped into the various cells of the cleansing biotope from the river and the downstream ponds, and is filtered before the clean water is returned back to the ponds, eventually cascading back to the river. Part of the treated water from the cleansing biotope also undergoes UV treatment and is supplied to a water playground. The plants in the cleansing biotope further beautify and enhance biodiversity in the park.

- **Green roofs and vegetated swales**
  Other sustainable features implemented in the project include green roofs on top of park structures and vegetated swales in place of concrete drains to convey stormwater runoff from the park and upstream catchments into the river. These are all designed to facilitate infiltration, detention and cleaning of stormwater runoff before it enters the river.

Fig. 10.5.3
Clear water in the naturalised river.

Fig. 10.5.4
Vegetated swales in the park.

10.6
KHOO TECK PUAT HOSPITAL

Khoo Teck Puat Hospital (KTPH), part of an integrated health care hub in northern Singapore, is developed by Alexandra Health Pte Ltd to provide high-quality, affordable, health management to the community. Set against lush greenery and soothing water features, KTPH is both "a hospital in a garden" and "a garden in a hospital".

Sustainable development and the preservation of biodiversity are at the heart of KTPH's environmental philosophy. Vast areas of the hospital, along with the adjacent Yishun Pond adopted in 2005 under PUB's "Friend of Water" programme, were earmarked for landscaping and planting to encourage habitat creation and a healthy ecosystem. The tranquil environment of the pond's water and green surronding provide a great sense of calm and peace to the visitors and patients alike. The integration with Yishun Pond also enable that clean water from the pond is used for the hospital's irrigation systems for landscaping needs. When it rains, sensors will regulate this water source to prevent wastage.

Fig. 10.6.1
Extensive green facade of KTPH.

Fig. 10.6.2
Serene bio-ponds help improve water quality.

Key Design Features

- **Bio-ponds**
  Various bio-ponds are provided at the basement landscaped area and on the first level of the hospital. With a wide range of trees and plants surrounding them, these bio-ponds attract people to take a leisurely stroll along their pathways or simply enjoy their beauty while resting on the seats surrounding the garden.

- **Corridor and roof-top plants**
  These plants contain mixed soil with polymeric materials for the filtering and drainage of stormwater through the soil. This runoff will be cleaned and harnessed as water top-up for Yishun Pond.

- **Green roof**
  The green roof helps to improve air quality, keep the buildings cooler as well as give the buildings a pleasing façade. The roof also channels runoff to Yishun Pond through the open drains.

- **Yishun Pond**
  Yishun Pond is a stormwater collection pond that stores and cleans water by sedimentation process. The pond is integrated with KTPH to provide a serene environment for the patients and visitors as well as water needed for irrigation.

Fig. 10.6.3
Lush green roof.

Fig. 10.6.4
Yishun Pond is integrated with the green surrounding of the hospital.

10.7
PRIVÉ

Developed by NTUC Choice Homes Co-operative Ltd and CEL Development Pte Ltd, Privé is an Executive Condominium at Punggol Field.

The landscape is envisioned to be a place for community gathering and bonding, and is designed to provide an evergreen atmosphere of serenity essential for biodiversity to flourish. With a boardwalk leading to the spiral pavilion placed in the centre of the biopond, residents are able to embrace nature at its finest. Besides acting as a natural filter, the pond also encourages biodiversity with its flora and fauna. In addition, green roofs and walls were built in the clubhouse, thus allowing residents and visitors to enjoy cleaner air and beautiful scenery while entertaining guests.

Fig. 10.7.1
Bioretention swales.

Fig. 10.7.2
Permeable pavers close to the swimming pool.

Key Design Features

- **Biopond**
  The biopond with wetland plantings encourages biodiversity by allowing water plants and small fishes to grow. This serves as an educational platform for the young on ecology and biology. In addition, the edge of the pond was designed as an embankment to encourage grazing birds to land.

- **Bioretention swales**
  Stormwater runoff is filtered by the bioretention swales through different layers of soil media and vegetation before it is discharged into the drainage.

- **Green roof and green wall**
  Both a green roof and green walls were incorporated to reduce heat build-up on exposed roof surfaces while slowing down stormwater discharge.

- **Permeable Pavers**
  Permeable pavers were used in the paved area close to the swimming pool to infiltrate surface runoff.

Fig. 10.7.3
Green roof at Club House.

10.8
RIVERVALE ARC

Developed by the Housing & Development Board (HDB), Rivervale Arc is a public housing estate along Rivervale Crescent near the scenic Serangoon Reservoir.

To enable residents to learn more about water and plant interaction, develop an interest in the ecology cycle, as well as to promote social interaction, HDB adopted ABC Waters design features when they developed a site of approximately 2.7 hectares into two separate precincts, each with its own unique facilities.

Adjoining the three-generation play areas, rain gardens were built to bring residents closer to water and educate them on the natural filtration system. Two green connectors from the play areas were also constructed to provide seamless connectivity to the future park connector along the northern boundary. In addition, an extensive green roof of approximately 1,400 m^2 was created on the roof of the multi-story car park (MSCP) for environmental benefits.

All precinct entrances from the surrounding buildings and the park connectors were designed to be handicap-friendly. The large central landscape area was also developed as a single level to ensure easy accessibility for both able and disabled residents. In addition, the area was designated as a vehicle-free space to ensure safety and reduce the effects of pollution.

Fig. 10.8.1
Rain garden that integrates seamlessly with amenities around residential blocks.

Key Design Features

- **Rain gardens**
  Rain gardens were strategically placed at natural depressions that allow stormwater to collect and progressively percolate through the soil filter media before being discharged into the nearest drainage system. They help to remove pollutants such as suspended solids and nutrients from stormwater runoff. In addition, rain gardens enhance the biodiversity in the estate as flora and fauna will gravitate naturally to sources of water in the landscape.

  To complement the water features, natural rocks, seating areas and trellises were located beside the rain gardens so residents could enjoy the beauty and appreciate the functionality of these natural water filtration systems.

  For public education, signage was erected to explain the principle, function and benefits for these green features as well as provide maintenance tips.

- **Extensive green roof**
  Green roof planting on top of the MSCP is an integrated system that comprises various sophisticated protection layers of lightweight and shallow growing media, and carefully selected plants. It is designed to create a water reservoir beneath the plants for water conservation, reducing stormwater discharge by allowing water to permeate the medium. This water can then be stored and used for the plants.

  To enable residents to understand the concept of a green roof, an educational signage with diagrams was erected to highlight some of the key benefits and explain the various components of the system used.

Fig. 10.8.2
Green roof being established on the multi-storey carpark.

10.9
SOAK AWAY RAIN GARDENS IN LOCAL SCHOOLS

In conjunction with the National University of Singapore, PUB implemented three new rain gardens in local schools. Termed "soak away" rain garden, this new rain garden design was developed by a research team from the National University of Singapore (NUS) under a research & development project with PUB. It aimed to tackle some of the existing limitations of installing rain gardens in Singapore and to promote community involvement in the implementation of rain gardens.

Conventional rain gardens have three well-graded soil layers and sub-soil pipes that need to be connected to a deep enough drain nearby. This requirement always calls for engineering expertise to design the drainage pipes and find a suitable drain to connect. This presents a limitation as sometimes, it is not possible as the site may not have a sufficiently deep drain to which the sub-soil pipes can connect. In addition, the soil media needs engineering expertise to prepare and this also limits the well-spread application of rain gardens.

To tackle these limitations, the NUS team designed and installed three test-bed soak away rain gardens in three local schools: Nanyang Junior College, Anglo-Chinese Junior College and Dunman High School. These test beds not only provide detention and treatment of stormwater runoff, but also improve the aesthetics and biodiversity within the school premises. The engineered soils and native plant species used in these gardens were derived from prior laboratory research to establish their suitability for use in local rain gardens.

Fig. 10.9.1
Soak away rain garden at Anglo-Chinese Junior College (Completed June 2013).

Key Design Features

- **Simple design**
  The soak away rain gardens can be designed with only one filter layer, without the need for subsoil drainage pipes. This simple design promotes widespread implementation and extensive community participation in spearheading such a project in future.

- **Engineering soil**
  To achieve consistent soil properties, engineered soil were developed and used in these rain gardens. The engineered soils comprised both raw and recycled materials at prescribed compositions. The use of recycled materials enhances the removal of specific target pollutants and reduces the reliance on sand as a raw material.

- **Native plant species**
  The plants selected were carefully chosen to ensure effective pollutant removal and sustain the hydraulic conductivity of filter media. Incorporating native plant species, this multi-functioning garden supports local biodiversity, maximises the different characteristics of the various breeds and ensures that the garden is robust and healthy.

- **Engaging local communities**
  Besides developing and testing of the soak away rain gardens, this project initiative also provided secondary and junior college students with learning opportunities. To enhance the community education experience, students were engaged in the designing of signages, which allowed the pupils to better understand the functionalities of the gardens. Teachers and students were also actively involved in monitoring of plant health, water quality and hydraulic conductivity of the rain gardens. They were provided opportunities for presentations at various symposiums to share their projects.

Fig. 10.9.2
Soak away rain garden at Nanyang Junior College (Completed March 2013).

10.10
SUNGEI ULU PANDAN

The ABC Waters Programme by PUB is aimed at transforming the utilitarian drains, canals and reservoirs into beautiful, vibrant and clean rivers, lakes and streams that integrate with the surrounding developments. With the support from the community, PUB has been creating new recreational spaces that bring Singaporeans closer to the water so they can better appreciate and cherish this precious resource.

Situated in close proximity to the Van Kleef Centre, the ABC Waters @ Sungei Ulu Pandan was developed to create an outdoor classroom setting where residents and students from neighbouring schools can learn more about the environment. A 600 metre stretch of Sungei Ulu Pandan, encompassing Clementi Ring, Sunset Ring, Clementi Green and Clementi Garden, has been transformed to include environmentally sustainable green features such as cleansing biotopes, vegetated swales, floating wetlands and a sedimentation basin. These specially selected plants and soil media help to improve water quality by cleaning stormwater runoff before it is channelled into the river. The ABC Waters design features also enhance the area's biodiversity and provide residents with more community spaces by the water.

Key Design Features

Clementi Ring

Located off the park connector in front of block 343, Clementi Ring is the start point of Sungei Ulu Pandan.

- **Vegetated swales**
  Transforming an existing 20-metre-long concrete drain into a natural stream, the vegetated swale removes the larger sediments from the stormwater runoff before channelling the water into Sungei Ulu Pandan.

- **Lookout deck**
  An elevated circular lookout deck with ramps that connect Clementi Road to Ulu Pandan Park Connector provides visitors with a scenic view of Sungei Ulu Pandan.

Fig. 10.10.1
Vegetated swales.

Sunset Ring

Sunset Ring is located opposite Clementi Ring and is sited next to the Van Kleef Centre. Both Clementi Ring and Sunset Ring mark the symmetrical design at the start point of Sungei Ulu Pandan.

- **Cleansing biotope**
  This system consists of specially selected plants and soil media that clean the stormwater runoff by filtering through the filter media and through nutrient uptake by the plants.

  During dry weather, runoff from the drain is channelled to the cleansing biotope via the vegetated swale. To protect the cleansing biotope system from erosion during wet weather, an energy dissipation zone made up of stones lined within the flow channel is created to reduce the impact from the high velocity flow. The retention time for treatment within the cleansing biotope can be regulated by varying the water level in the biotope system. Longer retention time would result in improved water quality so the plants would have more time to uptake nutrients. The cleaned water is then channelled to Sungei Ulu Pandan.

- **Lookout deck**
  At this circular viewing deck that connects Clementi Road to the Park Connector, visitors can enjoy a charming view of Sungei Ulu Pandan and also have an overview of the treatment trains of the stormwater runoff from the drain to the river through the cleansing biotope.

Fig. 10.10.2
Sunset Ring.

Clementi Green

Clementi Green is located along the park connector in front of block 307. This setting is an ideal location for an outdoor classroom due to its close proximity to the residential area and the Van Kleef Centre.

- **Sedimentation basin**
  This large pond is a sedimentation basin. Water from the drain flows into the sedimentation basin which holds the water temporarily. This reduces the flow velocities and allows the larger sediment to settle before cleaner water then flows into the river. Aquatic plants are planted along the edge to help in nutrient removal in the stormwater runoff while enhancing biodiversity of the area.

- **Sheltered community deck**
  The sheltered community deck, which is able to hold up to 150 people, provides students with an excellent outdoor classroom environment and is also an ideal venue for community activities. Visitors are able to enjoy a panoramic view of the river at the elevated lookout deck situated above the sedimentation basin.

Fig. 10.10.3
Sedimentation Basin.

Clementi Garden

Clementi Garden is located along the park connector in front of block 371. Similar to Clementi Green, the stormwater runoff channelled by the tributary drain is treated before the water is discharged into the river.

- **Floating wetland**
  The floating wetland not only provides a natural habitat for flora and fauna and beautifies the landscape, the roots of the aquatic plants in the wetland also clean the water by absorbing nutrients from the water, thus improving the quality of water flowing to the drains.

Fig. 10.10.4
Sheltered Community Deck.

Fig. 10.10.5
Floating Wetland.

10.11
TELOK KURAU PRIMARY SCHOOL

As part of its school upgrading initiatives, Ministry of Education (MOE) plans to convert Telok Kurau Primary School's (TKPS) existing green field into an Indoor Sports Hall. This is an example of redevelopment where an increase in built-up areas results in a higher generation of runoff and presents PUB with opportunities to demonstrate the use of features such as the detention tank. In the event of rainfall, this tank helps in managing higher stormwater runoff by detaining the surface overflow. PUB will also provide opportunities for the school to carry out experiential learning for students by installing ABC Waters design features such as the rain garden, which cleans surface runoff before it is discharged into the waterway, green roof, and rainwater harvesting tank.

To create an outdoor experiential learning venue within the school compound that can evoke a spirit of inquiry and curiosity in students, educational posters and signage will be put up to accompany the various ABC Waters design features. TKPS teachers are also encouraged to actively contribute ideas during the detailed design stage to ensure that the completed features can be incorporated as teaching tools to complement teaching syllabus.

TKPS will reach out to the community via this redevelopment project, with the long-term goal of educating nearby residents on the benefits of a holistic water management system and enabling them to better appreciate water as a precious resource. This collaboration will instil greater awareness, ownership and participation in the community towards the ABC Waters Programme.

Fig. 10.11.1
Rain Garden.

Key Design Features

- **Stormwater detention tank**
  TKPS students will learn how concerted efforts can help, as well as the role of localised detention tanks in Singapore's flood management system. During a rainfall event, these tanks manage higher peak flow by detaining surface runoff. The detention tank in TKPS is sized to slow down the runoff to the canal such that the rate of discharge to the canal downstream remains the same as its pre-development rate during a rainfall event.

- **Rainwater harvesting system**
  The rainwater harvesting system allows the school to reuse the stormwater collected for non-potable use such as irrigation and general cleaning of the school compound, allowing the school to reduce its consumption of potable water.

- **Rain garden**
  The rain garden cleans stormwater runoff from the classroom blocks before discharging it into the rainwater harvesting tank for recycling purposes. Besides enhancing the aesthetics of the surroundings, students can also embark on an outdoor learning trail and discover the different biodiversities brought about by the rain garden.

- **Roof garden**
  The roof garden will be decorated with simple furniture as it serves as an outdoor experiential classroom for the students to acquire agricultural knowledge. Besides detaining stormwater temporarily, the roof garden at the new indoor sports hall also helps to clean the stormwater runoff before it is discharged into the nearby Siglap Canal.

  The collaboration with MOE to adopt a holistic stormwater management system by incorporating ABC Waters design features in the construction of schools provides students with educational tools for experiential learning.

10.12
THE INTERLACE

The Interlace is a unique contemporary residential development located in western Singapore. Situated strategically close to Kent Ridge and Labrador Park, this estate is an extension of the Southern Ridges – a green spine that encompasses Mount Faber, Kent Ridge and Hort Park – and is a tropical oasis within an urban landscape with over 176 different species of plants organised into different zones that mimic naturally occurring biotopes to encourage biodiversity of flora and fauna.

The unusual architecture is formed by 'stacking' six-storey residential 'super-blocks' in a honeycomb arrangement to form eight, large courtyard spaces. This arrangement comprises a number of public sky terraces, extensive green roofs, courtyards, vertical greenery, façade greenery and ABC Waters design features.

Key Design Features

- **Extensive green roofs**
  The unique architecture configuration enabled the creation of nine extensive and easily accessible roof gardens and intermediate sky terraces. The relocation of all surface roads to the basement level further enhanced the estate's effective green coverage, which improves biodiversity and increases residential amenities. The roof-top of each block is created with raised planters that provide users with greenery, and the stormwater is channelled to the recycle tank located in the basement.

Fig. 10.12.1
Green wall at the entrance.

Fig. 10.12.2
Spa valley surrounded by green walls.

- **Vertical greenery**
  Green walls were erected at various locations with large vertical faces to remove airborne pollutants and improve the biodiversity of an otherwise unused area. These green walls reduce the need for air-conditioning by minimising solar gain and reflected solar energy. These features also help to slow down stormwater runoff.

- **Facade greenery**
  This development comes with extensive balconies that promote terrace planting, which helps in slowing down the flow of stormwater runoff and eases the stress on the downstream stormwater drains.

- **Bioretention basin**
  Situated at the lowest point of the development site near to facilities such as the pet area, BBQ pits, play zone and golf putting, this bioretention basin or rain garden allows detention and treatment of stormwater runoff before entering into the public drain. Residents are informed about ABC Waters design features with proper educational signage. They can also enjoy the different vegetation and wildlife in the bioretention basin.

- **Vegetated swale**
  The 60-metre long vegetated swale along one side of the estate peripheries helps to slow down runoff and remove litter and sediments from the water. The elevated walkway alongside allows the residents and visitors to get closer and enjoy the natural drainage feature. With seating areas nearby the footpath, people can stop, observe and appreciate the integration of greenery and water in a beautiful and functional way.

Fig. 10.12.3
Water feature with lush vegetation.

Fig. 10.12.4
The vegetated swale is a natural and aesthetic way to channel runoff.

10.13
THE PEAK @ TOA PAYOH

The Peak @ Toa Payoh is an executive condominium under the Housing Development Board's (HDB) Design, Build and Sell Scheme (DBSS). This residential estate integrates ABC Waters design features into its drainage and landscape design.

The Peak features an intensive rooftop garden on its multi-storey car park (MSCP), lush landscape with pockets of green spaces and bioretention swales flanked by boulders to resemble stream interspersed amidst a wide range of social and recreational facilities.

Key Design Features

- **Bioretention swales**
  This ABC Waters design features provides efficient stormwater treatment through fine filtration, extended detention and biological uptake of nutrients. Interspersed with social and recreational facilities in the middle of the estate, these features allow residents to get closer to stormwater treatment green features.

Fig. 10.13.1
Intensive green roof.

- **Roof Garden @ Multi-storey Car Park**
  The roof garden incorporates lush planting with adequate seating areas and distinctive pathways. On top of being pleasing to the eyes, this beautiful and lush garden cools the environment and helps to slow down stormwater runoff.

- **Vertical Greening @ Multi-storey Car Park**
  Vertical greening with creepers helps to soften and beautify the multi-storey car park façade as well as remove airborne pollutant and add some biodiversity. These vertical greens also help to filter the stormwater as it flows over the vertical green surface.

- **Planter @ Balcony**
  Placed at every balcony, these planters improve the estate's aesthetics and help to intercept and detain some stormwater.

Fig. 10.13.2 The Peak @ Toa Payoh (Left). **Fig. 10.13.3** Bioretention swales near Central Plaza (Top right). **Fig. 10.13.4** Bioretention swales along walkways (Bottom right).

10.14
TREE HOUSE

Developed by City Developments Limited/Hong Realty Pte Ltd, the Tree House is an eco-friendly condominium situated at Chestnut Avenue.

Nestled in the greenery of the Upper Bukit Timah area, the estate aims to facilitate the residents to enjoy a tropical oasis in an urban development. The aesthetically pleasing Creeks and Tree Houses add to the vista creation. The planting areas are increased significantly by the green wall that spans the full height of one of the housing blocks. The 100-metre-long bioretention swale along the green buffer of the development filters, detains and treats stormwater runoff.

Fig. 10.14.1
Full height green wall (Top).

Fig. 10.14.2
Creeks within the development (Left).

Fig. 10.14.3
Elevated tree house (Right).

Key Design Features

- **Bioretention swales**
  The bioretention swales are located along the length of the southern boundary. Stormwater runoff from about 10 per cent of the development area is collected and soaked through the soil filter media and plants before it is discharged to the surface drain.

- **Green wall and sky gardens**
  In addition to an iconic full-length green wall on one of the blocks, sky gardens, with a variety of plant species, were installed on the 7th, 13th and 19th floors of all four residential blocks. These gardens reduce heat build-up on exposed roof surfaces while slowing down stormwater discharge.

- **Permeable pavement**
  This feature reduces the amount of stormwater runoff by allowing quick permeation of water.

- **Rainwater harvesting**
  Stormwater is channelled and directed to the harvesting tank in the basement. This harvested stormwater is used to irrigate the surrounding areas via a system of dip-irrigating pipes. Excess stormwater is discharged through the planters for further recycling.

Fig. 10.14.4
Bioretention swales along green buffer.

Fig. 10.14.4
Permeable pavers lining the walkway.

10.15
WATERWAY RIDGES @ PUNGGOL EAST

A joint collaboration between the PUB and the Housing Development Board (HDB), Waterway Ridges is the first housing project that integrates large-scale ABC Waters design features within a public housing precinct. Located in Punggol East, this project tested the effectiveness and feasibility of implementing ABC Waters design in a holistic manner within a public estate.

This development incorporated ABC Waters design features with the landscape area. The bioretention basins and vegetated swales collect and treat stormwater runoff from roofs, roads, playgrounds and green areas in the precinct, allowing the stormwater to seep through plants and soil media slowly. Sediment, nutrients and other impurities in the runoff are removed by flowing over a vegetated channel and filtering through the plants and soil. Eventually, the filtered clean water will flow into the reservoir via the nearby Punggol Waterway.

ABC Waters design features form part of the natural drainage system to detain and treat stormwater runoff from about 70 per cent of the precinct area. At the same time, water is stored in thick gravel layers below the features to maintain a runoff coefficient of 0.5 during storms with 10-year return period. Apart from enhancing the area's biodiversity, the ABC Waters design features also improve the aesthetics of the neighbourhood. The lawn type bioretention basins can cater for recreational uses during dry days.

Fig. 10.15.1
Waterway Ridges in Punggol East.

Key Design Features

- **Vegetated swales**
  Vegetated swales replace concrete drains to convey stormwater runoff from the park. Designed primarily to facilitate infiltration, detention and cleaning of stormwater, these features also enhance the aesthetics of the surroundings.

- **Bioretention basins**
  A comprehensive system of bioretention basins forms an important part of the natural drainage system in this precinct to detain and treat stormwater runoff for frequent storms (storms with 3 months return period). For bigger storm events, the runoff will overflow into the thick gravel layer below the bioretention basins for storage.

- **Bioretention basins (lawn type)**
  The lawn type bioretention basins acts as a recreational space when dry, and turns into a water collection area in the event of rainfall. The stormwater runoff is then ponded temporarily and filtered through the basin before being drained into the nearby reservoir.

- **Maintaining the pre-development site hydrology**
  With the detention and storage with ABC Waters design features, Waterway Ridges is designed to discharge a peak flow rate not higher than the pre-development site during storms with 10-year return period.

Fig. 10.15.2
Vegetated swales as aesthetically pleasing natural drains.

Fig. 10.15.3
A Bioretention Basin to showcase treated clear water

Fig. 10.15.4
Water features to showcase treated clean water.

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